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Communications in Computer and Information Science

2504

Computational Science and Computational Intelligence

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Las Vegas, NV, USA, December 11–13, 2024
Proceedings, Part IV

Part 4

Communications in Computer and Information Science

2504

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Editors

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Preface

It is our great pleasure to introduce this collection of research papers presented at the 11th International Conference on Computational Science and Computational Intelligence (CSCI 2024). This volume features a selection of papers accepted in the Research Track on Education (CSCI-RTED). It compiles noteworthy contributions in the field, presented at the conference held in Las Vegas, Nevada, USA, from December 11 to December 13, 2024.

The CSCI 2024 International Conference brought together papers from a diverse array of communities, including researchers from universities, corporations, and government agencies. Accepted papers are published by Springer Nature, and the proceedings showcase solutions to key challenges in various critical areas of Computational Science and Computational Intelligence.

Computational Science (CS) is the study of problems that are impossible to solve (or difficult to solve) without computers. CS can be considered to be the bridge between computer science and other sciences. The field is interdisciplinary by nature and includes the use of advanced computing capabilities to understand and solve complex problems. In short, CS is the science of using computers to do science. Computational Intelligence (CI) is the study of computational methods in ways that exhibit intelligence. These methods adapt to changing environments and changing goals. There is a significant overlap between the fields of CI and Artificial Intelligence (AI). However, there is also a difference: AI techniques often involve top-to-bottom methods (i.e., methods are imposed on solutions from the top) whereas CI techniques often involve bottom-up methods (i.e., solutions emerge from unstructured beginnings). An important part of CI includes a set of Nature-inspired computational approaches to address complex problems for which traditional methods are infeasible. Computational Science and Computational Intelligence share the same objective: finding solutions to difficult problems. However, the methods to reach the solutions are different. The main objective of the CSCI Conference is to facilitate increased opportunities for cross-fertilization across CS and CI.

Considering the above broad outline, the CSCI 2024 International Conference was composed of the following focused Research Tracks:

Artificial Intelligence (CSCI-RTAI); Big Data and Data Science (CSCI-RTBD); Computational Science (CSCI-RTCS); Computational Intelligence (CSCI-RTCI); Computational Biology (CSCI-RTCB); Cyber Warfare, Cyber Defense, & Cyber Security (CSCI-RTCW); Signal & Image Processing, Computer Vision & Pattern Recognition (CSCI-RTPC); Smart Cities and Smart Mobility (CSCI-RTSC); Education - CS & CE (CSCI-RTED); Health Informatics and Medical Systems (CSCI-RTHI); Mobile Computing, Wireless Networks, & Security (CSCI-RTMC); Software Engineering (CSCI-RTSE); Internet of Things & Internet of Everything (CSCI-RTOT); Social Network Analysis, Social Media, & Mining (CSCI-RTNA); Cloud Computing and Data Centers (CSCI-RTCC); and Parallel & Distributed Computing (CSCI-RTPD). The scope of each track can be found at: <https://www.american-cse.org/csci2024/topics>.

An important objective of the CSCI 2024 International Conference and its associated Research Tracks was to foster opportunities for cross-fertilization between the fields of Computational Science and Computational Intelligence. The CSCI Conference is deeply committed to promoting diversity and eliminating discrimination, both in its role as a conference organizer and as a service provider. Our goal is to create an inclusive culture that respects and values differences, promotes dignity, equality, and diversity, and encourages individuals to reach their full potential. We are also dedicated, wherever possible, to organizing a conference that represents the global community. We sincerely hope that we have succeeded in achieving these important objectives.

The Steering Committee and the Program Committee would like to extend their gratitude to all the authors who submitted papers for consideration. CSCI 2024 received submissions from 52 countries, with approximately 47% of them coming from outside the USA. Each submitted paper underwent a rigorous peer-review process, with at least two experts (an average of 2.6 referees per paper) evaluating the submissions based on originality, significance, clarity, impact, and soundness. In cases where reviewers' recommendations were contradictory, a program committee member was tasked with making the final decision, often consulting additional referees for further guidance. The CSCI Conference followed the guidelines of COPE (Committee on Publication Ethics):

- Typical submissions underwent a single-blind peer review process, in which the authors remained unaware of the identities of the reviewers, while the reviewers were informed of the authors' identities.
- Papers authored by one or more members of the program committee, including co-chairs, were subjected to a double-blind peer review process, ensuring that neither the authors nor the reviewers were aware of each other's identities or affiliations.

The Research Track on Education (CSCI-RTED) of CSCI 2024 Conference received 155 submissions, of which 28 papers were accepted, resulting in a paper acceptance rate of 18%.

We are deeply grateful to the many colleagues who contributed their time and effort to organizing the CSCI 2024 Conference. In particular, we extend our thanks to the members of the Program Committee, the Steering Committee, and the referees. We would also like to express our appreciation to the primary sponsor of the conference, the American Council on Science & Education. The list of members of the Program Committee for each track can be found at: <https://www.american-cse.org/csci2024/committees>.

We extend our heartfelt gratitude to all the speakers and authors for their valuable contributions. We would also like to thank the following individuals and organizations for their support: the staff at the Luxor Hotel (conference/meeting department) and the staff of Springer Nature, for their assistance in various aspects of the event.

We are pleased to present the proceedings of CSCI 2024 (selected papers of CSCI-RTED). These proceedings represent a collection of outstanding research contributions that reflect the diversity and depth of work in integrating emerging technologies into teaching and learning.

Co-editors: Research Track on Education (CSCI-RTED) of CSCI 2024 International Conference

August 2024

Soheyla Amirian
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Contents --Part IV

Subject-Specific Education and Curriculum Design

Transition Challenges in Discrete Mathematics: Comparing Domestic and International Student Performance	3
<i>Alan Bowen-James and Mary Ruth Freislich</i>	
Intrinsic Barriers to Supporting the Integration of Computer Science Into Elementary School Subject Areas	12
<i>Laycee Thigpen and Monica McGill</i>	
Incorporating CUDA Unified Memory into the Operating System Curriculum	29
<i>Janche Sang</i>	
Increasing Student Success by Implementing Autograded Programming Assignments	41
<i>Varick L. Erickson</i>	
Decoding Complexity: Empowering Learners in Algorithm and Theory Comprehension	59
<i>Dewan Tanvir Ahmed</i>	
Bouncing into Counting and Probability	71
<i>Peter M. Maurer</i>	
Building a Data-Driven Cybersecurity Lab: A Practical Framework for AI-Powered Threat Detection	84
<i>Goksel Kucukkaya, Murat Ozer, and Omer Ilker Poyraz</i>	
Curriculum for a New Academic Program with Bachelor's Degrees in Electrical Engineering and Intelligent Systems Engineering	103
<i>Ashu M. G. Solo</i>	
The Effectiveness of the Project-Based Learning in the Perfume Chemistry Course	117
<i>Chanyapat Sangsuwon, Shutchapol Chopvitayakun, Nuntaporn Aukkanit, Supatchalee Sirichokworrakit, and Kunyanuth Kularbphettong</i>	

Education and Artificial Intelligence

Artificial Intelligence and Challenges in a Research-Teaching Model	131
<i>Diego Trueba Garza and Muhittin Yilmaz</i>	
A Review of Generative AI in Computer Science Education: Challenges and Opportunities in Accuracy, Authenticity, and Assessment	144
<i>Iman Reihanian, Yunfei Hou, Yu Chen, and Yifei Zheng</i>	
Large Language Magic: Conjuring the Future of Education with LLMs	159
<i>Robert Langenderfer</i>	
Problem-Solving Using Logic and Reasoning, Mathematics, Algorithms, Python, and Generative AI: Part Three	165
<i>Shanzhen Gao, Weizheng Gao, Leah Hall, Aurelia M. Donald, Julian Allagan, Jianning Su, Joshua Nyantakyi, and Ephrem Eyob</i>	
Integrating Generative AI and Foundational Skills for Investment and Financial Decision-Making	182
<i>Weizheng Gao and Shanzhen Gao</i>	

Contemporary Artificial Intelligence Accelerator Cache Design Perspectives	192
<i>Diego E. Trueba Garza, Diego E. Trevino, and Muhittin Yilmaz</i>	

Teaching and Learning Strategies, and Related Research Studies

Features and Data Needs for a Digital Passport for Computer Science Teacher Professional Development Providers	209
<i>Joseph Tise, Laycee Thigpen, Monica McGill, and Robert Schwarzhaupt</i>	
Enhancing Student's Learning by Integrating the Concept of Project-Based and Challenge-Based Learning	225
<i>Kunyanuth Kularbphettong, Nareenart Raksuntorn, Pattarapan Roonrakwit, and Chongrag Boonseng</i>	
Investigating Key Factors Influencing Student Satisfaction in HyFlex Learning: A Confirmatory Factor Analysis Study	240
<i>Shutchapol Chopvitayakun, Montean Rattanasiriwongwut, and Nuntaporn Aukkanit</i>	
Adapting Computer Science Education to a New Student Era	255
<i>Katia Maxwell</i>	

Educational Hangman: A Web Platform to Generate Customizable Hangman Games for Learning Vocabulary in Primary School Children	269
<i>Carlos R. Jaimez-González, Fernanda Orozco-Tapia, and Betzabet García-Mendoza</i>	
Blending Computational Thinking and Creativity: Algorithmic Art with Python	285
<i>May J. Gao and Aurelia M. Donald</i>	
Virtual Reality in Education: Opportunities and Challenges	304
<i>Yvette Spivey, Roya Choupani, and Scarlet Clouse</i>	
Creating Better Group Projects in Higher Education	310
<i>Shannon W. Beasley and S. C. Spangler</i>	
The Applications of Smart Contracts in Classroom Teaching	322
<i>Yong Zhang</i>	
Improving the Effectiveness of Undergraduate Students' Core Competencies Using the Google Classroom	326
<i>Jaruwan Chutrong and Kunyanuth Kularbphettong</i>	
Experiencing Android App Development and Connecting Students Together	338
<i>Joshua Fife and Nada Alsallami</i>	
Author Index	351

Subject-Specific Education and Curriculum Design



Transition Challenges in Discrete Mathematics: Comparing Domestic and International Student Performance

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Abstract. The study aimed to investigate the impact of transition to university-level mathematics, specifically in a first-year Discrete Mathematics course, by comparing the performance of domestic and international students, as well as students enrolled in different teaching periods (first vs. second term). Contrary to expectations, students enrolled in the first term performed better than those in the second term, suggesting that delayed enrolment does not provide an advantage in adapting to discrete mathematics. There was a significant difference in performance between domestic and international students, with domestic students outperforming international students in both terms. The study found no significant interaction between the term of enrolment and student origin (domestic/international). It is suggested that the performance gap between domestic and international students may be attributed to the ‘first-time phenomenon’ - the shock of experiencing difficulty with mathematics among previously high-performing students. This effect might be more pronounced for international students due to their typically strong preparation in core mathematics and the added pressures of studying abroad. The evidence indicates that the unfamiliarity of discrete mathematics content and the high level of justification required in problem-solving may contribute to the observed differences, particularly affecting international students’ confidence and willingness to seek help. The study highlights the need for further qualitative research to better understand students’ perceptions of their difficulties and the strategies they adopt to overcome challenges in discrete mathematics.

Keywords: Discrete mathematics · Transition to university

1 Introduction

The present project deals with students in a specialized first-year Discrete Mathematics subject in a large Australian university. Previous work by the authors (Freislich & Bowen-James, 2022a) found that the provision of additional online support yielded higher achievement among students in the first of two core mathematics subjects, taken in their very first semester of university mathematics, in contrast to a finding of no difference among students in the second core unit taken in Semester 2. It was concluded

that the additional support had helped students to overcome difficulties associated with the transition to university mathematics, whereas the second semester group, which had already passed the first subject, were, because of passing, slightly more highly selected, and had had more time to adjust to university study.

The question of transition and adjustment is relevant to students in Discrete Mathematics 1, where the largest enrolment group contains a majority of students in the first teaching period of their university studies. Transition is of special relevance because discrete mathematics covers areas that differ from secondary material far more than does the content of core subjects. This would lead on to a prediction that students might handle discrete material better if enrolment in the subject were delayed to a little later than the very beginning of students' university studies. A group of slightly smaller size takes the subject in the second teaching period of their first year, thus making it possible to compare learning outcomes in groups at different stages of transition to university study. But students in the degrees that require discrete mathematics, mainly computer science and electrical engineering, are a very highly selected group, and the students who enroll voluntarily are often planning a mathematics major. High selection and choice of degree also mean that the students in Discrete Mathematics 1 tend to have strong mathematics preparation in their secondary school programs.

There is considerable evidence like that given by Varsavsky (2010) that, in Australia, in core first-year university mathematics, the best predictor for success is good preparation and performance in secondary school mathematics. One might conclude, therefore, that high selection could make the question of transition irrelevant, but the difference of material from that in core mathematics subjects implies that it is still worth examining.

The importance of preparation also leads to regarding another comparison as relevant, because the Discrete Mathematics 1 unit is taken by a high proportion of international students (about 35–40% of enrolments). Most come from China or India, so that their previous math education differs to some degree from that of domestic Australian students. In core mathematics subjects, previous work by the authors (Freislich & Bowen-James, 2022b) found that, before the provision of extensive online support, international students in core first year mathematics had higher achievement than domestic students, but the difference disappeared after the additional support was established. But it is still of interest to compare international and domestic students in Discrete Mathematics, because the discrete material is so different from the core material, and the research evidence for the importance of previous preparation implies that comparing groups from different backgrounds has potential value.

2 Background

2.1 Transition

First, there is continuing evidence that students in a wide range of backgrounds still have difficulties with the transition from secondary study of mathematics to studying university mathematics. In connection with first-year success, Australian work by Nicholas, Poladian, Mack and Wilson (2015) recognised the importance of previous preparation. Varsavsky (2010), also in Australia, found that bridging support could compensate for weaker secondary mathematics preparation, but also that the best predictor was still

previous coverage and performance, and a similar conclusion was drawn by Rylands and Coady (2009). Emphasis on the importance of subject knowledge is also found in studies carried out in highly selective education systems, such as the work of Rach and Ufer (2020) in Germany. But one should also note that slightly earlier work in the same system, by Rach and Heinze (2017), found that successful tertiary mathematics students needed to develop adequate learning strategies at university, measured by information about how they approached mathematical tasks, to support specific entering knowledge. Di Martino, Gregorio and Iannone (2023a) note that in international conferences on mathematical education between 2008 and 2021, such as the International Congress on Mathematical Education, there was increasing attention given to the transition from secondary to tertiary mathematics, including studies coming from countries which had high selection criteria for university entrance. In their own study (Di Martino et al., 2023b), they provide evidence for such transition difficulties from Britain, France and Switzerland. A first obvious reason for difficulty is the rapid pace at which university mathematics topics are taught, mentioned explicitly by students in the work of Harris and Pampaka (2016).

2.2 Particular Difficulties with Discrete Mathematics

First, one should note that background from secondary studies is unlikely to include topics in discrete mathematics, as recorded in the survey paper by Sandefur, Lockwood, Hart and Greefrath (2022), so that explicit preparation is likely to be rare.

Rach and Heinze (2017) note that research on students' transitional difficulties found that these tended to arise from the stricter tertiary requirements for justification of claims they made in argument. This is particularly acute for discrete mathematics, because discrete mathematics, from the earliest stages, requires a high level of rigorous argument. While earlier mathematics courses may have focused on computation and problem-solving algorithms, discrete mathematics requires that students prove why their solutions to problems are correct, using formal logical arguments. This leap from how to why can be disorienting, as noted by Epp (2003) in her study on the challenges of teaching mathematical reasoning. It is worth noting here that Jooganah and Williams (2016) report evidence that students' reliance on methods that worked well with tasks on the entrance examination for university can reflect rigidity, resulting from the use of skills that have become automatic, that makes required changes for university mathematics harder to develop. In this connection, one should be aware of the Irish national review quoted by Faulkner, Hannigan and Gill (2010), which found that university selection of mathematics students, based on the school Leaving Certificate marks, tended to encourage teaching focused on the examination. In addition, even when it is valid to assume procedural knowledge, Harris and Pampaka (2016) found that university teachers tended to assume that their use in argument required little explanation because the application was regarded as obvious.

The abstract nature of many concepts in discrete mathematics also contributes to student difficulties. Graph theory, combinatorics and formal logic may seem far removed from the 'real world' applications that students have come to expect from their mathematical studies. This perceived lack of concrete relevance can make it harder for students to engage with the material, that is, the computational focus that students have grown

accustomed to is less prominent in discrete mathematics. Research evidence for particular difficulties with combinatorics, graph theory and difference equations is recorded by Annin and Lai (2010), Medova, Palenкова and Rybansky (2019), and Sandefur, Somers and Dance (2018). Such work supports the claim that discrete mathematics at tertiary level is potentially more challenging than core mathematics, despite common changes at tertiary level towards higher standard for justification.

2.3 Transition and Confidence

For some decades, research has emphasized the importance of confidence in the learning of mathematics, with the review by Watt and Goos (2017) concluding that it is one of the most important factors affecting such learning at all levels. In research about transition, recent attention has been paid to the importance of students' beliefs about their ability to cope with their mathematics studies. Geisler and Rolka (2018) found, in a study of highly selected students, initially low self-perception of such ability was strongly predictive of later dropout from mathematics programs, and Geisler, Rach and Rolka (2023) found that such students were more likely to fail to attend examinations. The small interview study by Hernandez-Martinez (2016) documented high levels of stress among students with good school qualifications who found university mathematics extremely difficult. Di Martino and Gregorio (2018) obtained responses describing transition among very highly selected mathematics students at the University of Pisa. Most described the experience of transition as extremely stressful, with the first experience of difficulty or failure in mathematics - the 'first-time phenomenon', that of the first experience of difficulty with mathematics - as a fundamental shock to their confidence, and a source of feelings of shame. Students' comments on their experience of first difficulty contained explicit perceptions of lowered confidence and lack of any idea of how to cope. Earlier work by Bamforth (2007) found that, among a group of students having problems with transition to university mathematics, those who accessed existing support passed their first year, whereas those who did not use it failed. Di Martino and Gregorio (2018) found very similar results among the more highly selected group in their study, with students in difficulty mentioning explicitly that they should have sought help earlier than they did.

2.4 Background of International Students

It is often difficult to assess the mathematics preparation and performance of international students, but adequate preparation for core mathematics can be inferred from the results mentioned in the introduction. In addition, some have been through the university's Foundation Studies program, which contains mathematics and is recognised by the university for entrance. International study is expensive, which is an additional implicit selection factor. But the infrequency of secondary background in discrete mathematics, and the importance of a strong focus on core mathematics for university entry, means that the discrete material is likely to be unfamiliar to international students to a degree at least comparable to its unfamiliarity to the domestic group.

In addition, given that study as an international student is very expensive, and preparatory selection qualifications need careful selection and dedicated study, it is possible that the ‘first-time phenomenon’ at university could be a more extreme challenge for international students in discrete mathematics than it is for the domestic group. Problems about seeking help could also be increased by cultural or language uncertainty.

3 Method

3.1 Sample

Simple random samples were taken from Terms 1 and 2 enrolment groups in first-year Discrete Mathematics 1 in the same year. The numbers are in Table 1.

Table 1. Sample numbers

Term	1	1
Domestic	122	111
International	71	75
Total	194	186

3.2 Data Collected

Background. Data defining the four groups were collected, as well as students’ gender. It was not expected that gender differences in achievement would be found, and a rapid check in fact found no differences.

Achievement. Achievement scores were derived from students’ performance in the final examination for Discrete Mathematics 1. Examinations covered the same material, with questions at a similar level of difficulty. Learning outcomes on each task were ranked on a common scale adapted from the Structure of the Observed Learning Outcome (SOLO) Taxonomy defined by Biggs and Collis (1982). The taxonomy defines five levels of outcome (presented in Table 2), based on the logical consistency and adequacy of task coverage in students’ responses to assigned educational tasks.

Scores from 0 to 5 were assigned to students’ solutions to examination questions, as used in previous studies by the authors (Freislich & Bowen-James, 2019, 2022). Scores reflect the first four levels of the SOLO taxonomy, omitting the highest level, which was regarded as inaccessible in the context. The Relational level requires logical consistency, and the top scores required this, with 5 for a valid response and 4 for one containing a minor error that did not involve a contradiction or misconception. If the response did contain a logical error, points from 0 to 3 were given, corresponding to the amount of relevant and valid material given by the student. Zero corresponds to the SOLO Prestructural level, and also covers giving no attempt at an answer. Score 1

corresponds to the Unistructural level. Scores 2 and 3 correspond to the Multistructural level, with the solution invalidated by errors of logic, and the score depending on how far the relevant arguments contribute to a valid solution. The method is consistent with the requirement made by the North American Accreditation Board for Engineering and Technology (ABET, 2020), that adequacy of evaluation of teaching program is not achievable without direct study of students' learning outcomes.

Table 2. The SOLO taxonomy

Level	Definition
Prestructural	Essentially no valid response
Unistructural	One aspect of the problem correctly identified, but no diversity of aspects, so that questions of consistency cannot arise
Multistructural	Multiple relevant information presented and used, but without considering relationships between different parts, so that inconsistency appears
Relational	Multiple relevant information presented and used in a way that recognizes relationships and achieves consistency within the given task
Extended abstract	Multiplicity recognized and consistency achieved over a context beyond that of the given task

3.3 Analyses

Four groups were defined by the two factors, the term of enrolment and the domestic/international dichotomy. Achievement scores given by the common scale adapted from the SOLO taxonomy were compared. Within each term group, domestic and international groups were first compared separately, to justify the inclusion of this factor. The main comparison used a two-way factorial analysis of variance.

4 Results

Descriptive statistics are in Table 3 together with the results of the preliminary comparison between domestic and international students in the same term, which was used as a guide for the main analysis.

Results of the analysis of variance are in Table 4. Both main effects give significant differences, without significant interaction between factors, but significance is greater for the contrast between domestic and international students.

Table 3. Descriptive statistics and initial comparison

Term		Domestic	International		
1	Mean	25.75	23.27	t	1.65
	St. dev.	10.01	10.19	df	191
	N	122	71	p	0.100
2	Mean	24.09	20.00	t	3.10
	St. dev.	8.65	9.07	df	184
	N	111	75	p	0.002

Table 4. Analysis of variance

Source	Sum of squares	df	Mean square	F
Effects	1568.33	3	522.78	5.82***
Term	490.37	1	490.37	5.46*
Domestic/international	968.10	1	968.10	10.77***
Interaction	57.85	1	57.85	0.64
Residual	33698.76	375	89.86	
Total	35267.09	378		

Note: *** $p < 0.001$, * $p < 0.05$.

5 Discussion

The clearest aspect of the results is that they resolve the argument about enrolment later than the first term at university, at least at the level of one term's difference. The results are contrary to this being an advantage. In particular, good adaptation to university core mathematics would not provide direct preparation for discrete topics, so that an argument for mathematical maturity would not be justified. First term enrolment is the preferred pattern among students, so that later enrolment may reflect more complicated programs.

The comparison of interest is that between domestic and international students. It was noted above that the international students are well prepared in core mathematics, and that their performance in core mathematics courses compares adequately or sometimes favorably with that of domestic students. They have also been through the complications and expense entailed by international study, which should mean that they have organizational skills and strong commitment to their studies, both of which should contribute to success. It follows that the distinguishing factor is the unfamiliarity of the material in discrete mathematics, and the high level of justification required for solutions to problems in the subject.

The reasons suggested by the background literature come from two important aspects of the findings. The first set deals with what was named the 'first-time phenomenon' by Di Martino and Gregorio (2018), which is the shock to confidence occasioned by

difficulty with mathematics among students who have previously performed well in the subject. One can assume that survival of the difficulties in embarking on international study, and the importance of core mathematics as preparation, have made any difficulties in a mathematics subject more surprising and discouraging to the international group than to the domestic group. In the Background section, it was noted that, even among highly selected students, lower confidence was associated with a greater likelihood of dropout from university mathematics programs, and also with evidence that discouragement was associated with students giving up trying to perform, as evidenced by failure to present themselves for tests and examinations. The point here is that learning mathematics is achieved by doing mathematical tasks, so that discouragement can impair the total learning process, because it can limit the willingness to embark on relevant tasks. Studies using interview material found that many students reacted to the shock of new experience of difficulty by feeling ashamed of their difficulties. This feeling is likely to make it more difficult to ask for help, and evidence for the importance of using support resources and asking for help was also examined in the Background section, where it was also noted that this could have cultural complications for the international students.

The second set of relevant information concerns the finding of rigidity in students' continuing use of school methods no longer adequate for university tasks. Faulkner, Hannigan and Goll (2010) give evidence that this is likely to be increased by secondary teaching focused on handling examination problems. This suggests a reason why the international students' performance indicates greater difficulty in adapting to discrete mathematics, because their entrance qualifications are much more important than those of domestic students, given the greater difficulty of achieving entry to international study. Such considerations mean that the difference between core and discrete mathematics is likely to prove more difficult for them to adjust to, and at the same time, for difficulty to be a greater shock to them.

Reasonable explanations for the results are therefore suggested by the background literature. These reasons, however, are such as to suggest that further qualitative work is required, in which interview or discussion material could give evidence about students' perceptions of their difficulties and the strategies they adopt to overcome them.

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Intrinsic Barriers to Supporting the Integration of Computer Science Into Elementary School Subject Areas

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Abstract. Problem. The integration of computer science (CS) into K-5 classrooms alongside subjects like math, science, and literacy is growing but requires addressing intrinsic barriers related to teachers' beliefs, values, and dispositions, which remain underexplored.

Research Question. Our research question for this study was *What are intrinsic barriers to supporting the integration of computer science in the elementary grade level subject areas?*

Method. We conducted a mixed methods study, including a survey ($n = 160$), a set of focus groups ($n = 23$), and a set of interviews with experts ($n = 9$) with K-12 education decision makers and curriculum designers. We synthesized the results, establishing categories within intrinsic barriers.

Findings. We found four categories of intrinsic barriers: limited teacher content knowledge, pedagogical content knowledge, and teacher beliefs about CS, as well as varied teacher perspectives on CS integration. Some of these also related to relearning or learning supporting educational technologies, limited buy-in, and how to meet the learning needs of all of the students in their classrooms.

Implications. This study elucidates intrinsic barriers that K-5 classroom teachers face, particularly in the context of previous related research. We found that all of the intrinsic barriers uncovered have been encountered in other integration research. This provides the community with an opportunity to learn how barriers in similar fields were mitigated so that the intrinsic barriers in K-5 CS integration can potentially employ similar strategies.

Keywords: Intrinsic barriers · barriers · education · elementary · K-5 · second order · content knowledge · pedagogical content knowledge · computer science

1 Introduction

Barriers to introducing new pedagogy, curriculum, and educational technology are not new. For example, Blackwell et al. and Keengwe et al. investigated barriers that teachers face when integrating new educational technologies into their

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classrooms [1,2], finding that performance expectancy, effort expectancy, lack of (or unreliability) of equipment, lack of support and other resource-related issues all can impact integration.

Previous research categorizes barriers to teaching students into two primary types: first-order (extrinsic) barriers and second-order (intrinsic or personal) barriers [1,3]. *Extrinsic barriers* encompass *facilitating conditions*, which include challenges such as insufficient support and insufficient resources [2]. Extrinsic barriers can significantly hinder teachers from incorporating computer science (CS) into their core curricula, with several barriers unique to elementary education. This includes teachers trying to integrate CS into their curricula. Such barriers include lack of curriculum, lack of funding, limited professional development, limited administrator knowledge about CS, limited time to plan and teach, lack of local policies and priorities, and limited community support [1].

Intrinsic barriers to teaching reflect teacher performance expectancy, effort expectancy, and social influence [1], including perceptions, beliefs, and attitudes. Key intrinsic barriers to successful integration of CS in K-5 have previously been identified from both teachers and support staff (e.g., administrators, policy makers, curriculum designers). This includes evidence that teachers needed additional understanding of what CT is [4], teachers held limited computational thinking (CT) teaching expertise [5], and teachers struggled with how to assess students' CS learning [5,6].

We conducted a mixed methods study to better understand the types of intrinsic barriers teachers face when focusing on K-5 CS integration, primarily from the perspective of supporting staff. Since administrators and curriculum designers can be in positions to advocate for reducing the barriers, it is important to establish their understanding of these barriers and how to reduce them. Our research question for this study was:

What are intrinsic barriers to supporting the integration of computer science in the elementary grade level subject areas?

2 Background

Beyond investigating barriers to K-5 computer science (CS) integration, we also examined obstacles to adopting digital technologies for learning. This approach not only highlights research already available in related areas, but also helps us consider potential parallels with the barriers identified in our study. Given that first-order and second-order barriers suggest a hierarchical structure, we will refer to second-order barriers as *intrinsic barriers* throughout this paper.

2.1 Intrinsic Barriers to Technology Integration

Technology integration in classrooms involves many factors, including teachers' perceptions, beliefs, and motivations about both student learning and technology [7-9]. For example, Blackwell et al. found a strong correlation between

teachers' positive beliefs towards technology's educational value and their actual implementation of technology in their classrooms [1], while an impediment to adoption may be related to teacher fear and anxiety [2, 10].

Deeply ingrained beliefs about effective early childhood pedagogy shaped how some teachers chose to integrate technology into their curriculum [11]. Barriers also have been found that indicate that negative technology beliefs and unwillingness to change practices contributed to a lack of technology adoption in the classroom [9, 12]. Additional barriers include teachers' beliefs about students' roles (including agency in how to structure technology given sometimes limited resources at home) and about students' lack of opportunities at home to support learning [12]. Teachers use of technology in their daily lives played a significant role in determining their perceptions of barriers [12, 13].

While often perceived as barriers to adoption, teachers' low interest in teaching CS was perceived as a low-level barrier [14]. Integrating technology transformed key aspects of teachers' work like holding students accountable (teacher checking student work on a computer) and providing timely feedback (teacher typing feedback on a document online) [15]. Teachers also have acknowledged their challenge in supporting the socio-emotional needs of students and parents, ensuring they grow not just academically but also as individuals and as part of a supportive community [15]. A key finding that emerged in Durff's study indicated that teacher success in adoption of tech into their pedagogical repertoire could be determined by how experienced they were able to locate appropriate resources for their grade/age levels and for content areas [13]. More closely related to mindset, Durff also found that teachers who were more focused on preparing students for their futures were more likely to integrate technology into their pedagogical practices.

2.2 Intrinsic Barriers to Subject Integration

While there were a significant number of extrinsic barriers to integrating subjects across K-5 found in previous research [21], only a few intrinsic barriers could be found (Table 1). These include limited teacher content knowledge in all subject areas being integrated [16–18]. This includes definitions, constructs, frameworks, and parameters for what constitutes integration [18]. A lack of knowledge of resources is another hindrance for teachers who are developing teaching of integrated subjects [19]. It has also been found that a lack of experience teaching integrated subjects (pedagogical content knowledge) was a barrier [16]. With respect to beliefs and attitudes, limited understanding of the relevance of science at a personal level by teachers can be a barrier [20] as well as personal philosophy and attitudes [16].

Table 1. Key Intrinsic Barriers to Integrating Subjects within K-5.

Intrinsic Barriers
Lack of pedagogical content knowledge [16]
Limited teacher content knowledge in all subject areas being integrated [16–18]
Limited teacher knowledge about definitions, constructs, frameworks, and parameters for what constitutes integration [18]
Limited teacher knowledge of resources [19]
Limited understanding of the relevance of subject at a personal level by teachers [20]
Limiting personal philosophies and attitudes about teaching integrated subjects [16]

2.3 Intrinsic Barriers to K-5 CS Integration

Table 2. Key Intrinsic Barriers to Integrating Computing into Other K-5 Subject Areas.

Intrinsic Barriers
Limited comfort teaching integrated CS [22]
Limited computing knowledge [5, 23]
Limited knowledge of assessing CS learning [5, 6]
Limited knowledge on how to build interdisciplinary connections [22]
Limited knowledge of technology [6]
Limited pedagogical knowledge [22]
Limited pedagogical understanding for meeting students' diverse instructional needs [5]
Limited teacher buy-in for teaching CT [5]
Limited teacher self-efficacy [22]
Limited understanding of how CT/CS connects to their classroom [24]
Limited understanding of the importance of their students learning CS [22]

A key barrier to successful integration of CS into other K-5 subject areas has been identified as teachers held limited CT teaching expertise [5] (Table 2). Stokke found that K-5 teachers lacked an understanding of what CT is, which, arguably, is needed to teach integrated CS in K-5, particularly in the pre-reader grades of K-2 [4].

Teachers also struggle with how to assess their students [5, 6] as well as their own lack of training with technology [6] and computer science [25]. Low self-efficacy in teaching CS [22] and low teacher-buy-in for teaching CT [5] were others. This included a limited pedagogical understanding for meeting students'

diverse instructional needs [5]. Overall interest in learning and teaching CS may be a barrier, although limited [4].

3 Methodology

To address our research question, *What are intrinsic barriers to supporting the integration of computer science in the elementary grade level subject areas?*, we employed a mixed methods approach as part of a larger study [26, 27]. We developed a survey that included both closed and open-ended questions, along with demographic data of participants and their schools, to capture a wide range of perspectives. The survey items were designed to gather participants' insights on current K-5 CS integration efforts, considering 1) the objectives at the state, district, and school levels, 2) their methods for integrating CS, including the teaching materials they use, and 3) the curriculum standards that schools are meeting or striving to meet through CS integration.

After completing the survey data collection, we conducted focus groups with participants who indicated their willingness to participate. We developed an interview protocol for these focus groups based on the survey findings and aligned with our research questions. The discussions included questions about school and district goals for integrating CS into subject areas, pedagogical practices adopted by schools, and barriers have decision-makers in your district/school faced as they anticipate implementing those plans. There were a total of six focus groups that all met one time for an hour each. Focus groups The focus group discussions were transcribed and deductively coded by one researcher, linking the codes to survey items and introducing new codes as necessary. By analyzing the combined survey and focus group data, we identified common needs among decision-makers, specific curricular and professional development requirements for K-5 teachers, administrators, and districts, and created user persona profiles based on aggregated responses.

3.1 Participant Selection

Using a stratified proportional sampling method [28], we aimed to achieve broad representation without needing to investigate every individual state, district, or school. We established specific criteria to identify a sample of approximately 100–200 schools across different states and districts that would reflect the diversity of schools nationwide. The criteria included participant race/ethnicity (with an emphasis on underrepresented groups in computing), school types (30% urban, 40% suburban, 11% town, and 19% rural), and schools designated as Title 1 (58%), indicating a higher proportion of students from low socio-economic backgrounds. We also took into account that marginalized populations are less likely to complete surveys [?], and we considered this as we established our sampling by giving more weight to those groups.

We selected 30 states from which to choose participants based on recommendations from Code.org. This included 16 states with existing CS policies at the

elementary level and 14 without such policies. We identified over 1,600 decision-makers in the chosen schools through their association with Code.org. Additional recruitment was done through Computer Science Teachers Association (CSTA) chapters in these states, social media, newsletters, and emails to attendees of the 2021 CSEdCon who had opted for further communication. We also visited state Department of Education websites to identify superintendents and administrators from the 30 states. We ultimately reached our target number of survey participants (150–200). From those who participated, we conducted focus groups with key decision-makers, such as superintendents, administrators, and district-level curriculum specialists, who might be involved in selecting materials for integrated CS instruction.

Upon completion of the survey, participants were directed to a form where they could enter a random drawing for a stipend. Participants could also indicate interest in joining a focus group.

3.2 Data Collection and Analysis

After completing the survey data collection, we organized focus groups comprising participants who had indicated interest. These focus groups were deliberately composed of key decision-makers such as superintendents, administrators, and district-level curriculum specialists, who play significant roles in decisions regarding the integration of CS into various subjects. To guide discussions, we developed an interview protocol based on survey findings and aligned with our research objectives.

Subsequently, we transcribed the discussions and applied deductive coding techniques, aligning codes with survey items and introducing new codes as necessary. These codes led to the establishment of themes and categories. Through analysis of both survey and focus group data, we identified common needs among decision-makers, delineated specific curricular and professional development requirements for K-5 educators, administrators, and districts, and developed user persona profiles based on synthesized responses.

3.3 Participants

Survey Participants Of the survey participants ($n=160$), 46 (29%) were district leaders, 34 (21%) were school leaders and 19 (12%) were curriculum development specialists. Of the participants, K-5 CS teachers and classroom teachers comprised only 6% each. Regarding gender ($n=157$), the vast majority of participants were female (72%). Among the survey participants, 72 (45%) served students from rural communities, 47 (29%) from suburban communities, 46 (29%) from cities, and 35 (22%) from towns (participants could select more than one answer). Additionally, 43% (68) of participants represented a single school, 31% (49) a single district, 21% (33) multiple schools, and 6% (10) multiple districts.

Participants hailed from diverse states, with Iowa leading at 18% ($n = 29$), followed by West Virginia and California at 8% each ($n = 13$), and New York at

7% ($n = 11$). Almost all of the 30 identified states had at least one representative. Despite Iowa's significant representation, an analysis of key data markers, including CS integration status in K-5, geographic location, and identified needs and barriers, did not reveal any skewing of results.

In terms of school types, the majority of responses (77%, $n = 138$) came from public schools, with 14% ($n = 23$) from private schools, 7% ($n = 11$) from charter schools, and 4% ($n = 7$) from magnet schools. Seventy-two percent ($n = 115$) of participants were associated with schools or districts designated as Title I (serving students from families with lower income), while 23% ($n=36$) were not sure of their designation.

Focus Group Participants A total of 47 participants indicated that they were interested in participating in a focus group. We selected 30 participants who could attend certain meeting times and grouped them in the following focus groups, with 23 ultimately participating:

- From rural areas who offer K-5 CS ($n=3$)
- From districts/schools that offer K-5 CS and who serve students from low-income families and that offer K-5 CS ($n=2$) and those who serve other students ($n=4$)
- From suburban areas who offer K-5 CS ($n=5$)
- From schools/districts that do not offer K-5 CS ($n=4$)
- From individuals from any category above ($n=5$)

Among the focus group participants ($n = 23$), it was found that 38% served students in rural areas, while another 38% served suburban populations. Only 14% worked with students from towns, and 10% with those from cities. In terms of organizational affiliation, 48% of focus group participants were from single districts, 43% from single schools, and 9% from multiple districts; none were from multiple schools. Additionally, 70% were affiliated with districts or schools designated as serving students from lower-income families (Title I), while 26% were not. One participant was uncertain about their district or school's Title I status.

Expert Interviewees We recruited researchers and curriculum designers studying CS integration into various subject areas in primary schools from studies they have published and shared and some of whom were engaged in Research Practice Partnerships (RPPs). While most of our questions focused on content covered in a different paper, we still used this data to search for barriers to integrating CS in K-5. Participants (with pseudonyms) included:

- Andrea (Professor in School of Education): Research focused on integration of CS into K-5, including teacher PD
- Benjamin: Involved with K-12 CS framework development, national and state K-12 CS standards
- Elizabeth (STEM/CS supervisor at large school district): Former teacher focused on integrating CS into K-5 classrooms

- Mary (Professor of learning sciences): Focused on integrating computing in K-5 math
- Patty (Education researcher): General interest of integrating CS into K-5 math curriculum
- Roxanne (Education researcher): Supporting districts integrating CS into literacy block for grades 3–5
- Sallie (Professor of CS): Integrating math and CS into K-5 subjects, including for English language learners.
- Terry (Professor with focus on CS education): Involved in Math+CS integration, including alignment to standards
- Wesley (Professor/researcher focused on K-5 CT and coding): teaches instructional design and development

4 Results

4.1 Limited Teacher Content Knowledge

While some comments were made about teachers' content knowledge, most of these were presented in the context of a need for professional development. However, many focus group participants spoke about teachers' overall lack of experience teaching CS as being a challenge, including the need for additional professional development. Five focus group participants agreed that teachers often misunderstand what CS is and "digital learning", "educational technology", and "technology use" are sometimes classified as computer science. This creates an issue "because a lot of districts are saying, "Well, we are doing computer science because we have digital learning," and that's not true."

Two said their schools lack trained CS teachers. One participant's school "staff is very not trained." One focus group participant witnessed the fact that there are teachers in their district "...that barely can use their own computer", while another noted that most teachers "haven't even ever seen code."

Further, expert interviewee Terry described the limited knowledge that teachers have dealing with "a level of debugging or troubleshooting." At one school, he witnessed the technology coach "be present and really be hands-on and support some of those troubleshooting components that really disrupt instruction, but then at other times the technology coach wasn't there." Expert interviewee Benjamin added "there [is] a learning curve for tools or platforms or languages, there's also the academic content."

When considering how to best support teachers, three focus group participants presented teachers having different levels of CS knowledge as a barrier. One person stated, "when we started, [CS] was new to all of our teachers, so everybody could enter at the same place" and now, different teachers have varying levels of CS knowledge."

Three other participants indicated that their schools are training media specialists to teach CS in K-5, since for various reasons the teachers are not yet able to.

4.2 Limited Pedagogical Content Knowledge

In addition to limited content knowledge, limited pedagogical content knowledge specific to CS was raised as a barrier. One survey participant noted the lack of knowledge about how to approach teaching and learning computer science as a barrier. Expert interviewee Benjamin has witnessed teachers teaching CS and “found that teachers don’t generalize their teaching knowledge and practice from one discipline or more general to a novice discipline... I think that comes from a lack of confidence, time to practice and build those explicit connections.” Benjamin also noted, “what supported going beyond that was deepening their content knowledge, and thinking about trying to view curricula as more flexible and ways of addressing content, but also exploring different approaches.” Expert interviewee Wesley shared that he witnessed, “I would see months down the road, teachers were at the same level [of integrating CS knowledge]... And it’s because they just never got beyond those basics.”

Limited Knowledge Designing Integrated Lessons. Multiple participants discussed the challenges with designing lessons that integrate CS. Expert interviewee Andrea spoke to the level of difficulty many teachers have when creating integrated lessons, noting that “integration is very hard for teachers because it requires a lot of time and explicit planning.” She added she learned “it was very, very hard for teachers to think about...how to do crosswalks with their own [state CS] standards and think about where [CS integration into other subjects] fits into their instruction.”

Limited Knowledge Teaching Integrated Lessons. Expert interviewee Elizabeth mentioned that teaching CS integrated into another subject is probably harder than teaching just code “because it takes learning in a way that [teachers] weren’t taught themselves.” For example, Elizabeth shared “...teachers don’t necessarily know that during that 90-minute reading block, they can read about science and do some program writing.”

Limited Knowledge of How to Meet the CS Learning Needs of All Students. Expert interviewee Andrea added that the teachers “teach very different populations of kids” requiring teachers to integrate lessons to students in their classrooms. She noted, “We also learned for students, the scaffolding that we were providing, especially for students with disabilities, was still not enough.” Expert interviewee Benjamin shared, “when writing IEPs and such, computer science is not considered. What that means, this is pretty true at the secondary levels, that school systems do not designate supports for computer science.”

He further noted that “We have a huge [English learner] population in our district. How do we make sure language isn’t a barrier with our special education kids? How do we make sure that the level of [CS] activities is still doable for all kids or accessibility for kids? How can we make sure we are integrating all those things in to make sure that every kid can be successful within the classroom?”

4.3 Teacher Beliefs

Limited or Negative Beliefs About the Value of Learning CS. Participants shared that teacher recognition of the importance of CS being taught at the elementary grade levels is a step that needs to be taken to successfully bring CS into K-5. Expert interviewee Patty noted that having “...certain teachers that were motivated to try CS for various reasons such as, *'I like it because it's technology,'* and there were some that were, *'I like it because it's going to support my math scores, my math teaching, my math learning.'* There weren't that many that were just like, *'I like it because I think CS is important.'*”

Expert interviewee Mary shared that teachers were “way more motivated when it's something that they already know about and care about.” Expert interviewee Wesley echoed that teachers were motivated to try coding when they “realized that actually coding is really useful” and that it could be used to improve their teaching.

Low Self-Efficacy. Expert interviewee Patty stated the idea of “You can teach [CS-integrated curriculum] with no CS experience, just learn with the kids” was not effective in convincing the teachers to teach integrated CS. Even after repeated modeling and scaffolding, one administrator found that their teachers were still not comfortable teaching CS. One focus group participant stated that when integrating CS into content areas, they tried, noting that they

...would introduce that lesson, launch it that first year and co-teach it with that teacher. Maybe that second year you'd co-teach it again, but you'd pull away a little bit but come the third and fourth years...you wouldn't be in that classroom anymore. Now that I'm in year seven... They should be 100% comfortable by now. There's no reason they shouldn't, but for some reason, they still need me in the room. That's a barrier I never anticipated.

Expert interviewee Wesley stressed the importance of teachers' positive view of CS because he found, “at the end of the day, it didn't matter how much [teachers] learned...if they don't see this as something that they can use, and something that they enjoy, then they're not going to use it.”

4.4 Varied Teacher Perspectives

Teacher Fear, Intimidation, and Limited Comfort Levels. Eight focus group participants named teacher fear and intimidation as barriers. Expert interviewee Sallie noted that PD was key to overcoming the intimidation that teachers feel about integrating CS into other subject areas, since many of the teachers “were very scared before they showed up.” One participant noted that teacher buy-in is a need, sharing that “we'd need the teachers to feel comfortable that they could do it.”

Three focus group participants think teachers are afraid of CS and technology. One focus group participant believed that teachers are scared of teaching CS,

stating that “teacher fear and discomfort with coding” presents barriers at their school. Additionally, one focus group participant noted that teachers have both “a fear of not knowing how or what to teach around computer science within other content, but the fear of not knowing the impacts of if they don’t do it the way they’ve always done it.”

Teacher Exhaustion. Six focus group participants shared teacher exhaustion as a barrier for administrators trying to integrate CS into subject areas. One administrator said, “We also felt that we couldn’t just throw it on teachers right away. They’re not doing well, and they’re overwhelmed as it is, so we’re easing into this.” Another said “Trying to introduce new things right now is met with a barrier that I’m chiseling, but I’m not trying to go through it with a bulldozer.” Expert interviewee Terry noted the challenge of finding teachers who are enthusiastic teachers to teach CS. He said, “There’s a wave of early adopters of folks who were super enthusiastic about it, but....it became more and more challenging to find teachers who were enthusiastic about it.”

Limited Motivation. One focus group participant noted that their district “had been talking about [CS implementation] for years, but actually couldn’t get our teachers to implement it—until [our state] passed legislation that we have to have this now.” Another participant noted that “some of our new teachers are more reluctant to take on another thing.” One administrator stated their teachers said “they can’t do another thing.”

Limited Teacher Buy-in. Eight focus group participants shared the lack of teacher buy-in as being a barrier. The participants observed lack of buy-in from teachers with attending professional development. One participant shared, “finding the people who are willing to get the training to do it, that was our biggest obstacle.” The seven other participants described the lack of buy-in from the teachers overall regarding CS implementation.

Five of the participants discussed the goal of increasing teacher buy-in. One building leader shared that when trying to integrate technology “it’s just an area that is guarded by [K-4th grade] teachers. That’s one that they don’t tend to let go of easily and want somebody else coming in. They have their topics that they want their kids to write. There are certain standards that they need to hit.”

Low Teacher Interest/Willingness to Adopt New Practices. Teacher interest in teaching was perceived as being a challenge, with 70% ($n = 81$) of survey participants who teach CS in K-5 citing a lack of teacher interest to teach CS. Five focus group participants further echoed this, stating that teachers’ “attitudes and mentalities” about teaching CS presenting a barrier. Relating to CS, one participant said, “I think the classroom teachers... wouldn’t [engage with the] curriculum and implement it because they’re not interested in it. They don’t see how it applies to their content areas necessarily.” One administrator

shared in general that they have noticed “reluctant teachers...that [have] only always [taught CS] a certain way. They aren’t really willing to change a whole lot.”

5 Discussion

5.1 Mapping Barriers Identified by Support Staff to Previous Research

We identified four categories of intrinsic barriers from support staff: limited teacher CS content knowledge, limited teacher pedagogical content knowledge, limited teacher beliefs about CS, and varied teacher preparation on CS integration into other subjects (see Table 3). Notably, although previous research is limited in K-5 space specifically for integrating CS into other subject areas, the findings map to this limited research. This provides some confirmation that there is an understanding of the supports teachers (and curriculum designers) need to integrate CS.

Table 3. Intrinsic barriers to supporting teachers’ delivery of CS education as identified by participant responses. * indicates limited feedback from participants to support.

Intrinsic Barriers
<i>Limited Teacher CS Content Knowledge</i>
Limited General CS Content Knowledge
Limited Knowledge of Supporting Educational Technologies
<i>Limited Teacher Pedagogical Content Knowledge</i>
Limited knowledge designing integrated lessons
Limited knowledge of how to meet subject learning needs of all students
Limited knowledge assessing students
<i>Limited Teacher Beliefs about Subject</i>
Limited or negative beliefs about the value of learning subject
Low self-efficacy teaching subject
<i>Varied Teacher Perspectives on subject integration</i>
Teacher fear, intimidation, and limited comfort levels
Teacher exhaustion
Limited motivation
Limited buy-in
Low teacher interest/willingness to adopt new practices*

5.2 Content and Pedagogical Content Knowledge

Issues related to content knowledge and pedagogical content knowledge are found in both technology integration and integration of other subjects in primary schools. For example, there is considerable research on technology integration through researchers studying the Technology, Pedagogy, and Content Knowledge (TPaCK) framework [2].

Limited teacher content knowledge of CS and how to integrate CS into existing subjects is to be expected, since K-5 teachers likely haven't learned CS in their pre-service training or in professional development. Israel et al. and Yadav et al. have also found this in their research focused on the U.S. Further, Howard found that limited knowledge of supporting educational technologies is also an intrinsic barrier faced by teachers. This finding also makes sense, since teachers need to also learn which modalities are best to use when teaching their students and also integrating CS learning with other subject areas. Even when teachers hold appropriate CS content knowledge, however, there is still a constant examination of tools and manipulatives to determine which might resonate best with their students. This barrier is amplified with the evolving nature of digital tools and requires teachers to continually stay committed to learning and relearning them.

Pedagogical content knowledge is another intrinsic barrier identified by participants. Teachers hold limited knowledge designing integrated lessons in general, even in subjects that they already teach [18]. This is no different when introducing CS [22]. In particular, participants noted that teachers hold limited knowledge of how to meet CS learning needs of all students [5]. This is problematic and is the core of the CS for all students movement. Finally, participants noted that teachers hold limited knowledge assessing students as they learn CS [5, 6].

While some have called for integration of CS in the early grades as a solution to the barrier of lack of time for a new subject (including some participants in our study), the findings reflect the deep need for teacher training that recognizes the complications of teaching and assessing learning in integrated subjects. This solution also fails to recognize that, for example, if math was taught 30 min each day, integrating CS into math may require more time to teach to the original math standards and simultaneously meet the required CS standards.

Beyond general CS content knowledge and pedagogical content knowledge, professional development and pre-service teacher training will require advances in assessing CS learning for early grades. Any PD also may benefit from curriculum design frameworks like Universal Design for Learning and culturally-relevant pedagogy for it to be impactful for all students.

5.3 Teacher Beliefs and Perspectives

Participants noted that teachers sometimes hold limited or negative beliefs about the value of learning a new subject. This aligns with previous research both outside of CS [1] and within CS [22]. Further, participants noted the issue of teachers holding low self-efficacy teaching CS [22]. Previous research has shown that

teacher self-efficacy plays a role in teachers valuing their jobs and also has been shown to impact student learning.

Participants noted that teacher fear, intimidation, and limited comfort levels teaching integrated subjects has been identified before, in general subject integration [2,10] and when integrating CS into existing subjects [22]. Notably, and likely intertwined, are additional intrinsic barriers including limited buy-in by teachers to teach CS [5] and limited teacher interest and/or willingness to adopt new practices. While the latter borders on being framed as deficit-based, we recognize that previous research has shown this to be true in integrating two or more subjects [9,12,14,29]. We also recognize that these issues can be alleviated by recognizing that the environments in which teachers work contribute to these findings. We also recognize that the respondents in our study are mostly in positions to make some changes that can drive teacher interest.

However, we also recognize that participants often noted the very real issue of teacher exhaustion, particularly during and post-COVID. This, combined with teacher pay (particularly in some states within the U.S.) [30] and a general pattern in the U.S. to attack and reduce support for public education [31], have started to drive more teachers to leave the profession. When participants note, then, that teachers are not motivated to learn a new subject, one cannot blame the teachers.

Finally, while we focused on K-5, barriers have been identified by others across the K-12 landscape, particularly in high school [32]. Further investigation into barriers for integrating CS into other subject areas in later grades could provide additional insight.

5.4 Limitations

While our literature review was thorough, it was not conducted as a systematic literature review. It is possible that the intrinsic barriers identified have been previously reported in the extant literature of K-5 CS integration.

Despite our extensive efforts to build an email list targeting individuals at districts and schools who may not be affiliated with Code.org, we faced challenges in reaching potential participants from this category. Approximately 90% (1,588) of survey recipients were affiliated with Code.org, accounting for around 60% of the total respondents. Consequently, the 160 participants represent roughly a 15% response rate.

Although our study focused on 30 states (16 with state-level CS policies and 14 without), expanding the survey to all 50 states might have increased the response rate. Nonetheless, the detailed and nuanced responses from participants as well as the mixed methods approach that includes experts provide a solid basis for identifying a comprehensive list of barriers.

6 Implications and Conclusion

This study was confirmatory in that nearly all of the findings are supported by previous research findings. The broad list of intrinsic barriers provide confirma-

tion that there are systemic issues within the U.S. public education system that impact the integration of CS in primary schools. This research implies, then, that **curriculum designers and school leaders in our study appear to collectively understand the intrinsic barriers faced by teachers—particularly those for which they play an agentic role in addressing.** In fact, there is precedence for overcoming these barriers in other, related fields—such as general integrating of subject areas. Approaches that have been successful in integrating science and math or literacy and physical education could prove to be insightful when tackling barriers in CS integration.

This study, then, can be used to build the capacity of teachers through the systematic removal of the barriers. Many of the participants noted that they are already actively tackling the challenge of integrating CS into core subjects. Whether the barrier is centered around limited buy-in from teachers or limited knowledge assessing students, research-based methods for countering these barriers can be identified and implemented. By so doing, local and state education agencies can appropriately support teachers and thereby grow CS education to a wide range of K-5 students.

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Incorporating CUDA Unified Memory into the Operating System Curriculum

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Abstract. Memory management, particularly virtual memory, is a crucial topic in Operating System curricula. This paper explores the integration of CUDA Unified Memory into OS coursework to enhance student understanding of these concepts. By using GPU CUDA Unified Memory as a practical example, students were given a hands-on homework assignment containing several experiments designed to deepen their comprehension of memory management techniques. The experiments included observing page faults, techniques for reducing page faults, and oversubscription of GPU memory. This paper details the design rationales behind the hands-on experiments, aiming to provide a comprehensive learning experience. Pre-test and post-test assessments indicate that the assignment improves student learning outcomes, demonstrating the effectiveness of this pedagogical approach.

Keywords: Memory Management · CUDA · Unified Memory · Paging System · Operating System Curriculum

1 Introduction

Memory management, particularly virtual memory and paging systems, is a crucial topic in Operating System (OS) curricula [18]. To enhance student understanding of these complex concepts, incorporating CUDA (Compute Unified Device Architecture) Unified Memory [3] into the coursework provides a practical, hands-on approach. This paper examines the use of CUDA Unified Memory as an effective tool for teaching memory management techniques.

GPUs (Graphics Processing Units) have become essential in various fields such as scientific computing [8], machine learning [11], simulations [17], etc. due to their parallel processing capabilities. It consists of a scalable number of streaming multiprocessors (SMs) and each SM contains a group of streaming processors (SPs) [13]. CUDA is a parallel computing platform and programming model developed by NVIDIA, which allows developers to leverage the power of GPUs for general-purpose computing [9]. It is important to note that only portions of these programs are executed on the GPU, while the remainder runs on the CPU and main memory.

The GPU device has its own off-chip device memory, as illustrated in Fig. 1. Before the introduction of Unified Memory, programmers had to differentiate between data in main memory, allocated via `malloc()`, and data in device memory, allocated via `cudaMalloc()`, and manually implement the transfer of such data between the two locations using `cudaMemcpy()` whenever necessary [3]. This manual task increased the complexity of program implementation and raised the likelihood of bugs. Unified Memory, a feature of CUDA, simplifies memory management by providing a single address space accessible by both the CPU and GPU. That is, to allocate data in Unified Memory, the function `cudaMallocManaged()` is called, which returns a pointer that you can access from host (CPU) code or device (GPU) code. Therefore, with Unified Memory, programmers no longer need to distinguish between the two memory locations and can treat them the same way. Essentially, Unified Memory abstracts main and device memory from the programmer, allowing the system to handle this automatically. Additionally, it serves as an excellent educational tool for demonstrating concepts in virtual memory management and paging systems.

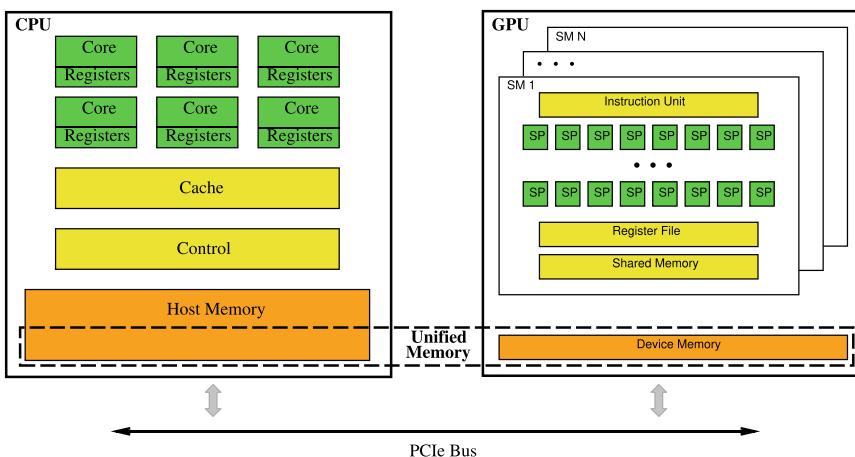


Fig. 1. CPU and GPU architecture

The hands-on homework assignment presented in this paper is designed to bridge the gap between theoretical knowledge and practical application. It consists of several meticulously constructed experiments, including the observation of page faults, techniques for reducing or preventing page faults, and the oversubscription of GPU memory. These experiments provide students with real-world examples and enable them to directly observe the behavior of memory management mechanisms.

The rationale behind these experiments is to offer students a comprehensive learning experience that goes beyond traditional classroom instruction. By engaging with CUDA Unified Memory, students can better understand the effects

of different strategies on memory performance and efficiency, thereby gaining a deeper and more practical understanding of memory management. This paper details the design rationales behind the hands-on experiments, aiming to provide a robust educational framework that enhances the learning experience in OS courses. By utilizing CUDA Unified Memory, the assignment not only reinforces theoretical concepts but also equips students with valuable practical skills applicable to real-world scenarios.

The organization of this paper is as follows. Section 2 discusses the related work in the memory management topic for student practices, including relevant homework assignments and programming projects. Section 3 focuses on the CUDA Unified Memory experiments, detailing the experimental setup, tools used, and the rationale behind each experiment’s design. Section 4 presents the results of an assessment using pre-test and post-test evaluations. Finally, Sect. 5 offers a brief conclusion and outlines future work.

2 Related Work

In an introductory operating systems course, the majority of homework assignments related to the virtual memory topic are written exercises rather than hands-on programming tasks. These assignments are specifically designed to help students practice and understand the theoretical concepts. However, there are notable exceptions. For instance, there is a significant project where students are asked to implement the virtual memory scheme in the educational Pintos operating system [14]. Similarly, students undertake a project to implement a Virtual Memory Page Fault Profiler as a Linux kernel module [4]. These projects provide practical experience and a deeper understanding of virtual memory through hands-on programming challenges.

Another interesting hands-on project is described in [7]. In this assignment, students use Linux tools like `perf` and `vmstat` to gather metrics on various aspects of a program’s behavior, including its interactions with the processor, cache, and operating system. After collecting data from multiple programs, students must explain their findings in a brief report, relating the data to fundamental principles of processor, memory, and system design.

An assessment of Unified Memory performance with data prefetching and memory oversubscription can be found in [10]. They evaluated the execution times of four benchmark applications using different versions of code, including the traditional CUDA memory model, the Unified Memory model, and Unified Memory with data prefetching. Additionally, they investigated the performance of applications using Unified Memory with memory oversubscription.

The work presented in [12] describes the implementation of a source-to-source refactoring tool that automatically translates traditional CUDA programs into modern versions using Unified Memory. The tool was built with the Clang LibTooling [1], using the Abstract Syntax Tree of the program’s source code to perform context-aware refactoring on it and generate the translated code. Note that the above two works [10] and [12] are more research-oriented and may not

be suitable for an introductory OS course, but are better suited for advanced courses.

3 Hands-On Experiments

Students are asked to use the `tar` command to extract sub-folders and program templates from a given archive file. There are three major parts in this homework assignment. Below are the detailed descriptions and the design rationales.

Part 1: deviceQuery

The purpose of this experiment is to help students understand the hardware configurations of an Nvidia GPU, especially the size of the physical memory on the GPU card, which will be referred to when explaining the outcome in Part 3. Students needed to type `make` in the `deviceQuery` sub-directory, obtained from [2], to build the executable file `deviceQuery` from the provided `Makefile`. Then, they should run the executable file. Students were required to take a screenshot of the result and include it in their report. They must also answer questions such as: How many Streaming Multiprocessors (SM) are there? How many CUDA cores? How much global memory? What is the GPU clock rate? How many registers available per block?

In our Linux lab, each workstation is equipped with an entry-level Nvidia Quadro P620 GPU card. We also have another workstation with a high-end RTX 2080Ti GPU. As shown in Fig. 2 and Fig. 3, the memory size of the Quadro P620 is 2 GB, while the RTX 2080Ti has 11 GB.

```
$ ./deviceQuery
./deviceQuery Starting...

CUDA Device Query (Runtime API) version (CUDART static linking)

Detected 1 CUDA Capable device(s)

Device 0: "Quadro P620"
  CUDA Driver Version / Runtime Version      11.4 / 11.4
  CUDA Capability Major/Minor version number: 6.1
  Total amount of global memory:             1991 MBytes (2087649280 bytes)
  ( 4) Multiprocessors, (128) CUDA Cores/MP: 512 CUDA Cores
  GPU Max Clock rate:                      1354 MHz (1.35 GHz)
  Memory Clock rate:                       2505 Mhz
```

Fig. 2. Partial output of running `devicequery` on a Quadro P620

Part 2: Page Faults

There are three experiments in Part 2. Their objective is to observe the page faults that occur on both the CPU and GPU sides using a CUDA program,

```

Device 0: "NVIDIA GeForce RTX 2080 Ti"
  CUDA Driver Version / Runtime Version      11.4 / 11.4
  CUDA Capability Major/Minor version number: 7.5
  Total amount of global memory:            11016 MBytes (11551440896 bytes)
  (68) Multiprocessors, (64) CUDA Cores/MP: 4352 CUDA Cores
  GPU Max Clock rate:                     1650 MHz (1.65 GHz)
  Memory Clock rate:                      7000 Mhz

```

Fig. 3. Partial output of running devicequery an RTX 2080Ti

and then apply two different methods to avoid these page faults. In the first experiment, students needed to use the following command:

```
nvcc vAddUM.cu -o vAddUM
```

to compile the sample program `vAddUM.cu` discussed in class. Our program `vAddUM.cu` is similar to the program in [6], except that we use a third array to store the results. This makes it easier to observe and identify where the page faults occurred.

Figure 4 shows the list of the source code `vAddUM.cu`. As shown in lines 17, 18, and 19, it calls `cudaMallocManaged()` to allocate three arrays, `x`, `y`, and `z`, respectively, in Unified Memory. Each of these array is $2^{20} \times \text{sizeof}(\text{float}) = 4$ Mbytes in size. It can be assumed that `cudaMallocManaged()` initially creates these arrays on the GPU side, but not dirty (i.e., no initial data). As will be shown later, when the code in lines 21-24 initializes the arrays `x` and `y`, it causes page faults on the CPU side. Furthermore, because the data is not dirty, there is no need to transfer the data from the GPU to the CPU. However, accessing and checking the values in the array `z` in line 39, which also causes page faults on the CPU side, is a different case. Because the array `z` is dirty (i.e., modified in the line 9), it has to be transferred from the GPU to the CPU.

Students were instructed to use the command below to collect and view profiling data from running `vAddUM`:

```
nvprof ./vAddUM
```

Note that we are interested in the page fault numbers shown in the last few lines of the profiling result, especially the numbers of `Host To Device`, `Device To Host`, and `Total CPU Page faults` for later comparisons. A sample of the partial profiling output running on a Quadro P620 can be found in Fig. 5.

It can be seen that there are 36 page faults on the CPU side. However, there is no direct information about the page faults that occurred on the GPU side. As mentioned in class, students can use the “Min Size” of the data packet in the `Host To Device` row to determine this. If the value of “Min Size” is 4 KB (i.e., page size), as shown in Fig. 5, it implies that page faults occurred. Note that the number of “GPU Page Fault Groups” shown in Fig. 5 does not indicate the actual number of page faults occurring on the GPU. Instead, these faults are written to a special buffer in system memory, and the Unified Memory driver processes multiple faults together as a group [16].

```

1 #include <iostream>
2 #include <math.h>
3 // Kernel function to add the elements of two arrays
4 __global__
5 void vecAdd(int n, float *a, float *b, float *c){
6     int index = blockIdx.x*blockDim.x + threadIdx.x;
7     int stride = blockDim.x * gridDim.x;
8     for (int i = index; i < n; i+=stride)
9         c[i] = a[i] + b[i];
10 }

11 int main(void) {
12     int N = 1<<20;
13     float *x, *y, *z;
14     float msec;
15     cudaEvent_t start, stop;

16     // Allocate Unified Memory -- accessible from CPU/GPU
17     cudaMallocManaged(&x, N*sizeof(float));
18     cudaMallocManaged(&y, N*sizeof(float));
19     cudaMallocManaged(&z, N*sizeof(float));

20     // initialize x and y arrays on the host
21     for (int i = 0; i < N; i++) {
22         x[i] = 1.0f;
23         y[i] = 2.0f;
24     }

25     cudaEventCreate(&start);
26     cudaEventCreate(&stop);

27     int blockSize = 256;
28     int numBlocks = 12;

29     cudaEventRecord(start);
30     vecAdd<<<numBlocks, blockSize>>>(N, x, y, z);
31     cudaEventRecord(stop);
32     // Wait for GPU to finish
33     cudaEventSynchronize(stop);
34     cudaEventElapsedTime(&msec, start, stop);
35     printf("Kernel time: %f ms\n", msec);

36     // Check for errors (all values should be 3.0f)
37     float maxError = 0.0f;
38     for (int i = 0; i < N; i++)
39         maxError = fmax(maxError, fabs(z[i]-3.0f));
40     std::cout << "Max error: " << maxError << std::endl;
41     // Free memory
42     cudaFree(x);
43     cudaFree(y);
44     cudaFree(z);
45     return 0;
46 }

```

Fig. 4. List of source code vAddUM.cu

It is also important to justify the value of “Total Size”. From **Host To Device**, both arrays **x** and **y** have to be transferred to GPU when launching the kernel **vecAdd()** in line 30, yielding 8 Mbytes transferred. On the contrary, only the array **z**, 4 MB in size, is transferred from **Device To Host**. As mentioned before, the code in lines 21–24 does not migrate the arrays **x** and **y** from the GPU to the CPU because they are not dirty. Otherwise, the “Total Size” would be 12 MB from **Device To Host**. Furthermore, after several page faults occur, the CUDA unified memory library starts increasing the packet size (e.g., “Max Size”) for data transfer.

```
==3688504== Unified Memory profiling result:
Device "Quadro P620 (0)"
  Count  Avg Size  Min Size  Max Size  Total Size  Total Time  Name
    58  141.24KB  4.0000KB  0.9883MB  8.000000MB  961.8110us  Host To Device
    24  170.67KB  4.0000KB  0.9961MB  4.000000MB  374.3940us  Device To Host
    24      -          -          -          -          -  4.037000ms  Gpu page fault groups
Total CPU Page faults: 36
S ■
```

Fig. 5. Profiling vAddUM on a Quadro P620

In the second experiment, students were asked to copy the file **vAddUM.cu** to another file, **vAddUM_Init.cu**. Next, they edited the file **vAddUM_Init.cu** to remove the initialization of the data arrays **x** and **y** in **main()**, and then added the following code before line 3.

```
__global__ void init(int n, float *a, float *b){
    int index = blockIdx.x*blockDim.x + threadIdx.x;
    int stride = blockDim.x * gridDim.x;
    for (int i = index; i < n; i += stride) {
        a[i] = 1.0f;
        b[i] = 2.0f;
    }
}
```

They also needed to add a kernel launch of the function **init()** before line 29. Finally, they had to compile and run it with **nvprof**, take a screenshot, record the numbers for “**Host To Device**”, “**Device To Host**”, and “**Total CPU Page faults**”, respectively, and explain the differences compared to the results from the previous experiment.

Figure 6 shows the partial profiling result running **nvprof vAddUM_Init** on a Quadro P620. Compared with the results in Fig. 5, it can be seen that there is no data movement from “**Host To Device**” because the arrays **x** and **y** are initialized on the GPU side. For the same reason, removing the lines 21–24 in the original source code reduces the total number of CPU page faults from 36 to 12. That is, it can be inferred that the 12 page faults result from checking the values in the array **z** in line 39.

The third experiment uses an alternative way to reduce page faults and dynamic page migrations. To achieve this, the CUDA unified memory library

```

==364440== Unified Memory profiling result:
Device "Quadro P620 (0)"
  Count Avg Size  Min Size  Max Size  Total Size  Total Time  Name
    24  170.67KB  4.0000KB  0.9961MB  4.000000MB  434.2330us  Device To Host
    33  -          -          -          -          -  3.538353ms  Gpu page fault groups
Total CPU Page faults: 12
$ ■

```

Fig. 6. Profiling vAddUM_Init on a Quadro P620

provides the function `cudaMemPrefetchAsync()` for prefetching data asynchronously, thereby improving performance. Students were directed to duplicate the original file `vAddUM.cu` to a new file, `vAddUM_Pfetch.cu`, and add the following code before launching the kernel `vecAdd()`.

```

int device;
cudaGetDevice(&device);
cudaMemPrefetchAsync(x,N*sizeof(float),device,NULL);
cudaMemPrefetchAsync(y,N*sizeof(float),device,NULL);

```

They also needed to insert the following code before the final `for` loop in line 36 for asynchronously prefetching the array `z` back to the CPU.

```

cudaMemPrefetchAsync(z,N*sizeof(float),
                     cudaCpuDeviceId, NULL);

```

Same as in previous experiments, students were required to compile and run the executable `vAddUM_Pfetch` with `nvprof`. For the purpose of comparison, the numbers for “Host To Device”, “Device To Host”, and “Total CPU Page faults” should be recorded, and the reasons causing the differences should be explained in their report.

The partial profiling result of running `vAddUM_Pfetch` on a Quadro P620 can be found in Fig. 7. It can be seen that the packet’s “Min Size” is no longer 4 KB, either in “Host To Device” or in “Device To Host”. Furthermore, there is no output line showing “Total CPU Page Faults”. This means there is no CPU page faults occurred when asynchronously prefetching data prior to the execution.

```

==3688100== Unified Memory profiling result:
Device "Quadro P620 (0)"
  Count Avg Size  Min Size  Max Size  Total Size  Total Time  Name
    4  2.0000MB  2.0000MB  2.0000MB  8.000000MB  1.163249ms  Host To Device
    2  2.0000MB  2.0000MB  2.0000MB  4.000000MB  488.9220us  Device To Host
   13  -          -          -          -          -  1.646634ms  Gpu page fault groups
$ ■

```

Fig. 7. Profiling vAddUM_Pfetch on a Quadro P620

Students are expected to understand the trade-offs of using asynchronous prefetching. One of the significant advantages of this approach is that the

“asynchronous” nature helps hide memory access latency by overlapping data transfer with computation, thereby enhancing overall performance. Additionally, prefetching reduces the occurrence of page faults, which can otherwise interrupt the execution flow and degrade performance. However, this technique also has some drawbacks. Implementing asynchronous prefetching requires more effort from the programmer, as they need to carefully manage and predict data access patterns to effectively utilize prefetching capabilities. This added complexity can increase the development time and require a deeper understanding of both the application’s memory access patterns and the CUDA programming model.

Part 3: Oversubscription Execution

As discussed in class, one of the features of Unified Memory is the ability to oversubscribe memory, meaning it allows for the allocation of more memory than is available on a GPU [15]. Students were asked to observe this feature in this experiment. They needed to make a copy of the file `vAddUM.cu` into `vAddUM_Over.cu` and simply change the value of the variable `N` from `1 << 20` to `1 << 28` in line 12. Following that, they were required to compile and run the executable `vAddUM_Over` with `nvprof`, take a screenshot of the result, and explain why or why not the program can be executed. That is, if the program can be executed correctly, they should see the output `Max error: 0`, which is generated from line 40 in the code.

Figure 8 shows the partial profiling result of running `vAddUM_Over` on a Quadro P620. The program runs successfully even though the total memory allocated for the three arrays is $2^{28} \times \text{sizeof}(\text{float}) \times 3 = 3 \text{ GB}$, which exceeds the physical memory capacity of 2 GB on a Quadro P620 (refer to Fig. 2 in Part 1). This is feasible because the program does not require all three arrays to be simultaneously present in GPU memory.

Similarly, when the variable `N` is set to `1 << 30`, the program can still execute correctly on an RTX 2080Ti GPU, as illustrated in Fig. 9. This is despite the total size of the three arrays being $2^{30} \times \text{sizeof}(\text{float}) \times 3 = 12 \text{ GB}$, which exceeds the physical memory capacity of 11 GB on an RTX 2080Ti (refer to Fig. 3).

```
==3688810== Unified Memory profiling result:
Device "Quadro P620 (0)"
  Count  Avg Size  Min Size  Max Size  Total Size  Total Time  Name
  14897  140.78KB  4.0000KB  0.9961MB  2.000000GB  178.2859ms  Host To Device
    4327  434.02KB  4.0000KB  2.0000MB  1.791016GB  188.4523ms  Device To Host
    6232      -        -        -        -        -  575.2448ms  Gpu page fault groups
Total CPU Page faults: 8206
S ■
```

Fig. 8. Oversubscription of GPU Memory (3 GB) on a Quadro P620 (2 GB)

```

==646737== Unified Memory profiling result:
Device "NVIDIA GeForce RTX 2080 Ti (0)"
  Count  Avg Size  Min Size  Max Size  Total Size  Total Time  Name
  49437  169.68KB  4.0000KB  0.9961MB  8.000000GB  778.8249ms  Host To Device
  22336  233.54KB  4.0000KB  2.0000MB  4.974609GB  431.3000ms  Device To Host
  24588  -          -          -          -          2.533304s  Gpu page fault groups
Total CPU Page faults: 35619
$ █

```

Fig. 9. Oversubscription of GPU Memory (12 GB) on an RTX 2080Ti (11 GB)

Students were also expected to grasp the trade-offs associated with oversubscription. Specifically, oversubscription of GPU memory enables programs that exceed the physical memory limit to execute, which is advantageous for managing large datasets. However, it may result in slower performance due to higher data transfer overhead and increased occurrences of page faults and migrations, as shown in Figs. 8 and 9.

4 Assessment

To measure the effectiveness of the homework assignment for student learning and comprehension, 55 students were given assessment tests before and after the assignment. The same multiple-choice questions were used in the pre-test and post-test but in a different order. After the lecture and before the homework assignment, the students were asked to take a pre-test to determine their current understanding of the material. After the students completed the hands-on assignment, a post-test was given to measure whether there was any improvement in the students' performance.

The test consisted of 15 multiple-choice questions covering different aspects of GPU, CUDA, and unified memory technologies. Table 1 shows the results of the two tests. The second and third rows show the percentage of each question answered correctly before and after students conducted the hands-on assignment. The normalized gains [5], i.e., $(post_test - pre_test)/(100\% - pre_test)$, are calculated in the last row. As shown in Table 1, the average normalized gain is 57%, which is greater than the 30% specified in [5], indicating that the hands-on assignment has an effective impact on students' learning.

Table 1. Impact of Experiments on Student Learning and Comprehension

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Overall
Pre-Test(%)	58	55	40	25	38	35	53	27	44	36	33	29	33	31	55	39
Post-Test(%)	73	89	82	60	65	89	91	53	80	71	69	64	80	64	82	74
Normalized Gains(%)	36	76	70	47	44	83	81	36	64	55	54	49	70	48	60	57

5 Conclusion and Future Work

Incorporating CUDA Unified Memory into the OS curriculum has proven to be an effective strategy for enhancing student understanding of virtual memory management and paging systems. This paper presented a hands-on homework assignment that utilized CUDA Unified Memory to provide practical, real-world examples of key concepts. The assignment consisted of several carefully designed experiments, including the observation of page faults, techniques for reducing or preventing page faults, and the oversubscription of GPU memory. The rationale behind these experiments was to offer students a comprehensive learning experience that bridges theoretical knowledge and practical application. By engaging with these experiments, students were able to directly observe the behavior of paging system mechanisms and understand the trade-offs of different strategies on memory performance and efficiency.

The impact of this assignment on student learning was measured through pre-test and post-test assessments. The results indicated an effective improvement in students' understanding of virtual memory management and paging systems concepts. This suggests that the hands-on, experiential learning approach facilitated by the use of CUDA Unified Memory effectively reinforced theoretical knowledge and enhanced practical skills. This approach can serve as a model for other courses and disciplines where bridging the gap between theory and practice is essential for student learning and success. The positive outcomes of this assignment highlight the potential for similar educational strategies to improve learning outcomes in computer science and engineering education.

In the future, we are going to further integrate GPU and CUDA technologies into the OS curriculum. This can be achieved by developing more advanced assignments and projects that delve deeper into GPU memory management, scheduling, and concurrency. By expanding the curriculum to include these elements, students will gain deeper insights into the role of GPUs in modern operating systems, enhancing their knowledge and skills relevant to contemporary OS design and implementation.

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Increasing Student Success by Implementing Autograded Programming Assignments

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Abstract. Autograded programming assignments offer many potential benefits to programming courses. By implementing autograded programming assignments, rapid feedback can be provided to students, submitted code can be quickly checked for accuracy, grading can be consistent and equitable, and significant time can be saved, enabling instructors to focus more time on supporting students rather than grading. Numerous autograding tools are currently available which offer various advantages and limitations. The present work provides a brief review of common autograding tools and an explanation of how custom GitHub Classroom-based autograded assignments were implemented in a data structures course. Additionally, student data is analyzed to study the impact of autograded assignments on the data structures course and student success. By comparing five years of data structures class without autograding to four years of data structures class with autograding added, a significant positive impact was observed. The pass rate increased by 6.7% and student evaluation scores increased by 7.4%. Autograded assignments also provided useful data, such as identifying students who are struggling and enabling instructors to track student progress on assignments. With these benefits, autograding will be an increasingly important tool to help instructors make computer science courses more effective, equitable and accessible.

Keywords: Autograding · Education · Programming Courses

1 Introduction

Programming assignments are an integral part of most programming courses. While it is possible to manually grade student programs, manual grading is time consuming for instructors, delays feedback for students, and may cause grading to be inconsistent or inequitable from student to student. Recently, many autograding tools have become available which show strong potential to streamline grading of programming assignments. Such tools can enable instructors to quickly and accurately grade student work, provide instant feedback to students, and enable instructors to gauge student understanding more quickly and in greater depth [10, 12].

Many instructors are beginning to use autograding tools in programming courses. However, implementing autograding tools in a new or existing course can be challenging and time intensive. First, one must decide which autograding tools best fit an instructor's and course's needs. One must consider many factors including cost, availability, ease of integration with new or existing course materials and overall ease of implementation within a course. Next, one must create or implement assignments, which can be very time consuming if entirely new assignments and autograding tests must be created and validated. Finally, once the autograded assignments have been made, they must be deployed to students and instructors. Instructors and students must learn how to effectively use the autograding tools for submitting assignments and receiving feedback. As can be seen, the overall process for implementation can require a significant amount of effort.

The present work aims to assist educators and instructors in implementing autograding tools by providing an overview of related work, a detailed summary of existing autograding tools, an explanation of how GitHub classroom tools were implemented in a data structures course, and an analysis of the impact of these tools on the author's data structures course. It is important to note that each programming course is unique and there is not necessarily a one size fits all approach to implementing autograding. No autograding system is perfect and it is important to consider the advantages and limitations of these tools when using autograding in programming courses. The approach one might take can vary depending on the course, course materials, student and instructor preferences, resources available and types of assignments given. However, this case study about implementing autograding tools in data structures courses at California State University, East Bay, can provide very useful insights.

In Sect. 2, we examine several different works that utilize autograders and several different approaches to assigning grades to assignments. Section 3 examine the strengths and weaknesses of several different autograding systems followed by a discussion of our system choice in Sect. 4. Next, we discuss our approach to implementing an autograding system in a data structures and algorithm course in Sect. 5 followed by an exploration of our experiences and data using the autograding system in Sect. 6. We discuss future directions for our work in Sect. 7. Finally, we summarize our work in Sect. 8.

2 Related Work

There are a multitude of different autograding systems that have been implemented and utilized in programming focused courses [2, 3, 6, 8, 15, 17]. This section will examine several of these systems.

The authors of [13] discuss the process of implementing GitHub Classroom in two university-level statistics courses, highlighting the benefits such as improved project management and real-time autograding feedback. The authors found it much easier to provide feedback since student code could be remotely accessed via GitHub. Students also reported increased confidence in using Git

and GitHub, which students valued since these are skills relevant for careers in data science. One challenge in using the system the authors found was the steep learning curve for students using GitHub, especially in an introductory course.

The AutolabProject [2] is an open-source platform designed to automate the grading of programming assignments. It offers a flexible framework that allows instructors to create custom grading scripts and tests. By automating the grading process, Autolab reduces the workload on instructors and provides students with timely feedback on their submissions. The project has been widely adopted by educational institutions and continues to evolve with new features and improvements.

nbgrader [8] is an open-source system for managing and grading programming assignments written in Jupyter notebooks. It provides a flexible framework for creating and distributing assignments, collecting submissions, and automatically grading them based on predefined tests. nbgrader offers features like automated grading, code feedback, and the ability to integrate with popular learning management systems (LMS) such as Canvas and Moodle. It is widely used in educational settings to streamline the assignment and grading process, providing both students and instructors with efficient tools for learning and assessment.

In the work [16], the authors develop an auto-grading tool that uses semantics rather than traditional unit testing. Rather than simply counting passed tests, the tool uses the weakest preconditions and symbolic execution to detect path deviations. If such differences exist, the submission is marked as incorrect. This strategy can potentially offer more comprehensive feedback by generating counterexamples based on path differences and reduces the need for manually written test cases. However, this approach has two key limitations. First, it focuses on functional correctness and counterexamples but does not grade based on the distance between a submission and the correct solution. Second, the effectiveness is limited by the capabilities of constraint solvers and symbolic execution tools, potentially leading to false negatives.

3 Autograding Systems

In this section, we survey several different systems and discuss the features each has to offer. Although there are numerous autograding systems [17] available, we focus on a few widely used systems suitable for a Data Structures and Algorithms course. Specifically, we examine the Autolab Project, GitHub Classroom, GradeScope, ZyLabs, and Codio. The following is a brief description of each autograding system reviewed in the present work. A detailed side by side comparison of each system's advantages and limitations is provided in Table 1.

3.1 Autolab Project

The Autolab Project [2] is a project originally developed for programming courses at Carnegie Mellon University. It is now an open-source project and several other universities have since adopted it. Instructors develop unit tests for

each assignment and run student assignments against these unit tests. In order to provide security, the system runs each student solution within a Docker [4] container. The project has an active user base that maintains the code. Instructors are not required to use any specified testing framework. An instructor could use an existing testing framework such as Catch2, develop a shell script that checks for a specific output, or similar approaches. One issue with this particular system is the initial setup. The instructor will need to set up and maintain a server that runs Autolab. This may be a barrier for an instructor who does not have access to a server. In addition, for some instructors, the setup time and maintenance time may be prohibitive if an instructor does not have IT support. However, if an instructor is able to dedicate time and resources to developing autograded assignments, the Autolab Project can offer very good flexibility with the use of open source tools and enable these tools to be offered to students potentially for free or for very low cost compared to other options.

3.2 GitHub Classroom

GitHub Classroom [15] has similar functionality to Autolab. However, unlike Autolab which uses webserver approach for management, GitHub Classroom leverages Git and GitHub to streamline the process of creating, assigning, and grading programming assignments. It provides an interface for educators to set up assignments, specify grading criteria, and automate grading processes through GitHub Actions. Data is stored in the cloud in GitHub, so it is not necessary for instructors to provide their own server. GitHub Actions is a container-based automation tool within GitHub that allows users to create workflows to build, test, and deploy code directly in repositories. It uses YAML configuration files to define specific tasks that can be triggered by events such as pushing code, opening a pull request, or creating an issue. Instructors can create an autograding action whenever students push their code to the repository. This allows students to see their grade shortly after pushing code. The autograding action is highly customizable and can accommodate a wide variety of approaches including testing frameworks such as Catch2 or GoogleTest. Another helpful feature of GitHub Classroom is the fact that all student repositories are private to each student but visible to instructors. An instructor can directly check a student's most recent code pushed to GitHub. Since a student's pushed code can be directly viewed, instructors can more easily monitor student progress and answer questions while assignments are in progress.

3.3 Gradescope

Gradescope is an AI-assisted grading tool available on an individual or institutional subscription basis. Gradescope allows instructors to streamline grading for many types of questions and assignments. For example, handwritten calculations and short answer questions can be processed as well as coding questions. The analysis in the present work will focus on Gradescope's programming autograding tools.

The Gradescope programming autograder uses Docker to build a container image each time a student’s assignment needs to be graded. In order to create autograded assignments, instructors must create and test their own test files, including a setup (Bash) script and an executable script that compiles and runs the autograding tests and produces the output in a results.json file. Gradescope offers an interface which enables instructors to test the instructor-made auto-grading tests and control what feedback students receive.

Gradescope’s autograded programming tools do require significant setup and testing by instructors in order to verify that the assignments and tests are working properly. Additionally, the quality of the autograding and feedback depends directly on the assignments and tests built by the instructor. Once the setup is completed, Gradescope’s autograder offers some advantages compared to other options. If instructors plan to include other types of questions in assignments or exams (such as hand calculations, multiple choice, or short answer questions), Gradescope offers tools that streamline the grading of non-programming questions. Gradescope can also integrate seamlessly within an LMS such as Canvas if one has an institutional license.

3.4 ZyLabs

ZyLabs provides interactive textbooks, programming exercises, and automated grading tools. The autograding feature in ZyLabs allows instructors to assess student submissions quickly and accurately. By executing student code against predefined test cases, ZyLabs provides immediate feedback on correctness, efficiency, and style. This automated grading process saves instructors time and provides students with timely insights into their work. Another notable advantage of ZyLabs tools is that the programming exercises and tests are already made and ready to use in courses. For instructors looking to quickly implement autograded questions, the ZyLabs can be a good option to consider. ZyLabs also offers tools for instructors looking to develop their own custom assignments and tests as well. ZyLabs has two different IDEs available: the proprietary web IDE and a cloud-based Visual Studio Code IDE. Both options have the benefit of removing the complexities of setting up a toolchain. However, a drawback is that other IDEs cannot be easily used.

3.5 Codio

Codio [3] is an integrated development environment (IDE) that provides a cloud-based platform for software development and education. It offers a range of features, including code editing, version control, and collaboration tools. One of its key features is the built-in autograding system, which allows educators to automate the process of grading programming assignments. By integrating with various testing frameworks and grading scripts, Codio can automatically assess student submissions, provide immediate feedback, and generate detailed reports on performance. This automation saves time for instructors and helps students to provide timely feedback on their work. Codio has a proprietary web IDE and

a cloud-based Visual Studio Code IDE similar to ZyLabs. Like ZyLabs tools, the programming exercises and tests are already made and ready to use in courses. For instructors looking to quickly implement autograded assignments without needing to invest significant time upfront to develop and test new assignments, Codio can be a good option to consider.

Table 1. Summary of major autograding tools available for programming assignments, including strengths and limitations.

Autograding System	Strengths	Weaknesses	Other Notes
GitHub Classroom	<ul style="list-style-type: none"> - Offers Autograding for common use-cases - Exposes students to Git and GitHub workflows - Effectively free with reasonable usage limits (3,000 minutes) - Open-source - Allows export of assignment scores in LMS-compatible format - Active userbase for troubleshooting and development of new features - In-browser Visual Studio Code IDE available 	<ul style="list-style-type: none"> - Relies on GitHub. - Updates can be unpredictable - For introductory courses, Git and GitHub workflow may be overly complicated for some students. - May require instructor maintenance if support is dropped from a specific feature - If autograding tests/development require heavy computing, then costs could be incurred - Creating autograding assignments is time-consuming - Autograded assignments are not widely shared among instructors 	GitHub Classroom exposes students to Git and GitHub workflow. Students must use an IDE which is compatible with Git (some cloud based IDEs cannot be used or cannot integrate as seamlessly). Student repositories are visible to the instructor, allowing instructors to more easily answer student questions if a student pushes their current code to GitHub Classroom.
Autolab	<ul style="list-style-type: none"> - Free - Runs on instructor-managed server - Open-source - Allows export of assignment scores in LMS-compatible format - Active userbase 	<ul style="list-style-type: none"> - Standard use-cases for grading is left to the instructor to implement - Requires additional time for initial setup of Autolab server and ongoing maintenance. - Autograded assignments are not widely shared among instructors - Slower feature development 	Autolab may be a more preferable choice if an instructor wants more control over how and where student assignments are stored. However, there are costs to acquiring and maintaining a server.
Gradescope	<ul style="list-style-type: none"> - Active userbase - Technical support available - In-browser IDE - Assignment scores can be exported to LMS. Can integrate inside LMS if instructor has an institution license for GradeScope 	<ul style="list-style-type: none"> - Can be costly (\$1 to \$3 per student) and requires institutional license for best LMS integration. - Students not exposed to industry standard IDE - Instructors are responsible for developing autograding tests 	Gradescope also offers AI-assisted tools to help grade non-programming questions such as hand calculations and short answer questions.
ZyLab, Codio	<ul style="list-style-type: none"> - Wide selection of assignments already available - Custom assignments available and flexible approaches to autograding - In-browser IDE - Active userbase - Technical support available - LMS integration available. 	<ul style="list-style-type: none"> - Solutions to most of the premade assignments are findable online - Can be costly (\$1 to \$3 per student) - Limited IDEs options (cloud-based Visual Studio Code or proprietary IDE) 	Codio and ZyLabs have very similar approaches and features available. Both require students and/or the institution to pay for the service. IDE options are limited.

4 System Discussion

Overall, all of the autograding systems are highly customizable. Every system evaluated was able to run customized autograding tests developed by the instructor and some basic testing based on text-based matching. Free open-source systems generally rely on a container-based approach to run student solutions and

verify functionality via some sort of unit testing. The Codio and ZyLabs tools are particularly promising for instructors looking to implement autograding with premade assignments and resources already available. One notable drawback of Codio and ZyLabs is that solutions to many of the premade assignments can be found online.

5 Autograding Development and Implementation

This section examines the work required to implement an autograding system as part of the author’s CS301 (Data Structures and Algorithms) course at California State University, East Bay. This section aims to provide additional context and insights into one possible use case.

5.1 Selection of Autograding Tools

After evaluating several systems, GitHub Classroom was chosen based on several key benefits. Since our computational needs were low, it was free for both students and instructors. The workflow also familiarized students with Git and GitHub, essential tools in modern software development and in future courses. GitHub Classroom offers multiple options for both local and cloud-based IDEs. Grades could be directly exported to the Canvas or Blackboard LMS, and we were able to design unit tests that provided tailored feedback to students, enhancing their learning outcomes. Additionally, since instructors could directly view each student’s repository and latest code pushed, providing feedback and answering questions can be greatly streamlined.

5.2 Architecture

Figure 1 shows the architecture for GitHub Classroom. Instructors use a traditional web interface to manage students and setup the assignments for students. In order to deploy an assignment to students, the instructor creates an assignment and generates an invitation link which creates a repository for each student. Figure 2 shows a more detailed view of the student workflow. Students run unit tests provided by the instructor locally on the student’s own machine. Each time the project is pushed to their repository, a GitHub Action is initiated. This action creates a container that grades the assignment against the same unit tests and the autograder assigns points based on the unit tests passed. The autograder results are pushed back to the student repository as a badge indicating how many points were earned. As noted previously, instructors also have access to student repositories, enabling instructors to monitor progress and more easily answer student questions while students work on the assignment.

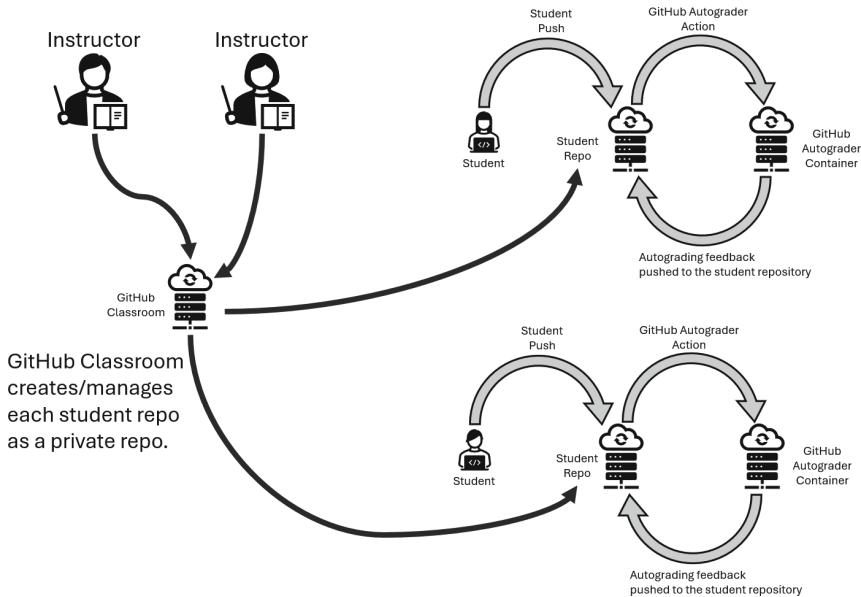


Fig. 1. The overall architecture for GitHub Classroom. Student assignments are stored as private repositories generated by copying a template repository. When students push code back to GitHub, autograding tests run.

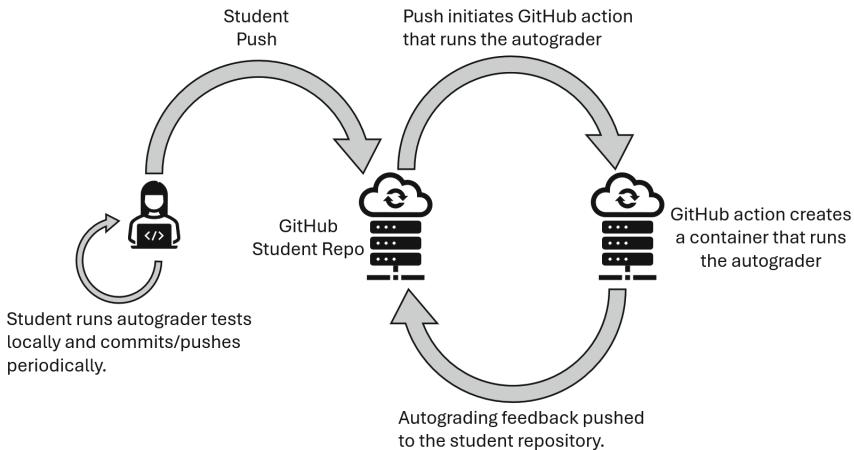
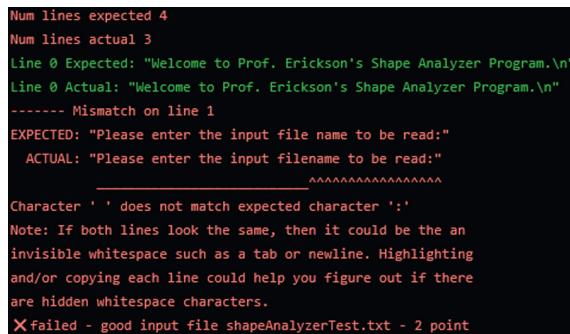


Fig. 2. GitHub Classroom autograder workflow. Students run the Catch2 autograder tests locally as they develop their project. When a student does a push to their repository, it initiates a GitHub action that starts an autograder. The GitHub autograder runs the Catch2 tests in a separate container. When the autograder finishes, the container pushes feedback to the student.

5.3 Output and Catch2 Autograding

The main challenge to creating autograding is the development of unit tests to verify the functionality of the program and assign points accordingly. GitHub Classroom's built-in autograder has comparison console output checks using exact match, included match (passes if expected output appears anywhere), a Regex-based match, or a custom grading command. While the text-matching tests are useful for some situations and for very simple programs, console-based input and output tests cannot be used in some situations such as when data is outputted to data files or elsewhere instead of the console. For example, classes that do not produce console output need a different mechanism for autograding. In these situations, we can use the custom grading command. For our course, we decided to use the Catch2 unit testing framework for our autograding.



```
Num lines expected 4
Num lines actual 3
Line 0 Expected: "Welcome to Prof. Erickson's Shape Analyzer Program.\n"
Line 0 Actual: "Welcome to Prof. Erickson's Shape Analyzer Program.\n"
----- Mismatch on line 1
EXPECTED: "Please enter the input file name to be read:"
ACTUAL: "Please enter the input filename to be read:"
                                ^^^^^^^^^^^^^^^^^^
Character ' ' does not match expected character ':'
Note: If both lines look the same, then it could be an
invisible whitespace such as a tab or newline. Highlighting
and/or copying each line could help you figure out if there
are hidden whitespace characters.
✗ failed - good input file shapeAnalyzerTest.txt - 2 point
```

Fig. 3. Representative feedback for students when text-based tests do not pass. The autograder shows the exact location where the text does not match. This functionality was added to a fork of the original autograder and has been made available in GitHub [1].

We also use a custom GitHub action [1] forked from the original action developed by GitHub [5] Education. In our fork [1], we provide more detailed feedback for students when performing console output text matching tests (see Fig. 3). Developing and testing the autograding tests is one of the most time consuming aspects of preparing assignments. Preparing such tests could require 30–50 hours of time per assignment, or more, depending on the complexity of tests needed, amount of edge cases checked and other factors. When the autograded assignments are deployed for the first time, there is a high likelihood that some bugs or unhandled edge cases may still arise and require extra time to troubleshoot.

5.4 Deploying Assignments to Students

Once assignments have been developed and tested, the final step is to prepare to deploy the assignments to students. In order to ensure a smooth and clear

implementation, several important tasks were completed. First, detailed documentation and instructions for each assignment was written in a README.md file. In our data structures class, many of our assignments are fairly complex and require detailed instructions. Additionally, these instructions need to call out additional details that students need to be aware of. For example, some autograder tests will not run properly unless functions are implemented in a certain order. Students may also need to adjust settings such as ensuring the working directory is properly set when working with external data files. Taking great care to write supplemental instructions in a readme file is essential to ensuring students have sufficient information in order to complete the assignments. Additionally, at the beginning of the semester, it is important to provide students detailed instructions and an explanation of how to set up CLion, set up GitHub, how to access assignments, how to access autograder feedback, and how to see one's final score. Since many students have never used autograded assignments in GitHub classroom before, we found that creating an "Assignment 0" dedicated to helping students get set up and learn the tools was helpful.

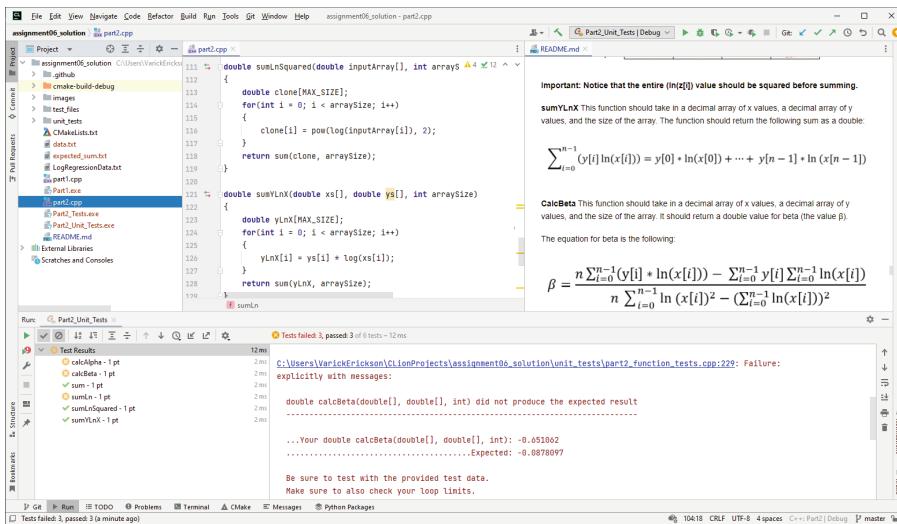


Fig. 4. A representative autograded programming activity as seen on the CLion IDE. Student completes code in the center, views instructions on the right, and sees autograding test results in the lower-left. In the bottom-right, error messages and feedback are displayed.

5.5 CLion IDE

We strongly preferred to use an IDE with GitHub integration. Given the popularity of Git and GitHub, there are many different choices for IDE with such

integration features. CLion and Visual Studio Code are two such popular choices [7, 9]. Both are free and are cross-platform compatible. However, for our class, we chose to use CLion as the primary development environment due to its student-friendly setup process and preconfigured C++ compiler. Additionally, its built-in Markdown file reader streamlines access to assignment instructions within the IDE. Figure 4 shows how a readme can be left open in one window so a student can refer back to the assignment instructions easily. CLion also has an integrated Catch2 visualizer that makes it easier for a student to identify and interpret unit tests more easily, which can be seen in the lower portion of Fig. 4. Note that CLion is available for free to students and educational institutions. CLion is a memory-intensive program, so students unable to run CLion could still consider using Visual Studio Code or other options if necessary.

6 Lessons Learned

This section summarizes the key observations and data collected when implementing autograding in the author's sections of the data structures course.

6.1 Benefits

Several key benefits were observed after implementing autograding in the data structures course. The main benefits are listed below and summarized further in the following sections.

- Since the amount of time required to grade assignments was significantly reduced, more time was available to assist students. There was also a significant drop in questions regarding assignment scores.
- An increase in student questions and interactions in the course was observed, likely due in part to more rapid feedback on coding assignments. Students did not need to wait until assignments were graded to get feedback, encouraging students to reach out for help and ask questions more often. Encouraging students to ask questions can significantly enhance the learning process.
- The success rate of students increased significantly after autograding was implemented. When comparing the years of data structures class without autograding to data structures class with autograding added, a 6.7% increase in the pass rate was observed, as shown in Fig. 5.
- Students generally gave positive feedback about how the autograding helped improve the learning process and how autograding improved the effectiveness of assignments in the course. This improvement in student satisfaction can be directly observed from the course evaluation surveys. While some students gave negative feedback (as explained further in the challenges section), the overall feedback about autograded assignments was very positive. As shown in Fig. 6, course student evaluation scores also increased by 7.4% showing students prefer the autograding to traditional manual grading.
- Instructors could also track student progress on assignments and identify at risk students who are struggling on early assignments.

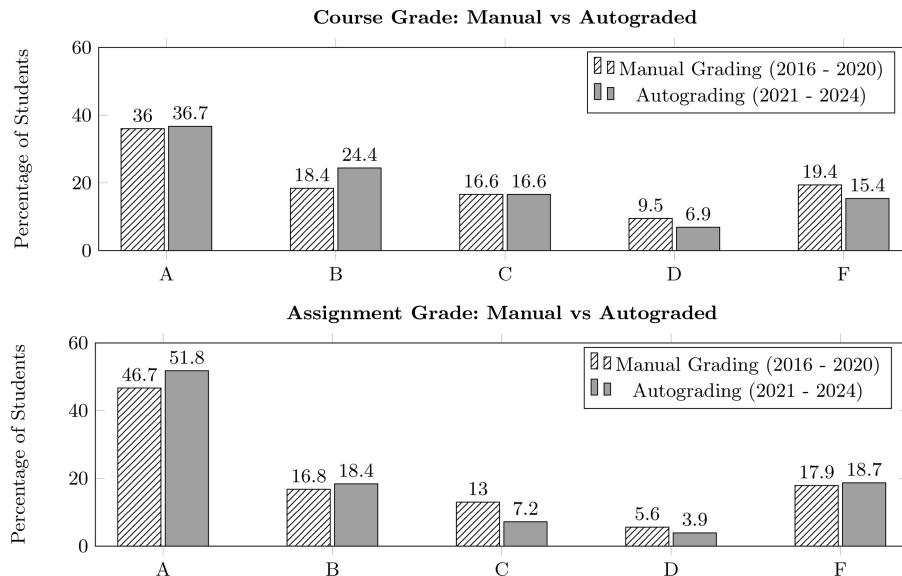


Fig. 5. Impact of autograded assignments on final course grades and the assignment portion of the data structures course grade. For the course grades, the percentage of students earning C grades remain nearly the same and there is a slight increase in the number of A grades (0.7%). Most notable is a 6% increase in the percentage of students earning B course grades. Also of note, the number of D course grades decreased by 2.6% and the number of F course grades decreased by 4%. For the assignment scores, the most significant change was the percentage of students earning A grades which increased by 5.1%. The number of B assignment grades also increased slightly (1.5%). The number of C and D assignment grades decreased by 5.8% and 1.7%, respectively. The number of F assignment grades increased slightly (0.8%).

To quantify the impact of autograding, course data from year 2016 to 2024 was analyzed. From 2016 to 2020 assignments were graded using manual grading. From 2021 to 2024, autograding was used to grade assignments. Note that the other course materials (lecture slides, grading policy, assignment topics, etc.) were kept consistent during this period. While the COVID-19 pandemic and online learning occurred in 2020–2021, note that the data and analysis that follows is calculated by pooling all student grades and assignment scores over the entire 2016–2020 and 2021–2024 time periods to help offset variations from section to section and semester to semester (approximately 300 students per dataset, as shown in Table 2).

To measure the change in student success rates, assignment and course grades were collected and the percentage of students earning A, B, C, D, and F grades was calculated. Figure 5 compares the grades for the data structures course with autograded assignments versus the course with manually graded assignments. An increase of 6.7% in the pass success rate was observed after implementing autograding. The most notable increase was in the number of B grades with an

increase of 6%. There was also a significant decrease in the number of D and F grades (−2.6% and −4%, respectively). The number of C grades remained nearly the same.

Figure 5 also shows the changes with respect to assignment grades. A slight increase of 0.7% in A grades and a notable 6% increase in B grades were observed. The proportion of C grades remained relatively stable. A significant decrease was seen in non-passing grades, with D grades declining by 2.6% and F grades by 4%. These results show a general improvement to student understanding.

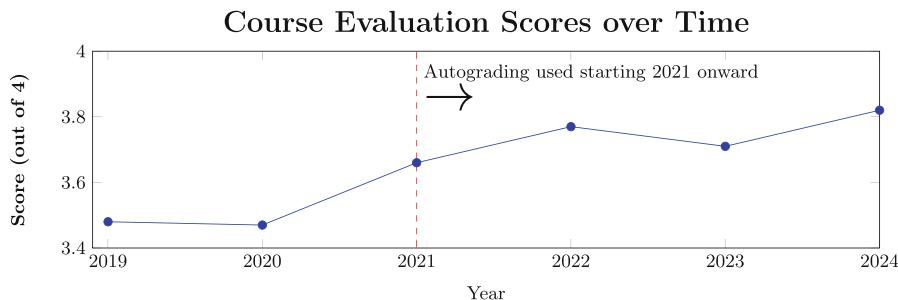


Fig. 6. Student course evaluation scores from 2019 to 2024. A clear increase is shown in the evaluation scores starting in 2021, which is when autograding was implemented.

Table 2. Mean course evaluation score data by year. The median score from 2016 to 2020 was 3.48 across the author's 9 sections and 284 students. The median score from 2021 to 2024 was 3.74 across 12 sections and 332 students. This is a 7.4% increase in the course evaluation score after the implementation of the autograder.

Year	Mean Evaluation Score (out of 4)	Median Score	Additional Comments
2016	3.43	Median Score 3.48	9 Sects. 284 students
2017	3.67		
2018	3.92		
2019	3.48		
2020	3.47		
2021	3.66	Median Score 3.74	12 Sects. 332 students
2022	3.77		
2023	3.71		
2024	3.82		

A similar approach was used to examine the student reaction to the auto-grading system. Course evaluations were collected for each section taught for the

2016–2020 and 2021–2024 periods to determine if the autograder system would affect course evaluations. Figure 6 and Table 2 shows a significant change in the student course evaluations. When manual grading was used from 2016 to 2020, the median course evaluation score was 3.48 out of 4.0. After autograding was implemented, the median student evaluation score increased to 3.74/4.0. This result suggests that autograded assignments likely increased students’ ability to learn the material and the overall effectiveness of the course. Many students appreciated having unlimited attempts to submit code ahead of the due date and being able to receive instant feedback after submitting. Autograding also further incentivized students to ask questions, adopt a growth mindset, and seek to understand assignments, particularly portions of the assignment which were marked incorrect by the autograding.

6.2 Challenges

The most significant challenge of implementing autograding is the time required to develop unit tests for assignments. Significant time was also spent creating instructions in the README.md file and preparing “Getting Started” instructions to help students get set up. Occasionally, students would encounter issues installing CLion, which also required further assistance.

Another challenge that was anticipated was ensuring that all students learned how to best use the autograder and feedback to complete assignments. To ensure all students were able to set up GitHub, set up CLion, and learn how to use the assignments, the first assignment of the semester was an “Assignment 0” due the second week of class, which included a full tutorial video, written step-by-step instructions to install CLion and set up GitHub, and explanations of the assignment workflow. Since most students did not have experience using Git, only commit, push, and pull commands are used for the workflow. The majority of students completed this assignment easily with scores of 90% or higher, as the students simply needed to follow the instructions given and complete the assignment on time. It was very beneficial to communicate to students that the GitHub Classroom autograder and unit tests actually mimic the coding workflow one might use in industry so that students see the value of the tools and are motivated to use them correctly. Providing Assignment 0 with tutorial videos and detailed instructions was overall very effective in ensuring that students knew how to properly use the autograding tools to make the most of each assignment. If students need longer than a week to set up these tools, the Assignment 0 and setup instructions can also be made available prior to the start of the semester.

The Assignment 0 and setup process also provided some interesting predictive data about a student’s preparedness for the data structures course. Students who were underprepared for the data structures course tended to struggle to complete even Assignment 0 on time. Interestingly, a very strong correlation was observed between student performance on Assignment 0 and whether a student would be able to later pass the data structures course [11, 12]. Such correlations and data could be valuable tools to help instructors better assist struggling students.

Implementing the autograder also resulted in some negative feedback from students, which was expected, but also gave some interesting insights. Sometimes, student code would generate outputs not expected by the autograder which were so unexpected that the autograder would crash before it was able to generate potentially helpful error messages. Sometimes it was necessary to edit the unit tests or create new tests to better anticipate common mistakes or other unexpected results generated by student code. Occasionally, some students would complain about not being able to earn partial credit for submitting code that failed the auto-grading tests. Rarely, a frustrated student would request that their code be manually graded without the autograder (although the manual grading would apply the same rubric and lead to the same point score as autograding). In other prerequisite courses, students might have become accustomed to receiving partial credit for submitting code that did not run properly. However, in the data structures course, the expectation is that students have prerequisite knowledge of C++ programming and are able to write code that compiles and runs properly. While some students were upset by the lack of “partial credit” for submitting code that failed autograding, students were encouraged to reach out to the instructor for help and review the custom-made error messages in the unit tests for feedback. Having a system for Q and A such as Discord or Slack was very beneficial for creating an online community and enabling students to discuss questions (without sharing code). Well-prepared and motivated students generally reached out for help, while poorly prepared students were more likely to complain about the autograder but not ask for help. However, at the end of the semester, many students commented that the autograded assignments were challenging compared to programs in introductory courses, but these assignments also caused students to finally really start to understand and write complex programs.

One unexpected challenge was how different compilers and operating systems can affect the autograder points. The default Xcode compiler used by MacOS has many non-standard initialization behaviors that we would not expect. In particular, the Xcode compiler, by default, initializes many variables to zero. This was an issue for pointers and integers. The student would find that the tests would pass locally on their machine but find the tests fail on GitHub. For example, a student may forget to initialize a size variable to zero in the constructor. Locally, the unit tests pass since the unit tests assume an initial state of zero for the size variable and the Xcode compiler happens to initialize the variable appropriately to zero at declaration. However, when the student pushes the code to GitHub for the official autograding, tests would fail since the standard g++ compiler used by the linux autograder container does not use zero as an initialization value at declaration. Another example was the file loading among Linux, Windows, and Mac OS. For linux and MacOS, filenames are case sensitive. However, Windows is not case-sensitive. The student may be required to open “dictionary.txt” but instead opens “Dictionary.txt”. The test runs successfully locally on a Windows machine, but when the code is pushed

to GitHub, the Linux container is unable to find “Dictionary.txt” and the code fails the unit test(s).

Another challenge encountered was rapid changes to the platform. For example, after several years of using the autograder, we encountered warnings about deprecated library dependencies, and we noticed that the original autograder library was not being actively maintained. Although GitHub Education eventually created a new autograder [14], at the time, we had to create a fork of the original autograder library to do maintenance. When we updated the autograder libraries and also took the opportunity to introduce enhancements to help students more easily identify errors in test results based on text matching (such as making sure text and whitespace exactly matches the expected output). The forked autograder now highlights the exact point where text discrepancies begin, aiding students in pinpointing mistakes (see Fig. 3). By adding this feature, students spend less time on these minor errors that do not typically measure understanding and more time on the core functionality of the assignment.

7 Future Work

There are many opportunities to further improve autograding tools and gather more data as the tools are used. The following section explains some key areas which will be studied further in the future.

One area to investigate further is improving upon the limitations of current autograded tools. Artificial intelligence, machine learning, and other data analysis tools could also provide significant benefits when applied to autograding. By leveraging artificial intelligence and other tools, it may be possible to automate the more time consuming steps of autograded assignment creation, such as development of unit tests and providing targeted feedback to students. Another important limitation to address is the fact that the percentage of students earning failing F scores on assignments increased slightly after autograding was implemented. Autograded assignments are unlikely to help students who are underprepared for programming courses or those students who are unwilling or unable to seek help when submitted code fails the autograding tests. Making improvements to provide students better, customized feedback for submitted code could be beneficial. Additionally, if student code could be analyzed by artificial intelligence or other methods, it may be possible to flag students who are underprepared or struggling and offer more targeted guidance. Since many computer science degree programs seek to improve student success rates and close equity gaps, it is important to further study how autograding could help struggling students succeed. Autograding alone cannot fix equity gaps or fix all challenges students face. However, autograding tools can provide insights and data to help educators address the root causes when students struggle in courses.

Another very important benefit to explore further is the potential to gather data and enable continuous improvement. One promising area that will be investigated further is studying GitHub commit data. For example, utilizing com-

mit timestamps to detect academic integrity issues, like plagiarism, by measuring unusually short intervals between commits. Additionally, analyzing the content and timing of commits could help identify students who may need assistance, by flagging patterns that suggest difficulty in understanding or completing tasks. These applications could enhance educational support systems, improving the ability to detect academic issues and offer timely interventions for students. In group projects, commit data could be analyzed to measure team dynamics, contribution equity, and identify potential imbalances. By examining commit volume and types across contributors, instructors could detect if some team members are overly reliant on others or if the workload is unevenly distributed. Longitudinal analysis of commits could track the development of specific skills, such as code modularity, efficiency, and documentation. This approach could provide individualized feedback on a student's growth in particular competencies over time.

8 Conclusion

From choosing which tool to use, to developing unit tests, to deploying assignments and supporting students, implementing autograded assignments can require significant effort. However, as shown in the present work, autograded assignments can offer many significant benefits in programming courses. When comparing data structures class without autograding to data structures class with autograding added, a 6.7% increase in the pass rate was observed. Course student evaluation scores also increased by 7.4% showing students prefer the autograding to traditional manual grading. Autograded assignments also provide data enabling further insights, such as identifying students who are struggling and tracking student progress on assignments.

As computer science continues to evolve and grow, so too will computer science teaching methods. Advances in artificial intelligence and online learning will likely continue to improve autograding tools and further benefit students and instructors. These autograding tools will be an important resource to help instructors make computer science courses more effective, equitable and accessible.

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Decoding Complexity: Empowering Learners in Algorithm and Theory Comprehension

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Abstract. Teaching computer science is challenging because it involves explaining concepts, managing a wide range of student abilities, and most importantly keeping up with rapidly evolving technology. Moreover, teachers have limited resources, pressure to meet academic standards, as well as high expectations from parents and the community. Therefore, teachers need to balance theory with practical skills, exercise diverse learning styles to better explain abstract concepts while promoting problem-solving and critical thinking. This paper presents various strategies to deliver computer science theories and algorithm courses, highlighting their implications on student success. To better understand the benefits of the adopted strategies, graduate level algorithms and data structures and intelligent systems courses are considered for observation. The findings indicate a clear preference for traditional face-to-face instruction and hybrid classes, suggesting that online classes may not align with students' learning preferences and could negatively impact their academic performance. Additionally, the combination of various teaching and learning styles is highly effective in enhancing student learning experience for theoretical computer science courses. This paper offers suggestions for addressing these challenges by incorporating techniques such as in-class activities, whiteboard demonstrations, timely feedback, increased student-faculty interaction, mentoring, and, most importantly, showing empathy toward students. Both courses received positive feedback, with over 90% of students giving a satisfaction score of 8 or higher out of 10.

Keywords: Modality · Engagement · Teaching Pedagogy · Feedback · Class Activities

1 Introduction

Students often choose academic courses aligned with current job market trends, especially in fields like Computer Science, where companies such as Apple, Google, and Microsoft constantly adopt emerging technologies like Artificial

Intelligence, Machine Learning, Blockchain, Quantum Computing, and Cyber Security. These areas are considered “Technology Buzzwords” drive students to enroll in such courses with hopes of securing high-paying jobs, often without adequate background knowledge. As a result, many students struggle or drop out mid-semester due to the difficulty of the coursework [1,2].

Moreover, academically diverse students vary in their strengths, learning styles, and areas of interest. They may excel in some subjects while need support in others. To foster their potential, it is important to recognize their individual strengths and needs and provide them with support. By providing a supportive and flexible learning environment, educators can help these students thrive and reach their full academic potential [3]. Early feedback in a course is helpful to students as it allows timely corrections, reduces anxiety, and clarifies expectations. On the other hand, it helps teachers to understand students’ progress and so they can provide support and adjustment teaching methods if necessary. Fundamentally, early feedback promotes better academic outcomes and enables an effective learning environment.

By incorporating the combination of these methods and providing additional support systems for students who may be struggling, there is a high likelihood that students will become engaged, actively participate in the class, and excel in their coursework. The result signifies a remarkable level of satisfaction and contentment among students regarding their learning experience in the class. This overall positive sentiment is derived from the combination of several factors that have collectively contributed to a fulfilling and effective educational environment [4–7].

When teaching theoretical computer science courses, supporting academically struggling students is a vital responsibility for educators. Students may struggle to understand a topic, which can lead to a loss of motivation in the subject. Effective strategies to assist them include differentiated instruction, fostering self-advocacy, using positive reinforcement, offering extra help sessions, creating a supportive learning environment, and demonstrating patience and empathy [7–10].

This is not easy to unlock concepts and decode complexity of algorithms and theoretical foundations in Computer Science. In addition to utilizing various teaching and learning tools, we can support students facing challenges by offering flexibility and accommodating their individual circumstances. We have multiple strategies at our disposal, including permitting late submission of assignments, extending deadlines, offering makeup tests, and allowing resubmissions, etc. Additionally, to foster active class participation, we can implement active learning, encourage collaboration, and engage in in-class problem-solving activities [11].

Every student has unique learning preferences, which is why diverse teaching methods can greatly enhance their educational experience. These methods may include traditional lectures to deliver theoretical content, whiteboard demonstrations for visual clarity, animations for dynamic presentations, recorded lectures for flexible access, and in-class problem-solving to foster active participation.

Active learning strategies encourage hands-on involvement, while semester-long team projects help students apply their knowledge practically and build essential teamwork skills. With these objectives in mind, this paper proposes a set of guidelines aimed at empowering students to succeed in their academic subjects especially theoretical computer science.

This paper explores the impact of teaching modes, methods, assessments, and flexibility on students' learning experiences throughout an entire semester, using two theoretical computer science courses as case studies. Observations and recommendations based on the findings will also be provided. By examining how different instructional strategies influence student engagement and success, I plan to identify best practices for foster better understanding. These insights will help educators adjust their teaching approaches to support diverse learning needs in these challenging academic subjects.

The rest of the paper is organized as follows. Section 2 describes course design and course delivery strategies to empower students so that they can grasp theory and algorithms in computer science easily. Section 3 presents observation of the study and recommendation for instructors, and finally the paper is concluded in Sect. 4.

2 Course Design and Delivery Methods

In this paper, two theoretical computer science courses will be used to understand the impact of teaching modes, methods, assessments, and possible flexibility on students' educational journey in the semester. The contents covered in terms of theoretical aspects in two computer science courses are given below.

2.1 Course A: Algorithm and Data Structures

- The course will cover a variety of topics in algorithms and data structures, starting with the analysis of algorithms and problem-solving strategies. A major focus will be on understanding time and space complexities, including Big-O, Big-Theta, and Big-Omega notations, and analyzing the best, worst, and average-case performance of algorithms.
- Students will explore data abstraction concepts and commonly used data structures such as stacks, queues, vectors, and linked lists.
- Recursion and mathematical induction will be introduced as key techniques for algorithm design and proof.
- In terms of specific algorithms, students will study a range of searching and sorting techniques, such as insertion sort, quicksort, modified quicksort (median of three as pivot), merge sort, heapsort, counting sort, bucket sort, and radix sort.
- The course will also delve into search trees, including binary search trees (BST), AVL trees, and 2–4 trees, with optional topics like red-black trees and splay trees. Hashing techniques and heap structures will be covered in depth, as well as randomized algorithms such as skip lists and numeric algorithms.

- Students will learn about greedy algorithms with applications in Huffman coding, fractional knapsack, and task scheduling problems. Dynamic programming will be introduced through examples like the longest common subsequence (LCS), the 0/1 knapsack problem, and the matrix chain product.
- Graph algorithms will be a major area of study, including depth-first search (DFS), breadth first search (BFS), topological sorting, transitive closure, strongly connected components, biconnected graphs, various minimum spanning tree algorithms such as Prim's and Kruskal's algorithms, and shortest path algorithms like Dijkstra's and Bellman-ford single source shortest path algorithms as well shortest path in DAGs, and finally, Floyd-Warshall algorithm for all-pairs shortest paths.
- The course will also include discussions on disjoint set data structures, string matching algorithms such as Knuth-Morris-Pratt (KMP), Boyer-Moore-Horspool (Horspool), DFA, Boyer-Moore (BM), Rabin-Karp, and tries.
- The course will also include max flow and cut algorithms like Ford-Fulkerson and Edmonds-Karp, as well as the PageRank algorithm (optional).
- Finally, students will explore NP-complete problems and approximation algorithms, providing a foundation in computational complexity theory.
- Through these topics, the course aims to build a solid understanding of both the theoretical and practical aspects of algorithms and data structures.

2.2 Course B: Intelligent Systems or Artificial Intelligence

- The course begins with an introduction to Artificial Intelligence (AI) and the concept of problem-solving agents. Students will explore the fundamental elements of problems and how to solve them using various search strategies, including breadth-first search (BFS), uniform cost search (UCS), depth-first search (DFS), depth-limited search (DLS), and iterative deepening search (IDS). A theoretical comparison of these search strategies will be provided as well.
- The course will then cover informed search methods such as Best-First Search and A*, followed by local search methods like Hill Climbing (and its variants), Simulated Annealing, and Genetic Algorithms. Game-playing algorithms such as minimax and alpha-beta pruning will be studied.
- The course will then move on to knowledge representation and reasoning, starting with propositional logic and first-order logic where students will learn forward and backward chaining and resolution techniques.
- Next, the focus will shift to Constraint Satisfaction Problems (CSP), where students will learn to solve map coloring and scheduling problems using techniques like forward checking and heuristics (e.g., MRV, degree constraint, least constraining value). Other CSP techniques such as singleton propagation, AC3, tree-structured CSPs, and local search methods (e.g., the min-conflicts heuristic) will also be introduced.
- Students will also explore uncertain knowledge and reasoning, including the basics of probability, Bayes' Rule, and Bayesian networks, as well as inference and decision-making in these networks.

- The latter part of the course will introduce probabilistic reasoning, learning from observation, Markov decision processes, and reinforcement learning. Finally, students will study supervised machine learning algorithms to round off the syllabus.

2.3 Delivery Methods and Teaching Pedagogy

These courses can be delivered in one of the five modes:

1. Face-to-Face
2. Hybrid: Face-to-Face & Asynchronous Online Component
3. Hybrid: Face-to-Face & Synchronous Online Component
4. Online: Synchronous - Specific Meeting Times
5. Online: Asynchronous - No Specific Meeting Times

Each mode of instruction has its advantages and disadvantages. For theoretical computer science courses, a face-to-face format or a hybrid approach—combining in-person learning with asynchronous online components—would be most beneficial.

Students have unique learning preferences, so using diverse teaching methods can greatly improve their experience. This can include lectures for theory, whiteboard demos for clarity, animations for engagement, recorded lectures for flexibility, and in-class problem-solving for active participation [6]. Active learning and team projects help students apply knowledge and build teamwork skills.

Learning styles can generally be categorized into seven types: visual, aural, verbal, physical, logical, solitary, and social. While learners often exhibit a combination of these styles, some are typically more dominant than others. A key challenge is identifying tools or techniques that effectively encompass most learning styles. A course should be designed to have several learning styles and with the following objectives in mind:

a) Student Retention, Progression, and Graduation Rates

Student retention, progression, and graduation rates are popular indicators to determine success. These refer to the measures of how well students perform in their programs, advance in their coursework, and successfully complete their degrees. Improving these rates require at least providing supportive learning environments, academic and personal support services.

b) Increased Student Engagement

Increased student engagement is vital that involves actively engaging students in the learning process, which can lead to deeper understanding in their education. Engagement can be achieved through interactive teaching methods, group projects, problem-solving, and the use of technology like serious games. Engaged students are motivated and likely to attend classes regularly, participate in discussions, and complete assignments.

c) Boosted Faculty-Student Interaction

Improved faculty-student interaction is essential for fostering a supportive and productive educational environment. This interaction can take forms such one-on-one mentoring, participation in class discussions, periodic personalized feedback, and etc. Increased interaction helps build trust.

d) Prompt Feedback

Timely and constructive feedback to students' work is essential for effective learning. Prompt feedback helps students understand what they did well and where they need improvement. Regular thorough response from teaching assistants will also work as it can reinforce learning, correct misunderstandings, and motivate students.

e) Improved Learning Outcomes

Improved learning outcomes are the measurable educational achievements of students, including knowledge acquisition, skills development, and the ability to apply what they have learned in practical situations. Approaches to improve learning outcomes include using diverse teaching methods, use of technology, and ensuring that course content is relevant and challenging among others.

f) Increased Student Confidence

It is important to develop self-assurance regarding students' academic abilities and potential. When students believe in their abilities, they usually take on challenges, participate actively in class, and pursue their goals with determination.

g) Enhanced Applied Knowledge

Enhanced applied knowledge is the ability of students to use theoretical concepts in real-world scenarios. Most popular strategy to enhance applied knowledge is experiential learning through internships. The department and university can help students in this regard. Applied knowledge ensures that students are prepared for their future careers and can easily transition from academic settings to professional environments.

3 Observation and Remarks

The modality of a course—whether it is delivered in-person, online, or in a hybrid format—can significantly influence the academic setting in various ways. Some key aspects to consider be:

- Student Engagement: In-person courses promote direct interaction, enhancing engagement through real-time discussions and immediate feedback. Online courses can struggle with engagement but can maintain interest through multimedia content and interactive tools. Hybrid courses blend both, offering some face-to-face interaction along with flexible online components.
- Assessment and Feedback: In-person courses use diverse assessment methods and offer immediate, personal feedback. Online courses rely on digital assessments and may provide delayed feedback. Hybrid courses can integrate various assessment methods, offering a mix of immediate and reflective feedback.
- Instructor's Role and Workload: In-person instructors focus on direct teaching with a predictable workload. Online instructors need proficiency in digital tools and may face a more distributed workload. Hybrid instructors must

balance both methods, potentially increasing their workload and requiring versatile teaching strategies.

In a course, a diverse array of teaching methods can be employed to enrich the learning experience. These methods include traditional lectures, white board demonstrations, animation, recorded lecture videos, in-class problem solving, active learning, and group projects. Certainly, other instructors can employ different techniques that they find suitable for their target audience. An optional anonymous survey was conducted, asking several questions and recording the responses. There were 70 and 60 respondents for Algorithms and Data Structures and Intelligent Systems courses respectively.

Q1: From your perspective, which modality do you believe is the most effective for Algorithms and Data Structures or Intelligent Systems course?

Students were surveyed about their preferred instruction modality, with the option to select multiple preferences. Among the respondents, for Algorithms and Data Structures course, 62.9% preferred a hybrid approach that combines both in-person and online components, 34.3% favored face-to-face instruction, and 2.9% preferred online asynchronous classes. Surprisingly, no students selected online synchronous classes, as shown in Fig. 1. The demand for face-to-face classes for Intelligent Systems course is even higher 70%. These findings indicate a clear preference for traditional face-to-face instruction and hybrid classes, suggesting that online classes may not align with students' learning preferences and could negatively impact their academic performance. In challenging courses, face-to-face instruction is particularly beneficial as it provides ample opportunities for questions and answers.

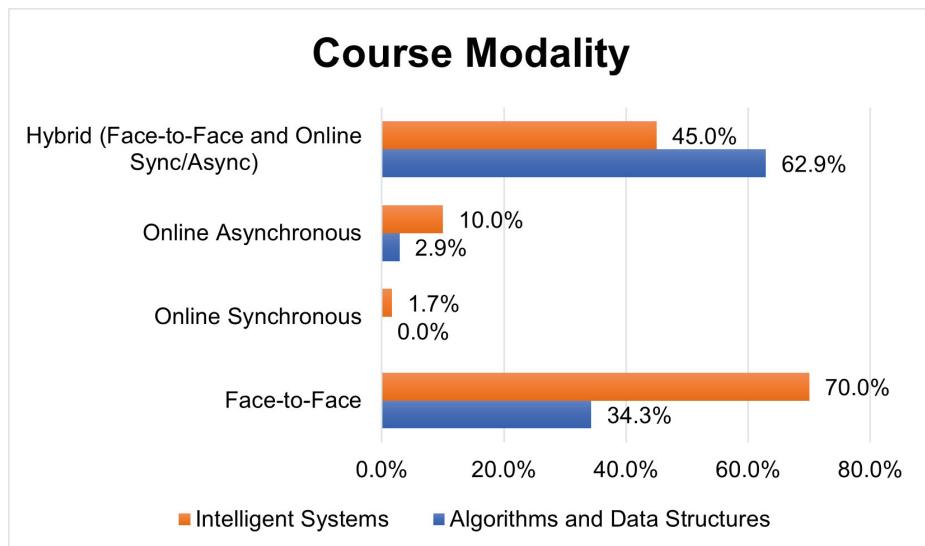


Fig. 1. Preferred course modality for theoretical courses.

Q2: Do you believe that a hybrid modality, combining face-to-face classes with online asynchronous components, is beneficial for Algorithms and Data Structures course?

Students' preferences for hybrid classes were recorded. As depicted in Fig. 2, a substantial 70% of students rated hybrid classes highly, giving them a score of 8 or higher, and affirmed that this modality works well for them. This could be because hybrid classes offer the flexibility of online learning combined with the engagement of in-person interactions, allowing students to balance their schedules more effectively. This blend can cater to diverse learning styles and needs, providing both the structure of face-to-face instruction and the convenience of online resources. Meanwhile, 22.8% of students rated hybrid classes between 5 and 7, indicating a neutral to slight preference. The 4.3% who did not prefer hybrid classes may find the mixed format challenging, perhaps due to a lack of consistent routine or difficulty adapting to different modes of instruction. They might also prefer the social interaction and immediate feedback that purely in-person classes provide.

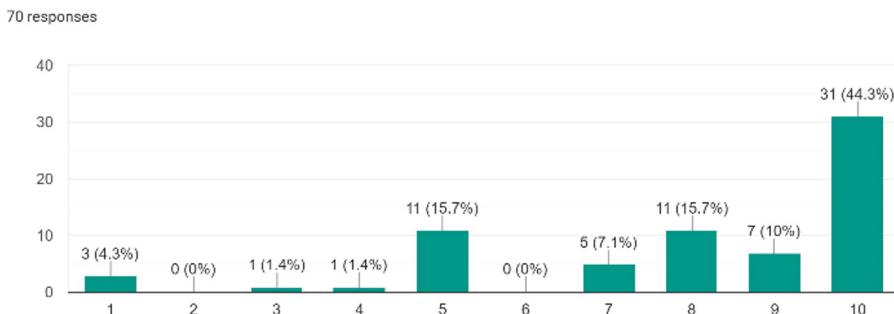


Fig. 2. Preference on Hybrid modality for Algorithms and Data Structures course.

Q3: What aspect of learning style(s) do you believe is the most effective to understand theory in Algorithms and Data Structures or Intelligent Systems courses?

As depicted in Fig. 3, when evaluating the effectiveness of various instructional methods across five categories, for Algorithms and Data Structures course, students indicated high approval ratings for traditional lectures, recorded lecture videos, in-class problem solving after mini lectures, and active learning, with approval ratings ranging between 60% and 90%. Notably, in-class problem solving was considered the most effective method, with a 90% approval rating. The trend is similar in the other course, except for recorded lecture videos and the semester-long project, which account for 33% and 10%, respectively. This suggests that educators should select teaching methods that are more effective for each specific course.

Q4: Do you think in-class problem solving is the most effective teaching method for a theoretical course?.

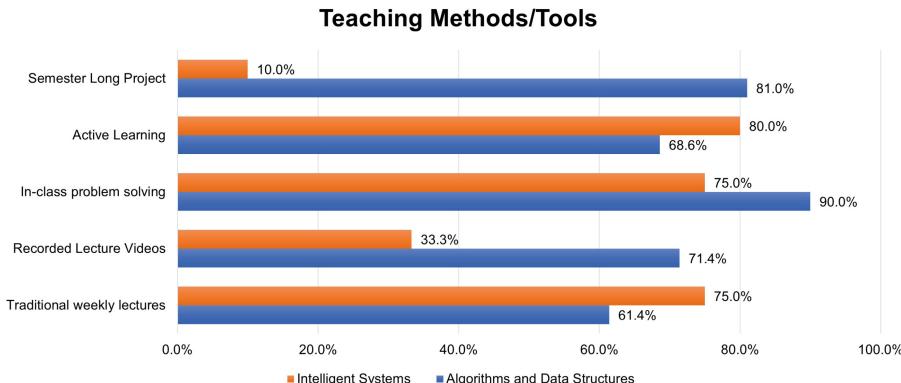


Fig. 3. The most effective learning styles for understanding course materials.

In-class problem solving stands out as a favored method among students when learning a complex topic. Typically, following a lecture on a particular subject, students engage in problem-solving activities in the classroom. This approach encourages teamwork and ensures a deeper understanding of the material through active participation and collective efforts. As demonstrated in Fig. 4, 94.2% of students rated this method with a score of 8 or higher, finding in-class problem solving highly effective for their learning experience in Algorithms and Data Structures course. The approval rating is 93.3% in the Intelligent Systems course.

Q5: How would you describe your overall learning experience in this graduate-level Algorithms and Data Structures or Intelligent Systems course, which incorporates various teaching and learning styles?

Fig. 5 shows the overall learning experience ratings for two graduate-level courses, Algorithms and Data Structures and Intelligent Systems. Both courses received overwhelmingly positive feedback, with most students giving ratings of 9 or 10. The Intelligent Systems course had slightly higher satisfaction, with 61.7% of students rating it a 10, compared to 48.6% for Algorithms and Data Structures. The absence of low ratings in both courses suggests that the combination of various teaching and learning styles used in these courses is highly effective in enhancing the overall student learning experience.

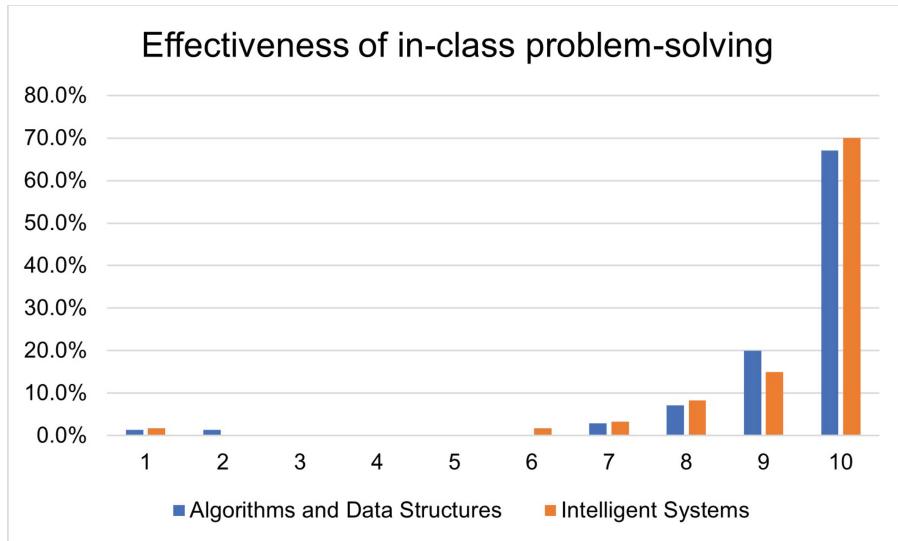


Fig. 4. The most effective teaching method for a theoretical course.

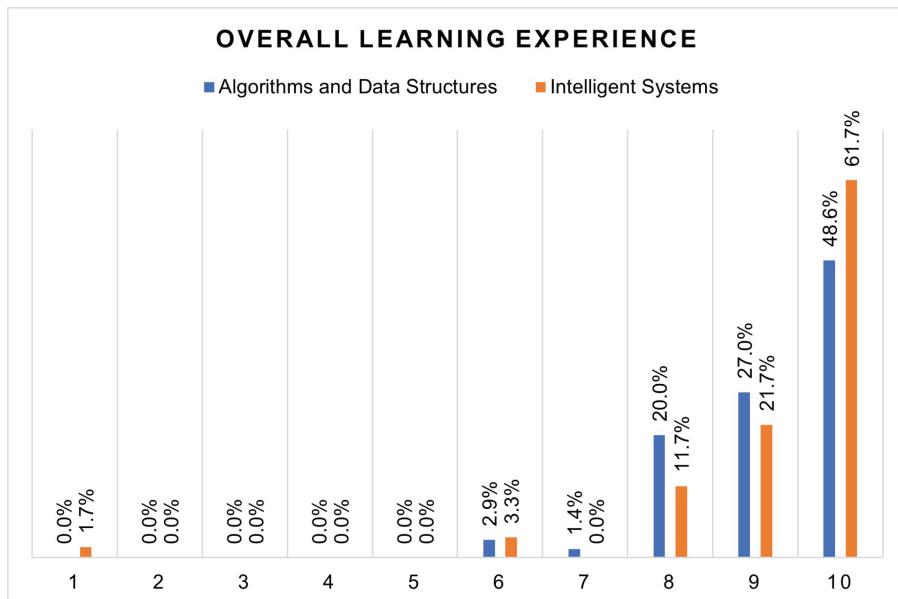


Fig. 5. Overall learning experience in Algorithms and Data Structures or Intelligent Systems course that combines several teaching and learning styles.

4 Conclusion

Teaching theoretical computer science courses is challenging due to its abstract concepts and reliance on logic and mathematics. These make it difficult for some students to grasp concepts. Instructors face the challenge of keeping students engaged and balancing theory with practical examples. Additionally, assessing students' understanding is difficult, as many problems have open-ended solutions that require subjective grading. This paper offers suggestions for addressing these challenges by incorporating techniques such as face-to-face or hybrid course modalities, in-class activities, whiteboard demonstrations, active learning, timely feedback, increased student-faculty interaction, mentoring, and, most importantly, showing empathy toward students when needed. Both the Algorithms and Data Structures, and Intelligent Systems courses received overwhelmingly positive feedback, with over 90% of students giving a satisfaction score of 8 or higher.

Disclosure of Interests. The author has no competing interests to declare that are relevant to the content of this article.

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Bouncing into Counting and Probability

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Abstract. Teaching abstract concepts to computer science students is a demanding task. Typical presentations such as white board drawings and PowerPoints are helpful, but it is even more effective to provide visual aids that enable students to perform their own demonstrations. This adds a tactile component to the learning process that enhances the visual and audible portions of a lecture. To this end, we have constructed a number of hands-on experiments using bouncy balls and ice trays. The materials are inexpensive, easily obtained, and can be retained by students for their own study. We have found this to be an effective way to turn abstract concepts into concrete examples. We believe that this practice has lead to enhanced learning for concepts in counting and probability.

Keywords: Education · Counting · Probability · Concrete examples

1 Introduction

One common topic covered in a Discrete Mathematics course for Computer Science students is counting [1, 2]. Counting also serves as an introduction to elementary probability. Getting the basic principles across to students is sometimes difficult without visual aids. Of course, it is natural to use PowerPoints, white-board drawings, and other hands-off types of visual aids. However I have found it easier to get the points across if a more tactile visual aid is used. In particular, I love to present these concepts using multi-colored bouncy balls in ice-cube trays. For example, Fig. 1 shows all permutations of three objects. I pass these visual aids out to students and have them discover the permutations themselves.



Fig. 1. All Permutations of Three Objects.

2 Permutations

First I try to motivate a counting principle that runs throughout counting, counting permutations. To illustrate this I have students two trays, yellow and white in Fig. 2. I have the students transfer the balls from the yellow tray to the white tray using random choices. Students fill the white tray from left to right in the first row.

How many choices are there for the first slot? Six.



Fig. 2. Starting Point and First Choice.

Next, students move the yellow tray over one slot, and make a choice for the second slot. How many choices are there for the second slot? Five, because, in the first slot, the red ball is used for the first slot and there are only five left.

Now, how many choices are there for the third slot? Four as shown in Fig. 3. Two of the balls have been used and there are only four left.



Fig. 3. The Third Choice.

You can continue this, if you wish, until all balls have been transferred. There will be three balls for the fourth slot, two for the fifth slot and one for the sixth slot. Different students will make different choices for each of the six slots. Since there are no restrictions on which ball to choose next, it is clear that the choices are independent, and that the multiplication rule applies. (Multiplication and addition rules should be covered before starting this demonstration).

There were $6 \times 5 = 30$ ways to choose the first two balls. Continuing we see that there are $6 \times 5 \times 4 \times 3 \times 2 \times 1 = 6! = 720$ ways to transfer all the balls.

Once we have transferred all the balls, we can view this as rearranging the balls from the yellow tray to the white tray, as shown in Fig. 4. Therefore, there are $n!$ ways to rearrange the order of n balls.

Now, let us suppose that the balls are not all different. Have the students replace the orange and pink balls with red balls and arrange them in random order. As shown in the first image in Fig. 5. Now, have the students rearrange the red balls in random fashion. The second image in Fig. 5 shows that the two outcomes are identical.

There are, indeed, 720 rearrangements but not all of them are distinct, so we have overcounted. By how much have we overcounted? There are six ways to rearrange the three red balls ($3!$). Therefore, the correct formula for the number of configurations is $6! / 3!$. When there are duplicate objects, we must divide by the factorial of the size of each set of duplicate objects.



Fig. 4. The Final Configuration.

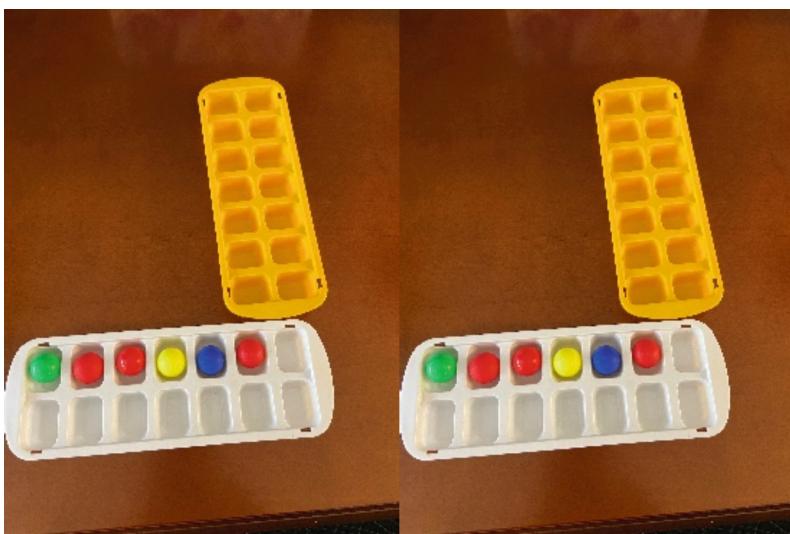


Fig. 5. Permutations with Duplicates.

3 Combinations

The formula for combinations of n things taken m at a time is hard to motivate. We can speed up the students' understanding by using bouncy balls and trays. As before, we pass out the bouncy balls and the trays so each student can participate in the demonstration. We start with the same configuration as before. But this time we have the students select

three balls at random and write the colors down in alphabetical order. In the example of Fig. 6, the student will write down “Blue, Orange, Yellow.”



Fig. 6. A Combination.

Now, have the students rearrange the selected balls. Does this change the alphabetical list? No. Next, have the students rearrange the balls left in the yellow tray. Does this change the alphabetical list? Certainly not.

Now, instead of selecting three balls at random, have them rearrange the six balls at random, and have them select the three bottom balls. Isn’t this the same as selecting three balls at random? There are $n!$ to arrange the six balls. After selection, there are $m!$ ways to arrange the selected balls without changing the outcome. There are $(m - n)!$ ways to rearrange the balls not selected. Neither of these rearrangements affects the outcome, so the formula for n things taken m at a time is

$$\frac{n!}{m!(n - m)!}$$

4 Combinations with Duplicate Objects

Suppose we have m different kinds of objects, but an unlimited number of each. A classic example of this is buying a dozen donuts from a donut shop with eighteen different kinds of donuts. How many ways are there to select a dozen donuts?

We can translate this question into a question about bouncy balls. In this example we have six different colors of bouncy balls, red, blue, green, yellow, orange and pink. We have an unlimited number of each. How many ways are there to select seven balls?

We start with a set of bouncy balls to illustrate this problem. We have two different kinds of multi-colored balls, stripey balls and plaid balls. We arrange them in a tray as shown In Fig. 7.



Fig. 7. Combinations with Duplicates.

The plaid balls represent selections from the set of six balls. Note that there are seven plaid balls. The stripey balls are place holders. There are five stripey balls, which divide the tray into six segments. The color of each ball is determined by the segment in which it is placed. The yellow tray contains the color key that gives the color assigned to each segment. The color key can be used to make the proper selection. The second image in Fig. 7 shows how the plaid balls get translated into colored balls. Slots 1, 2 and 3 have a single plaid ball. Slot 4 has two plaid balls, slot 5 has two plaid balls and slot 6 has no plaid balls. This gives a selection of one red, one orange, one blue, two green and two pink balls. Each distinct permutation of the plaid and stripey balls gives a new selection. Each selection can be encoded using the plaid and stripey balls. This is a “permutation with duplicates” problem. There are two sets of duplicates, one with seven elements and one with five elements. The total number of combinations in this example is given by the formula

$$\frac{12!}{7! \times 5!} = 792$$

For n selections from m categories is given by the formula. The bouncy ball experiment shows this clearly. Initially this seems like a very abstract concept. Because of this, students often have a great deal of difficulty with it. With the hands-on experiments, the concept becomes much clearer. It is usually a good idea to repeat the experiment with a varying the number of categories and selections.

$$\frac{(n + m - 1)!}{n! \times (m - 1)!}$$

5 Generating Combinations

Bouncy balls can also be used to illustrate the algorithms for generating consecutive permutations and combinations. Let's start with combinations. It's easier to use numbered balls for this purpose. Like the colored balls, the numbered balls are readily available online. However, since I don't have any of these at the present time, I've added numbered stickers to the colored balls. (Numbered stickers are also readily available online.)

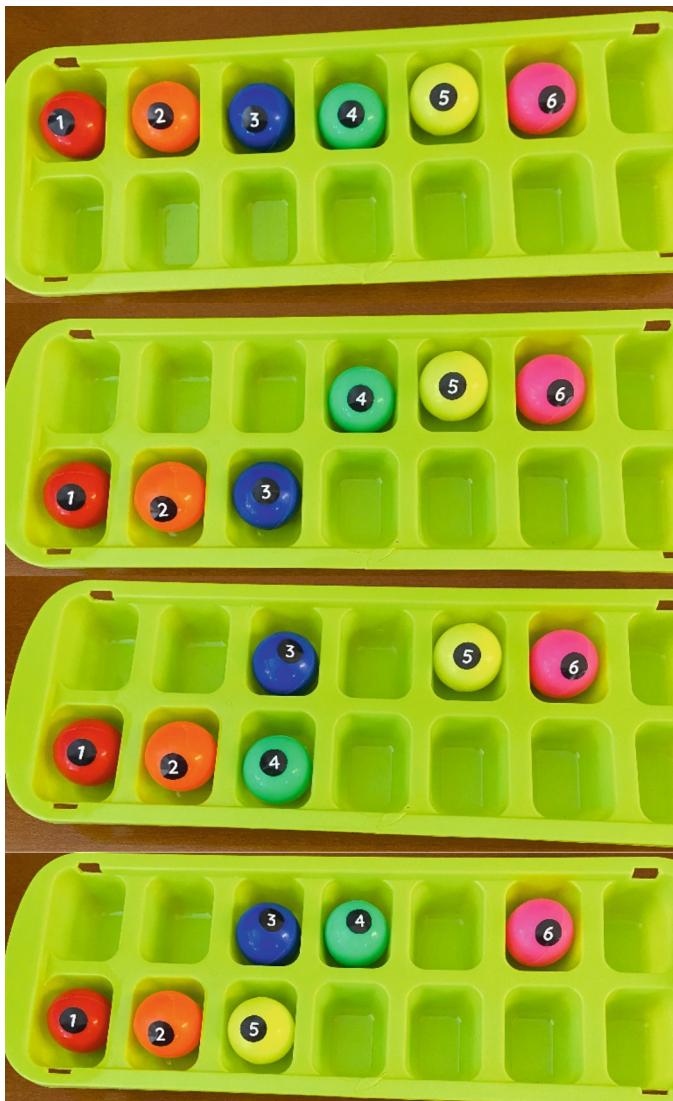


Fig. 8. Generating the First Combinations.

Assume we want to generate all combinations of six things taken three at a time. We start with all balls in the first row of the tray and move the first three to the second row. Then we replace the last ball, ball 3, successively with balls 4, 5 and 6 (Fig. 8).

Once ball 6 has been swapped in, we cannot continue in this fashion, so we swap out the second-to-last ball. We must swap balls 2 and 3 and make the following ball(s) consecutive. Figure 9 shows this. The process continues by swapping out the last ball until it is not possible to continue.



Fig. 9. Advancing to the Second-to-Last Ball.

Eventually, it will no longer be possible to advance the second-to-last ball, as shown in Fig. 10. The second image of Fig. 10 shows how we proceed from this state. We swap balls 1 and 2, and make the balls following ball 2 consecutive. Eventually, we reach the configuration in the third image of Fig. 10, which is the final state.

Students are asked to run through the entire procedure (20 combinations). After doing this, it is easy for students to translate it into code. The bouncy-ball experiment makes the procedure much more comprehensible than it would be otherwise.



Fig. 10. Advancing to the Third-from-Last Position.

6 Generating Permutations

One can also use bouncy balls to illustrate the more complex procedure of generating permutations. We start with all balls in order in the top row of the tray. In this case, we will use only the first row of the tray. Our objective is to reverse the order of the balls, but doing it in such a way as to generate all permutations of the balls.

The first rule is, if the last two balls are in ascending order, reverse them as in Fig. 11.



Fig. 11. The First Permutation Rule.

If the first rule does not apply, search the balls in reverse order looking for two balls that are in ascending order. In the first image of Fig. 12, this is balls 6 and 2. The first ball of this pair is selected as position i as shown in the second image of Fig. 12. Next, we search the positions after position i , for the smallest number greater than 2, skipping any balls with numbers less than 2. We mark this position as position j as in the third image of Fig. 12.

Once we have found positions i and j , we swap them. Then we sort the positions following position i into ascending order. Figure 13 shows this process.

This procedure continues until we reach the state of Fig. 13, which is the final state (Fig. 14).



Fig. 12. Finding Positions i and j.

7 Probability

The inspiration for using bouncy balls was the “urns and balls” example used to teach elementary probability. I had been using white-board drawings to illustrate this example when I realized that I didn’t really know what an urn was. I obtained the urn of Fig. 15, courtesy of eBay, and have been using it with colored bouncy balls obtained from the same place.

I empty the contents of the urn, and place three red balls and seven blue balls into the urn. I pass the urn around the class, and have each student choose a ball, write down the color and replace the ball. Then I use a show of hands how many got red and how many got blue. It is most convenient if the totals don’t match the probabilities exactly. This gives you the opportunity to introduce the law of large numbers, and explain how probabilities work in the real world.



Fig. 13. The Last Step.



Fig. 14. The Final Permutation.

It is a simple matter to illustrate the difference between selection with and without replacement. It is immediately obvious that these are two very different situations, since in selection without replacement, the urn never makes it around the room. Probability requires many other examples, and the urn is convenient place to carry a pack of cards and a few pairs of dice.



Fig. 15. The Balls and Urns Illustration.

8 Conclusion

The use of bouncy balls can help students understand abstract counting problems by performing hands-on demonstrations. This leads to improved understanding over abstract demonstrations on PowerPoints and white-board illustrations. Students have the demonstration in their own hands and can repeat the steps at their own convenience. With an urn it is possible to demonstrate several probability experiments. I have found “bouncing into counting and probability” to be an effective method for teaching abstract concepts.

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Building a Data-Driven Cybersecurity Lab: A Practical Framework for AI-Powered Threat Detection

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Abstract. The increasing sophistication and frequency of cyber threats has led to a critical need for advanced cybersecurity solutions and skilled professionals. In order to provide students with useful skills for handling contemporary cybersecurity challenges, this paper presents the design and implementation of a Data-Driven Cybersecurity Lab (DDCS), a cloud-based platform that combines data-centric approaches, machine learning (ML), and artificial intelligence (AI). We determined key elements for cybersecurity education, including data management, practical experience, and AI-driven threat detection, by examining industry requirements and current cybersecurity curricula.

In order to give students a hands-on learning environment where they can apply data-driven techniques to real-world scenarios, the DDCS lab was developed using cloud infrastructure and IBM Auto AI. Students constructed machine learning models for intrusion detection using the NSL-KDD dataset, proving the lab's usefulness in bridging the gap between theoretical knowledge and real-world application. The lab equips students for the quickly changing cybersecurity landscape by allowing them to work with large-scale datasets, create predictive models, and automate threat detection. This study demonstrates how the DDCS lab can be an essential teaching resource for preparing the upcoming generation of cybersecurity experts.

Keywords: data driven cyber security · Auto AI · cyber security education

1 Introduction

In today's digital landscape, the need for robust cybersecurity measures has never been more pressing. With the ever-evolving threat landscape and the increasing sophistication of cyberattacks, organizations across all sectors are facing unprecedented challenges in safeguarding their sensitive data and systems. To effectively combat these threats, there is a growing recognition of the importance of data-driven cybersecurity approaches.

Data-driven cybersecurity involves leveraging vast amounts of data to proactively identify, analyze, and mitigate potential security risks defined in [1]. By harnessing the power of data analytics and machine learning (ML) algorithms, organizations can gain valuable insights into their security posture, detect anomalies, and respond to threats in real-time. This proactive approach enables organizations to stay one step ahead of cybercriminals and minimize the impact of security breaches.

As organizations increasingly adopt data-driven approaches to bolster their cybersecurity defenses, the need for professionals skilled in handling vast datasets and applying advanced technologies like machine learning has grown exponentially. Recognizing these evolving demands, higher education institutions have begun reshaping their cybersecurity curricula to reflect the industry's shift towards data-centric security strategies. NICE framework also supports curriculum development involving designing, evaluating, and aligning training programs with organizational needs, focusing on instructional design, cybersecurity principles, and risk assessment to ensure effective workforce development [2]. These programs are designed to equip students with the hands-on skills required to meet the current and future needs of the cybersecurity workforce.

In order to meet the expanding demands for cybersecurity education, this study presents the concept and setup of a Data-Driven Cybersecurity Lab (DDCS). The lab aims to give students the skills they need to analyze and defend against contemporary cyber threats using data-centric techniques by utilizing cloud technology, IBM Auto AI in specific.

The actions listed in this study consist of:

Curriculum Analysis: A review of US colleges' current cybersecurity curricula to find areas for improvement and chances to include data-driven methods.

Description of Requirements: defining the essential elements and competencies required for a successful data-driven cybersecurity lab, such as AI-driven threat detection, data management, and practical experience.

Lab Development: Creating and designing the lab with IBM Auto AI and cloud-based resources to give students real-world experience and practical instruction. Using the NSL-KDD dataset as an example, demonstrate how the lab can replicate real-world situations and teach students how to identify threats in real time.

Evaluation: Determining how well the lab bridges the theoretical and practical application gaps, with an emphasis on getting students ready for real-world cybersecurity challenges.

By taking these actions, the study hopes to provide a thorough method for creating a state-of-the-art learning platform that caters to present as well as future demands in the cybersecurity industry.

2 Methodology

A methodical approach is needed to ensure that the Data-Driven Cybersecurity Lab (DDCS) is developed in accordance with industry and educational requirements. The curriculum analysis, requirements specification, and lab development

and demonstration are the three main stages of the methodology for this study. Every stage builds on the one before it to provide an all-encompassing, realistic cybersecurity training environment that incorporates data-driven methodologies.

3 Requirements Analysis

3.1 Curricula Analysis

The first phase involved a detailed review of existing cybersecurity curricula from four higher education institutions in the United States [3–6]. This analysis focused on identifying the gaps and opportunities for enhancing the practical skills of students through data-driven cybersecurity training. By evaluating a selection of data-driven and AI-based cybersecurity programs, we identified four key areas critical to modern cybersecurity education:

- 1) *Data Management*: Instead of lacking data, cybersecurity analysts face an overwhelming amount that needs to be processed and analyzed [7]. The programs uniformly address the challenge of managing large volumes of network/cybersecurity data from multiple sources. Courses emphasize teaching students how to collect, prepare, and interpret this data for security intelligence, enabling the prediction and detection of malicious activities.
- 2) *Hands-On Practice*: Practical, hands-on experience is another critical component. Students learn to handle network data and automate threat detection. These skills include visualizing, analyzing, and automating the identification of network anomalies and malicious activities through scripting and software tools, enabling more efficient cybersecurity operations.
- 3) *Artificial Intelligence and Automation*: A significant focus is placed on integrating machine learning and AI to enhance cybersecurity. Courses teach students how to apply these technologies to analyze network threats, predict vulnerabilities, and automate threat detection using data science libraries and tools. These tools are particularly important for identifying patterns in large datasets, allowing for the proactive and automated defense of cyber systems.
- 4) *Preparing for Real World Application*: These programs aim to prepare students for real-world cybersecurity roles by focusing on security intelligence, automation, and AI-based threat detection. Students learn how to transform raw data into actionable insights and integrate AI and data science into business operations and cybersecurity controls.

In the following sections, we will more closely examine the four key pillars identified from the course and program curricula. This analysis will lead to the development of specific requirements, which will guide the design, development, and testing of a learning platform and lab for data-driven cybersecurity. By analyzing these pillars, we can ensure that the platform aligns with both educational goals and industry demands, equipping students to face real-world cybersecurity challenges.

3.2 Requirements Refinement

The second phase focused on defining the specific technical and functional requirements of the DDCS lab. This was done by identifying the critical components necessary to support a data-driven cybersecurity approach:

Data Ingestion and Management: A data ingestion pipeline is crucial for a data-driven cybersecurity solution. It involves the process of importing and loading data into storage systems and typically, includes three primary components: the data source, a data conversion step, and the data destination [8]. Large datasets, like the NSL-KDD dataset, need to be supported for import in the lab in order to enable real-time data analysis. For this reason a data storage solution is also required to handle the raw, training and test data and the models. This storage may range from enterprise-level databases to simpler data storage, akin to saving files on a local hard drive. In cloud storage, data is distributed across multiple third-party services, rather than relying on dedicated servers typically used in traditional networked data storage [9]. Data management also includes cleaning up noisy data, mapping data sources to each other, merging data and converting data to structured formats.

Cloud Infrastructure: The lab was built as a cloud-based platform using IBM Cloud services to guarantee scalability and flexibility. The computing power, data storage, and networking capabilities required to manage extensive cybersecurity operations would be supported by cloud infrastructure.

AI and ML Integration: To apply machine learning and artificial intelligence to cybersecurity analysis, the lab needed certain tools. By automating model building and hyperparameter optimization, IBM Auto AI was chosen so that students could concentrate on analyzing and using ML models instead of creating them from the ground up.

Automated AI, often referred as the Auto AI, enables data scientists to quickly get started and accelerates experimentation for experts by providing a multimodal data science and AI environment that fosters collaboration and model optimization, offers rapid selection of top-performing models and algorithms, ensures consistency and integrity throughout the AI and ML lifecycle, features an integrated user interface for automated data preparation and hyperparameter optimization, simplifies deployment with just a few clicks, and automates the entire AI and ML lifecycle, which is a significant advantage [10].

Another important industry requirement is AI model explainability: Ensuring that models and their predictions are interpretable and understandable. Students learn to implement techniques that provide insights into how models make decisions, which helps in identifying the impact of concept drift and maintaining trust in model outputs. Explainability is also crucial for debugging, compliance, and ensuring that model behavior aligns with expected outcomes.

Practical Experience: The lab should enable students to participate in practical exercises that mimic real-world cybersecurity problems, like automated defense systems, threat prediction, and anomaly detection. Traditional teaching methods, such as lectures and literature, have proven insufficient for cybersecurity training because they fail to provide trainees with the necessary opportu-

nities to apply theoretical knowledge in real-world scenarios, whereas hands-on exercises are crucial for reinforcing and internalizing these concepts, effectively demonstrating how even minor mistakes, such as a small flaw in a service or firewall configuration, can severely compromise the overall security of a system or network [11].

[12] studied and characterized some of the efforts [13,14] to cover this gap and found that virtualization is popular since real hardware can be dynamically allocated, configured and managed to provide remote access to a number of networking experiments.

Similarly [15] offered a CyberSec Labs framework aimed at improving the skills of potential cybersecurity professionals, and highlighted the need of utilizing a data-driven cybersecurity approach, which gathers vast amounts of data from sources such as network traffic, log analysis, memory analysis, cyber incident data, intrusion detection and prevention systems, and OSINT methods, ultimately enabling the formation of best practices for mitigating cyber attacks through hands-on exercises like vulnerability analysis, penetration testing, and volatility analysis.

In cybersecurity education, it is crucial to focus not only on the development of data-driven solutions but also on their effective productionalization. This involves transitioning from theoretical models and prototypes to fully operational systems within real-world environments. Key elements of this process include scalability, integration with existing systems, deployment and maintenance.

a) Scalability: Ensuring that data-driven solutions can handle increasing volumes of data and users without performance degradation. Students are expected to learn to design systems that are scalable, enabling them to manage and analyze large datasets efficiently.

b) Integration with Existing Systems: Effective productionalization requires seamless integration with existing cybersecurity frameworks and IT infrastructure. Programs should teach students how to ensure that new solutions work harmoniously with existing systems and processes. One common solution for integration could be exposing data driven cyber security solution to a restful end point service where endpoints will allow different software components to communicate effectively, ensuring compatibility and functionality across the IT ecosystem.

c) Deployment and Maintenance: Transitioning from a prototype to a live system involves several critical tasks, including networking, IAM, monitoring and logging. Students gain experience with deployment strategies, ongoing maintenance, and troubleshooting to ensure system reliability and effectiveness.

Networking: Managing network configurations, protocols, and security to ensure effective communication between system components and protect against vulnerabilities.

Authentication and Authorization: Implementing and managing authentication mechanisms, including Identity and Access Management (IAM), to ensure

that users and systems making requests are properly verified and authorized. IAM systems help to control and manage access rights to critical resources, ensuring only authorized users can access sensitive data and services.

Monitoring and Logging: Setting up monitoring tools to track system performance, detect anomalies, and respond to threats in real-time. Configuring logging mechanisms for auditing, troubleshooting, and forensic analysis, ensuring logs are comprehensive and secure. One significant challenge in maintaining the accuracy of deployed models is concept drift, which occurs when the data used to generate predictions changes over time. For instance, changes in network traffic patterns, such as the introduction of new protocols or previously unseen attack vectors, can cause an Intrusion Detection System (IDS) trained on historical data to miss emerging threats, necessitating regular model retraining and updates to ensure accurate threat detection.

Evaluation and Feedback: The lab was built with tools that track student performance and give them immediate feedback on their actions during cybersecurity exercises in order to reinforce what they were learning.

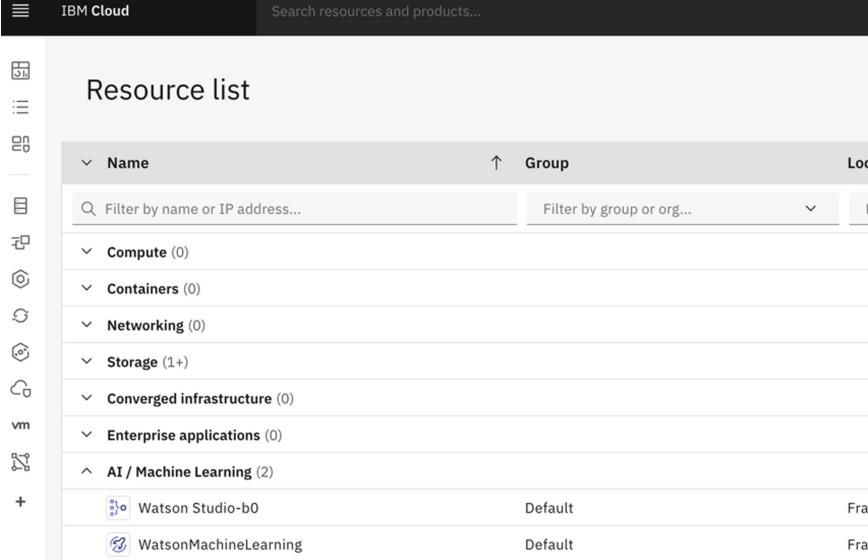
4 Proposed Solution and Demonstration

4.1 An Overview of Resources and Services in IBM Cloud

This phase involves the actual development of the DDCS lab, which is built using cloud-based technologies and IBM Auto AI for automating the data analysis and model building processes. IBM Cloud offers wealth of services for data driven cybersecurity. Once users login to the IBM WatsonX AI, the landing page is the Dashboard. Users should navigate to Resource List to access various resource list as seen below. These resources can be categorized under three categories Processing, Storage, Networking and Monitoring, and Analytics. A quick summary of resources is depicted in Fig. 1

1) Processing: IBM Cloud provides a range of compute services, including virtual servers, bare metal servers, serverless computing with IBM Cloud Functions, and Kubernetes-based container services. These services empower organizations to deploy and manage their applications with ease, ensuring optimal performance and scalability.

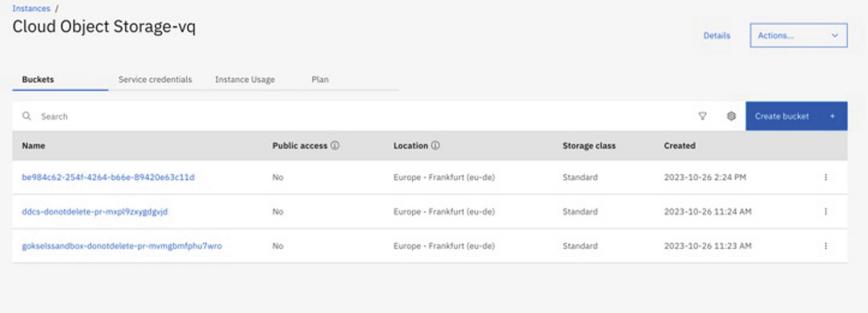
2) Storage: In addition to compute services, IBM Cloud offers managed database services such as Db2, PostgreSQL, MySQL, and MongoDB. Cloud object storage instances are automatically provisioned, allowing users to store and access their data securely. Moreover, AI and ML resources in IBM Cloud automatically generate cloud object storage instances and corresponding buckets, facilitating seamless data management and analysis. The cloud object storage generated for Auto AI experiment is shown in Fig. 2.



The screenshot shows the IBM Cloud Resource list view. The left sidebar contains navigation icons for Compute, Containers, Networking, Storage, Converged infrastructure, Enterprise applications, and AI / Machine Learning. The main area is titled 'Resource list' and displays a table with columns: Name, Group, and Location. The table shows two entries: 'Watson Studio-b0' and 'WatsonMachineLearning', both in the 'Default' group and located in 'Frankfurt (Germany)'.

Name	Group	Loc
Watson Studio-b0	Default	Fra
WatsonMachineLearning	Default	Fra

Fig. 1. IBM Cloud Resources List View



The screenshot shows the Cloud Object Storage list view. The top navigation bar includes 'Instances / Cloud Object Storage-vq', 'Details', and 'Actions...'. The main area displays a table of buckets. The columns are: Name, Public access, Location, Storage class, and Created. There are three entries:

Name	Public access	Location	Storage class	Created
be984c62-254f-4264-b66e-89420e63c11d	No	Europe - Frankfurt (eu-de)	Standard	2023-10-26 2:24 PM
ddcs-donotdelete-pr-mxp9zxyglgjvd	No	Europe - Frankfurt (eu-de)	Standard	2023-10-26 11:24 AM
gokseitandbox-donotdelete-pr-mvmbmfpshu7wo	No	Europe - Frankfurt (eu-de)	Standard	2023-10-26 11:23 AM

Fig. 2. Cloud Object Storage

3) Networking and Monitoring: IBM Cloud's networking and monitoring capabilities enable organizations to manage access to their resources securely. By leveraging IAM policies, users can control access to their storage buckets, ensuring data confidentiality and integrity. Additionally, features like whitelisting allow organizations to restrict access to specific IP addresses, further enhancing security. Figure 3 depicts how authorization and access is managed to the Auto AI assets. We performed whitelisting so that only specific IP addresses will access this projects storage: So Once the bucket is configured with IP addresses, the data in the bucket can be accessed from the configured IP addresses only.

We have added users through the invite option provided in the IAM section Fig. 4.

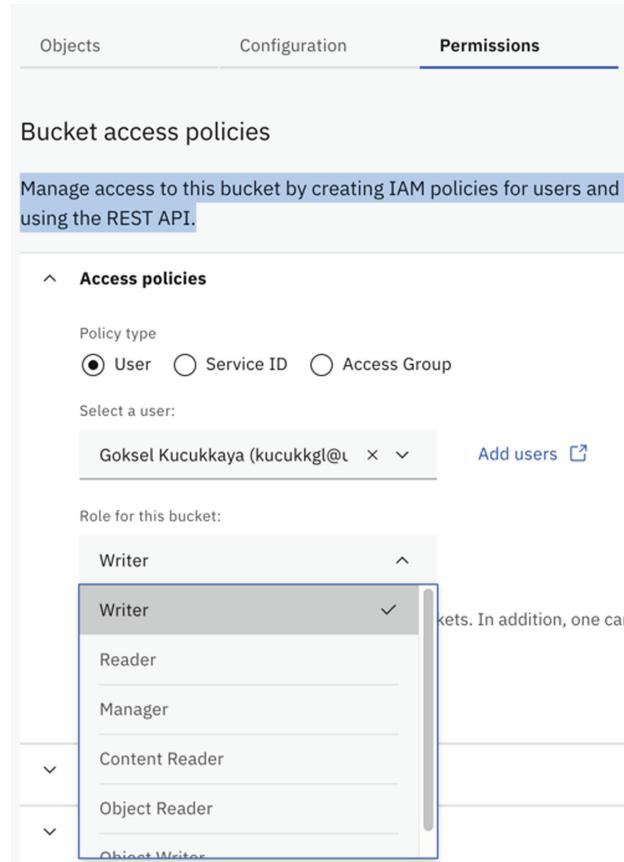


Fig. 3. IAM Policies

4) *Analytics*: For this project we used IBM WatsonX. We have created a project named as DDCS standing for Data Driven Cyber Security. We used data asset property to preview and visualize the dataset and perform feature engineering. Preview and visualization of the dataset are shown in Fig. 5 and Fig. 6.

4.2 Creating an Auto AI Experiment

Once the data is uploaded we can either process data manually, or start an Auto AI experiment. Figure 7 depicts the list of active AutoAI experiments.

Understanding data will help discovering important features and their relations [16]. In our cloud native AutoAI experiment we are using NSL KDD dataset. NSL KDD has been popular for researchers in the fields of Intrusion Detection Systems (IDS) based on machine learning algorithms. The NSL-KDD dataset is an improved version of the original KDD Cup 99 dataset, a benchmark dataset for evaluating IDSs and related security algorithms.

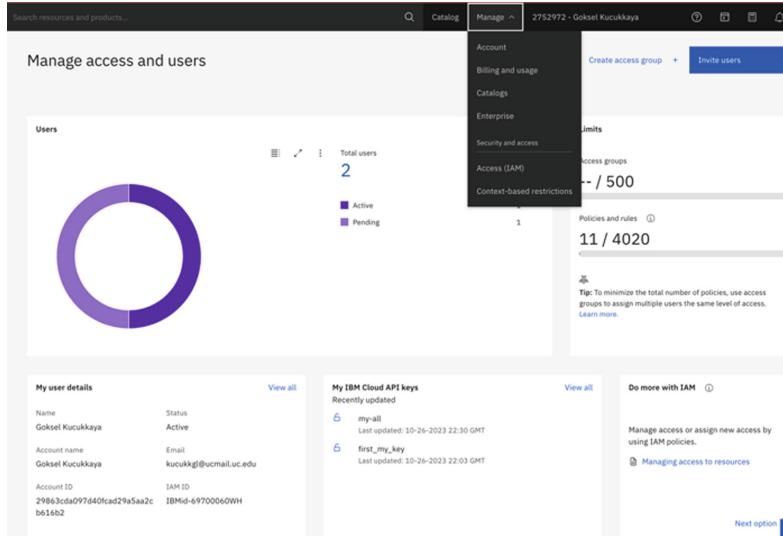


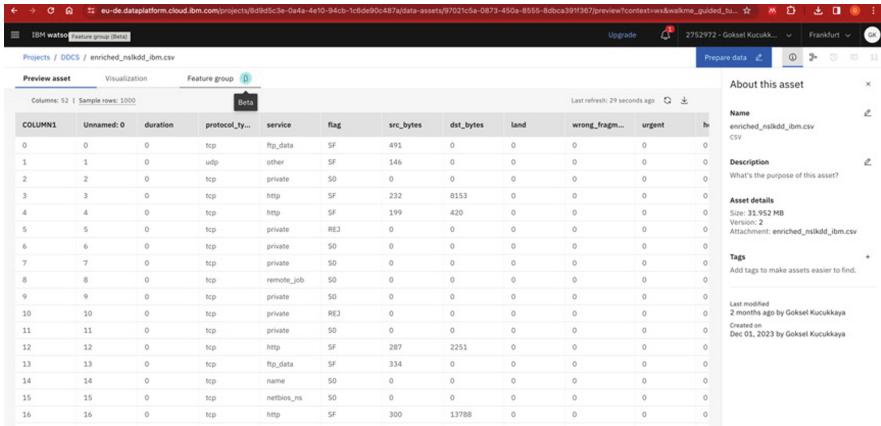
Fig. 4. IAM- Manage Access and Users

Before starting the AutoAI we did some manual preparations on the NSL-KDD dataset to focus on the cloud native AI properties more effectively. First, we have appended the feature names on the IDS dataset and converted to csv format since IBM WatsonX AI accepts csv format. Dataset has two potential target columns: attacks and the difficulty-level. We dropped difficulty-level to reduce the number of targets. The predicted column, attack, has 23 different attack types mostly named after the simulators generating these attacks while making up the NSL-KDD dataset. These are: neptune, warezclient, ipsweep, portsweep, teardrop, nmap, satan, smurf, pod, back, guess-passwd, ftp-write, multihop, rootkit, buffer-overflow, imap, warezmaster, phf, land, loadmodule, spy, perl.

We have formed another target column with a binary categorical value of 0 or 1 where 0 represented normal packets and 1 represented any packets at the IDS during an attack listed above.

NSL-KDD dataset has only three categorical features. As part of this study one of our motivations has been to use this model in production and have a pre-production test with the test data provided. However, NSL KDD dataset has separate files and for train and test purposes. For this reason, we have repeated the steps for test data as well.

Next, we have identified whether the categorical values in train and test data are compatible. We have identified that of the 70 different categories in the service feature of the train data, six are not present in the test data, and to provide consistent in pre-production test we have dropped the relevant records from train data, corresponding to an amount of less than 1% of all records. Since our demonstration is performed for a classification prediction on whether



COLUMN1	Unnamed: 0	duration	protocol_ty...	service	flag	src_bytes	dst_bytes	land	wrong_fragm...	urgent	he
0	0	0	tcp	ftp_data	SF	491	0	0	0	0	0
1	1	0	udp	other	SF	146	0	0	0	0	0
2	2	0	tcp	private	SO	0	0	0	0	0	0
3	3	0	tcp	http	SF	232	8153	0	0	0	0
4	4	0	tcp	http	SF	199	420	0	0	0	0
5	5	0	tcp	private	REJ	0	0	0	0	0	0
6	6	0	tcp	private	SO	0	0	0	0	0	0
7	7	0	tcp	private	SO	0	0	0	0	0	0
8	8	0	tcp	remote_job	SO	0	0	0	0	0	0
9	9	0	tcp	private	SO	0	0	0	0	0	0
10	10	0	tcp	private	REJ	0	0	0	0	0	0
11	11	0	tcp	private	SO	0	0	0	0	0	0
12	12	0	tcp	http	SF	287	2351	0	0	0	0
13	13	0	tcp	ftp_data	SF	334	0	0	0	0	0
14	14	0	tcp	name	SO	0	0	0	0	0	0
15	15	0	tcp	netbios_ns	SO	0	0	0	0	0	0
16	16	0	tcp	http	SF	300	13788	0	0	0	0

Fig. 5. Dataset Preview

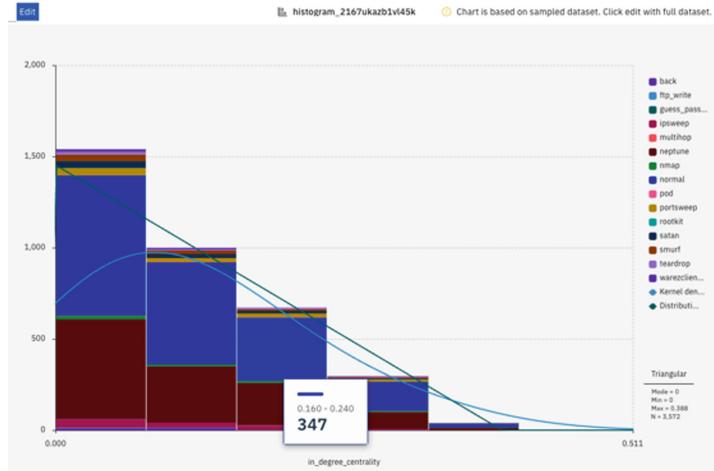


Fig. 6. Data Visualization and Insights

network traffic data leads to a malicious activity we defined a target column as in Fig. 8.

We allocated a dataset into training and testing sets to ensure the model learns from the training data while being evaluated on unseen testing data, providing a reliable measure of its performance and generalization as depicted in Fig. 9.

IBM Auto AI provides a model progress map, which tracks the development of models, including the automatic tuning of hyperparameters to enhance performance as given with Fig. 10. This feature efficiently adjusts parameters like learning rate and batch size, compares different model configurations, and high-

AutoAI experiments			
Name	Status	Model type	
ddcs_train_binary_raw AutoAI experiment	Completed	Binary classification	
CentralityEnrichedNSL-KDD AutoAI experiment	Completed	Multiclass classification	
ns1_kdd_centrality_basic AutoAI experiment	Failed	Multiclass classification	
7075 Demo AutoAI experiment	Completed	Binary classification	
DDCS AutoAI experiment	Completed	Binary classification	

Fig. 7. Auto AI Experiments View

Configure details

Create a time series analysis?
Enable this option to predict future activity over a specified date/time range. Data must be structured and sequential. [Learn more](#)

Yes No

What do you want to predict?
Prediction column [?](#)

attack_state

Prediction column: attack_state **CUH remaining:** 20 CUH

PREDICTION TYPE Binary Classification	POSITIVE CLASS 1	OPTIMIZED FOR Accuracy & run time
---	----------------------------	---

Experiment settings  Run experiment 

Fig. 8. Define Target Feature



Fig. 9. Automatic Allocation of Train and Test Data

lights the best-performing ones, ensuring optimal use of resources while improving accuracy, as demonstrated in the NSL-KDD dataset experiment.

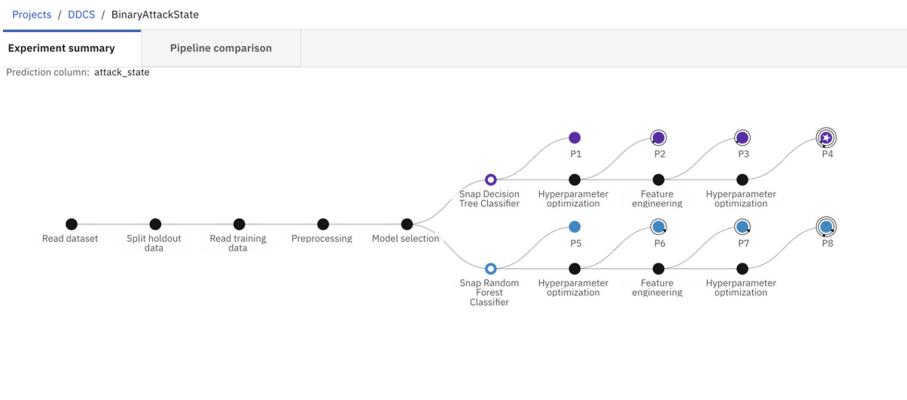


Fig. 10. Pipelines Progress Map

1) *Performance Evaluation:* In our experiment we will have results of various models in forms of performance metrics. The problem we are trying to solve belongs to cyber domain, requiring domain knowledge to select the appropriate performance metrics prior to the model selection. It is vital to have a good understanding of error types for selecting a model that suites the problem situation. Type I errors occur when a null hypothesis is rejected when it is actually true, which is also regarded as false positive. Type II errors represent the errors where null hypothesis is failed to reject when it is false, also represented as false negative. In the following section these errors will be broken down into more details

to discuss the performance evaluation of learning models. We first examined the confusion matrix defined by [17] as following:

$$CM = \begin{bmatrix} TP & FN \\ FP & TN \end{bmatrix}$$

where:

- TP is True Positive
- FN is False Negative
- FP is False Positive
- TN is True Negative

IBM Auto AI generates the confusion matrix during model evaluation, which is essential for assessing the performance of the selected model (Fig. 11).



Fig. 11. Confusion Matrix for Model Performance

2) *Feature Selection:* Feature selection is realized by identifying the irrelevant features in the feature space and removing them [18].

We will use this opportunity to explain the features in our lab dataset.

src.bytes: the number of data bytes sent by the source (client) in a network connection. In the case of a normal web browsing session, the src.bytes value may be relatively small, corresponding to the size of the HTTP request and any associated data. However, in a potential attack scenario, such as a data exfiltration attempt or a distributed denial-of-service (DDoS) attack, the src.bytes value could be unusually large, indicating a significant amount of data being sent from the source to the destination.

service: Service and protocol (a categorical variable)

duration: The length of time that a particular connection or activity persists. Unusually long durations for network connections could indicate potential security threats or malicious activities. For example, prolonged connections to unusual ports or from suspicious IP addresses might suggest reconnaissance activities or attempts to establish unauthorized access.

dst_host_serr_rate: percentage of connections that have SYN errors to the destination host. High values of this attribute may suggest potential issues with the destination host, network connectivity problems, or possibly malicious activities such as denial-of-service (DoS) attacks or port scanning.

dst.bytes: information about the size of the payload received by the destination host in a particular connection. Unusually large amounts of data received by the destination host (high dst.bytes values) might indicate potential security threats or malicious activities. For example, in the case of a data exfiltration attempt, an attacker might transfer a significant amount of data from the source to the destination.

dst_host_srv_diff_host_rate: rate of connections to different hosts observed for the same service on the destination host. A high value suggests that the service on the destination host is accessed by a diverse set of source hosts, while a low value indicates that a large portion of connections originate from a limited number of source hosts.

dst_host_same_src_port_rate: Represents the rate of connections having the same source port number to the same destination host. Unusually high values may indicate scanning or reconnaissance activities where an attacker is probing the destination host from a single or a few source ports.

Prior to feature selection one should enhance the feature space. IBM Auto AI offers feature transformers as given in Fig. 12 and as part of their suite of

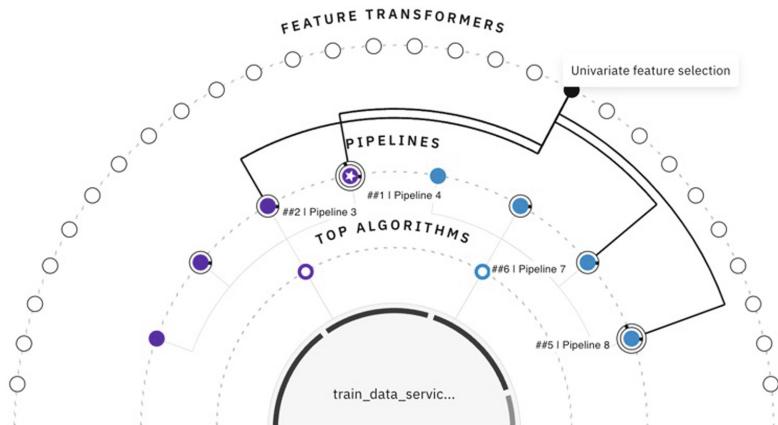


Fig. 12. Feature Transformation Dashboard

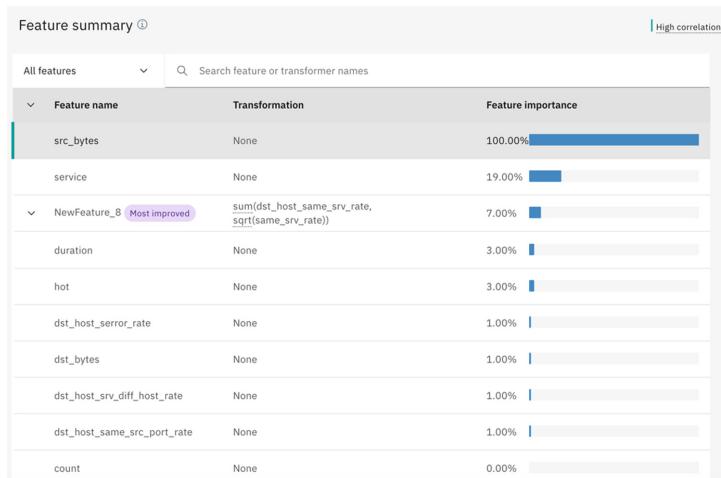


Fig. 13. Feature Importance

Create a deployment

Associated asset
BinaryAttackState - P4 Snap Decision Tree Classifier - Model

Deployment type

Online
Run the model on data in real-time, as data is received by a web service.

Batch
Run the model against data as a batch process.

Name
BinaryAttackDeployment

Serving name (1)
Deployment serving name

Description
Deployment description

Tags
Add tags to make assets easier to find.
Add a tag

Fig. 14. Allocating Cloud Based Deployment Space

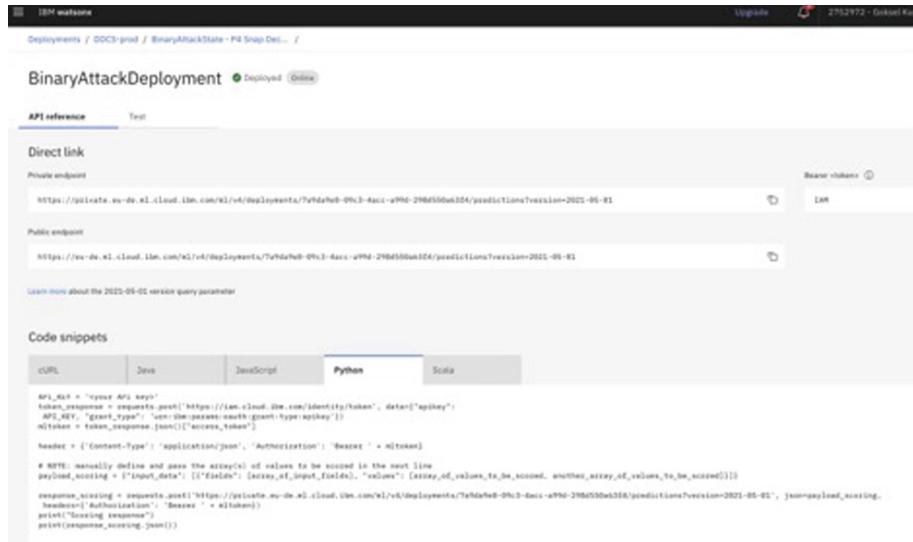


Fig. 15. Exposing Deployed Model With Restful Endpoint

```

headers={'Authorization': 'Bearer ' + mltoken})
print("Scoring response")
print(response_scoring.json())

Scoring response
{'predictions': [{'fields': ['prediction', 'probability'], 'values': [[1, [0.0, 1.0]]]}]}

```

Fig. 16. Prediction In Production

data science and machine learning tools. In our experiment AutoAI generated more than ten new features.

As can be seen at Fig. 13. the highest feature importance has been credited for the column and the transformed feature (by using dst.host.same.srv.rate and same.srv.rate) is in the 3rd place when features are sorted by their importance.

3) Model Deployment: Despite the promise in ML technology, more than 80% of ML software projects never make it to production resulting in significant losses [19]. For this reason, we do not wish to end Auto AI journey with the model selection, and we extend our effort to deploy models into cloud native production.

Allocating cloud-based deployment space is a crucial step in IBM Auto AI for promoting the model to production. This step ensures that the trained model has the necessary infrastructure to run efficiently and scale as needed. By deploying the model in the cloud, organizations can leverage features like continuous monitoring, scalable compute resources, authentication, and access control (e.g., IAM) to ensure that the model operates securely and is easily accessible for real-time decision-making Fig. 14.

The next step after allocating cloud-based deployment space in IBM Auto AI is to expose the promoted model via a RESTful endpoint. This allows the model to be easily integrated into external applications or systems, enabling real-time interaction for tasks such as threat detection and response. Figure 15 depicts the headers to consume the RESTful endpoint once it is exposed.

Once the RESTful endpoint is exposed, we can consume the endpoint for predictions by sending requests with relevant input data, such as features from the NSL-KDD dataset. The model, hosted in the cloud, will process the incoming data and return a prediction, such as whether a particular network event is classified as normal or a potential intrusion Fig. 16.

5 Conclusion

This study's development of the Data-Driven Cybersecurity Lab (DDCS) offers an essential learning tool intended to close the knowledge gap between theory and practice in contemporary cybersecurity training. Through the utilization of cloud technologies and machine learning tools such as IBM Auto AI, the lab facilitates students' participation in practical, data-driven cybersecurity activities that are precisely in line with industry demands.

The need for experts who can efficiently manage big datasets, apply machine learning models, and automate threat detection is greater than ever as cyber threats continue to evolve in terms of both complexity and frequency. In addition to providing students with a realistic environment where they can address real-world cybersecurity challenges, the DDCS lab gives students the skills they need to meet these demands. Students learn how to recognize anomalies, anticipate threats, and apply AI-driven solutions to secure systems and data by working with large datasets like the NSL-KDD.

With automated model building, performance evaluation, and real-world scenario simulation, the lab guarantees that students are ready for their future careers in cybersecurity. The DDCS lab offers a cutting-edge method of teaching cybersecurity that can change to keep up with the quick pace of technological advancement and the ever-changing threat landscape. This is achieved by incorporating data management, artificial intelligence, and practical experience into the curriculum.

This study shows how a cloud-based, data-driven cybersecurity lab can improve student learning tremendously and aid in the development of the technical and analytical skills required to safeguard vital infrastructures. In the future, the lab's capabilities could be increased by adding more datasets, sophisticated machine learning algorithms, and real-time threat simulations. This would increase the lab's value as a resource for cybersecurity professionals training in the field.

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Curriculum for a New Academic Program with Bachelor's Degrees in Electrical Engineering and Intelligent Systems Engineering

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Abstract. This research paper proposes a curriculum for a six-year academic program with a bachelor's degree (honors) in intelligent systems engineering and a bachelor's degree (honors) in electrical engineering. This program includes courses in digital electronics, analog electronics, computer organization, computer architecture, computer communication networks, communication systems, power engineering, firmware design, static and dynamic website design, development of chatbots and voice assistants, knowledge-based systems, fuzzy logic, neural networks, evolutionary computation, evolutionary multiobjective optimization, machine learning, image processing, computer vision, pattern recognition, voice recognition, natural language processing, data science, control systems, intelligent control systems, robotics, digital signal processing, signals and systems, mathematics, engineering physics, biology, etc. These degrees will allow graduates to have a good understanding of all of the main branches of intelligent systems engineering and electrical engineering.

Keywords: Education · Intelligent Systems · Computational Intelligence · Soft Computing · Artificial Intelligence · Machine Learning · Software Development · Firmware Development · Intelligent Control Systems · Electronics Engineering

1 Introduction

Engineering consists of theoretical engineering and applied engineering. *Theoretical engineering* is the creative development of mathematics, natural science, technical principles, or technical methods for usage in the development, analysis, characterization, modeling, control, automation, optimization, forecasting, simulation, or visualization of devices, algorithms, components, systems, machines, apparatuses, structures, processes, operations, or materials. *Applied engineering* is the creative application of mathematics, natural science, technical principles, or technical methods for the development, analysis, characterization, modeling, control, automation, optimization, forecasting, simulation, or visualization of devices, algorithms, components, systems, machines, apparatuses, structures, processes, operations, or materials. Therefore, intelligent systems development is in the domain of engineering. The preceding definitions [1, 2] of engineering, theoretical engineering, and applied engineering are by the author of this research paper.

Most researchers and developers working in the field of intelligent systems [3–76] have their primary education in another field like electrical engineering, computer engineering, computer science, mechanical engineering, aerospace engineering, software engineering, etc. Because their primary education is usually not in intelligent systems, they often are only familiar with one, two, or a few branches of intelligent systems. By offering a six-year academic program with a bachelor's degree (honors) in intelligent systems engineering and bachelor's degree (honors) in electrical engineering, it's possible for graduates to have an understanding of all of the main branches of intelligent systems and electrical engineering. These two fields can be used together.

Students should be able to get direct admission to this six-year academic program right out of high school. They shouldn't have to separately apply for admission to each degree. If a student wants to discontinue the six-year program after completing four years, she could be given a bachelor's degree (honors) in engineering.

Some universities have recently started offering bachelor's degrees in artificial intelligence. These bachelor's degrees in artificial intelligence have more of a focus on computer science rather than electrical engineering. By having a bachelor's degree (honors) in intelligent systems engineering, it's possible to have more of a focus on control systems, digital signal processing, robotics, and natural science than typically offered in a computer science program. Intelligent systems engineering can be applied to these fields.

The author of this research paper previously wrote a research paper proposing a four-year bachelor's degree (honors) in intelligent systems engineering [3]. Also, he previously wrote a research paper proposing a five-year academic program with a bachelor's degree (honors) in intelligent systems engineering and software engineering and master's degree in intelligent systems engineering and software engineering [4].

2 Suggested Curriculum

Below is a suggested curriculum for a new type of six-year academic program with a bachelor's degree (honors) in intelligent systems engineering and bachelor's degree (honors) in electrical engineering. In the proposed curriculum, there are two semesters or terms per year. Related publications are provided in the references for many of the proposed courses.

1st year, 1st semester:

1. Linear algebra [77–87].
2. Introductory calculus (differentiation and integration).
3. Introductory software development (using Python).
4. Engineering physics: mechanics.
5. Grammar, punctuation, and writing style [88, 89].

1st year, 2nd semester:

1. Secondary calculus.
2. Digital electronics.
3. Development of static and dynamic websites, chatbots, voice assistants, and text messaging services.

4. Engineering physics: wave motion, optics, and sound.
5. Government and public policy.

2nd year, 1st semester:

1. Tertiary calculus.
2. Fundamentals of intelligent systems.
3. Digital systems engineering (using Verilog and VHDL).
4. Engineering physics: electricity and magnetism.
5. Intellectual property law and patent specification preparation.

2nd year, 2nd semester:

1. Discrete mathematics.
2. Fuzzy logic and knowledge-based systems [5–63].
3. Analog electronics 1.
4. Computer organization, assembly language programming, and machine code programming [90].
5. Civil litigation procedure and lawsuit document preparation.

3rd year, 1st semester:

1. Probability and probabilistic reasoning.
2. Neural networks [62–70].
3. Analog electronics 2.
4. Embedded systems software design and microprocessor interfacing.
5. Engineering law.

3rd year, 2nd semester:

1. Statistics.
2. Signals and systems.
3. Evolutionary computation [61].
4. Analog electronics 3.
5. Employment and civil rights law.

4th year, 1st semester:

1. Mathematical programming.
2. Digital signal processing.
3. Analog control systems [91, 92].
4. Design project course using analog electronics.
5. Engineering entrepreneurship.

4th year, 2nd semester:

1. Digital control systems [92, 93].
2. Semiconductor device physics.
3. Electromechanical energy conversion and motors.
4. Software engineering methodology.
5. Introductory accounting.

5th year, 1st semester:

1. Algebra of linear systems [94].
2. Evolutionary multiobjective optimization.
3. Power generation, transmission, and distribution.
4. Communication systems.
5. Introductory macroeconomics.

5th year, 2nd semester:

1. Multivariable control systems [92, 95].
2. Image processing, computer vision, pattern recognition, and voice recognition [67].
3. Computer architecture [96].
4. Transmission lines and electromagnetic field theory.
5. Engineering ethics.

6th year, 1st semester:

1. Intelligent control systems [68–70].
2. Natural language processing [71–74].
3. Machine learning.
4. Computer communication networks.
5. Technology history documentary seminar.

6th year, 2nd semester:

1. Financial mathematics.
2. Data science [61].
3. Robotics [75, 76].
4. Biology.
5. Research methods.

3 Engineering, Math, and Science Courses

The engineering, math, and science courses listed above can include standard topics for each of these courses. For courses related to intelligent systems and control systems, the author of this research paper has included references he is familiar with for some of the best books and research papers in these fields as well as other important books and research papers.

The biology course is included because a lot of intelligent systems theory was inspired by human or animal biology. The biology course could inspire students to develop new intelligent systems theory. Dr. Madan M. Gupta [97] (a top researcher in intelligent systems, control systems, computer vision, biomedical engineering, and other fields) often recommended that intelligent systems researchers study biology. Dr. Gupta wrote, “Reverse biological engineering is used to apply biological principles to the solution of engineering and scientific problems. In particular, engineers and scientists use this reverse engineering approach on humans and animals in developing intelligent systems” [22–24].

The author of this research paper created multidimensional matrix mathematics and its subsets, multidimensional matrix algebra and multidimensional matrix calculus in

[77–87]. It would be a good idea to include teaching these new branches of math in a university course on linear algebra.

Consumption of large amounts of alcohol is a significant problem on university campuses [98, 99]. Therefore, it would be a good idea to require students to take a one-day short course at their convenience on the harmful effects of alcohol [98–100], recreational drugs, tobacco products, e-cigarettes, etc. This short course could be made available online for students to complete at their convenience.

4 Engineering Students Should Not Have to Take Nontechnical Courses

Engineering students should not have to take nontechnical courses. The content of these courses can be easily learned outside university and taking nontechnical courses means there is less time to take engineering, math, and science courses.

Engineering courses are much more important for engineering students just like arts courses are much more important for arts students. Arts students don't have to take engineering courses so why do engineering students have to take arts courses? It's a form of bigotry against engineering for universities to assign greater importance to arts courses than engineering courses. Courses in singing, dancing, acting, gender studies, and philosophy aren't more important than courses in calculus, electronics design, communication systems, control systems, and power engineering. If people in social sciences and humanities are offended by the assertion that engineering, mathematics, and science courses are more important for engineering students to take, this shows bias against engineering, mathematics, and science.

High school and elementary school are for providing a general education. High school and elementary school could be significantly enhanced to cover more important nontechnical material and engineering material. In university, students should be able to focus on their fields of study.

If intelligent systems engineering and electrical engineering students can forego the nontechnical courses, then these degrees can include additional courses in software development, mathematics, computer communication networks, communication systems, power systems, physics, chemistry, environmental science, etc. The author of this research paper had to eliminate courses in differential equations, vector calculus, numerical methods, fuzzy mathematics, computer control applications, digital integrated circuit design, analog integrated circuit design, thermodynamics and heat transfer, human physiology, animal physiology, and chemistry and a project course that he wanted to include in the curriculum because there wasn't time due to the nontechnical electives. The preceding courses in engineering, math, and science would be more useful than nontechnical courses for most engineers.

If engineering students are able to take more courses in engineering, mathematics, and science instead of nontechnical courses in undergraduate degrees, they will be less likely to need graduate degrees and more likely to get engineering employment.

Accreditation organizations and universities requiring students to take nontechnical courses instead of engineering courses are doing more harm than good. Accreditation organizations and universities should stop requiring engineering students to take nontechnical courses.

5 Nontechnical Courses

In the opinion of the author of this research paper, the 12 most useful nontechnical courses for most engineering students were included in the curriculum above. Students could take different nontechnical courses if they like depending on their interests.

Most people don't understand the rules of advanced grammar, punctuation, and style so a course on this would be useful and is included in the first semester of the curriculum. The author of this research paper recommends references [88, 89] for teaching this course.

The course on civil litigation procedure and lawsuit document preparation should teach the steps in suing someone and how to write important civil claim documents for money owing, personal injuries, and issues in the information age including online defamation [101–107], doxing [101–107], and impersonation [101–104, 108].

The government and public policy course should describe how the different levels of government work, how the United Nations works, and important public policy issues like climate change [109–113], the oppression of Palestinians [114–122], voter disenfranchisement, law enforcement corruption, racist profiling, the death penalty, cyberbullying, government reform, etc. Students could watch video documentaries [120–123] on different public policy issues.

The suggested technology history documentary seminar could include watching various video documentaries on the history of engineering.

6 Other Suggestions for Educational Improvements

As described in [31, 32], fuzzy logic can be used for assessing students when assessments are based on professors' opinions of student performance on projects, reports, essays, etc. Fuzzy logic can be used for assigning linguistic grades and for decision making and data mining with those linguistic grades [31, 32]. Many aspects of fuzzy logic including fuzzy sets, linguistic variables, fuzzy rules, fuzzy math, fuzzy database queries, computational theory of perceptions, and computing with words are useful in uncertainty management of linguistic evaluations for students [31, 32].

Professors should record lectures and make them available online so students can watch them at their convenience. The advantages of online lectures for students are they can rewind the lectures if they want to watch something again, they won't miss lectures due to illnesses or other reasons, they can watch the lectures at the most convenient times for them, and they can even watch the lectures in advance of taking the courses to work ahead. The disadvantage of online lectures for students is they can't ask questions during the lectures, but they can still ask questions to professors or teaching assistants after the lectures. In the opinion of the author of this research paper, the advantages outweigh the disadvantages.

University courses should be made available online to anyone who wants to take them anywhere in the world. University courses that require laboratory equipment can have in-person laboratory work too. Among the suggested courses above, only the control systems, power engineering, and robotics courses need laboratory equipment. A person who doesn't live near the university could make a short trip to the university for each

course requiring laboratory work. Anyone who takes the courses should be able to get a degree out of them.

Students should be able to take one course at a time and complete courses at their own pace. They should be able to take the exams when they are prepared. This would help accommodate students who are working full-time or part-time, students in the military, students who can't afford tuition for more than one course at a time, students with disabilities like blindness who need more time to study courses, students who are ill or have other medical issues, students dealing with family illnesses or other family medical issues, students suffering from bereavement, students who are fasting for religious reasons or observing religious holidays, etc. Most full-time students could aim to take one course per month.

Universities should help students get internships related to their fields of study in private companies during their summer breaks. For undergraduate students to get some research experience, professors could offer paid or unpaid research internships to undergraduate students during their summer breaks.

There is much more competition for internships during summers because most universities have their breaks from courses during this time. However, companies need students in the fall and winter too. Having breaks from courses during the fall or winter instead of during the summer would increase student employment. In the co-op system at the University of Waterloo, students have two work terms from September-December, two work terms from January-April, and two work terms from May-August during a five-year program.

7 Conclusion

The proposed curriculum for a six-year academic program with a bachelor's degree (honors) in intelligent systems engineering and bachelor's degree (honors) in electrical engineering will ensure that students graduate with a broad knowledge of the different fields of intelligent systems and electrical engineering and related fields in engineering, math, and science including digital electronics, analog electronics, computer organization, computer architecture, computer communication networks, communication systems, power engineering, transmission lines and electromagnetic field theory, firmware design, software engineering, static and dynamic website design, development of chatbots and voice assistants, knowledge-based systems, fuzzy logic, neural networks, evolutionary computation, evolutionary multiobjective optimization, machine learning, image processing, computer vision, pattern recognition, voice recognition, natural language processing, data science, control systems, intelligent control systems, robotics, digital signal processing, signals and systems, calculus, algebra, probability, statistics, discrete mathematics, mathematical programming, engineering physics, etc.

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The Effectiveness of the Project-Based Learning in the Perfume Chemistry Course

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Abstract. The Chemistry Perfume (CP) course consists of three components: lectures, laboratory experiments, and research projects. Lecture studied about history, source, applies to industry, bioactivities, and the chemical components of the essential oil: terpenes, alcohol, aldehyde, ketone, esters, and aromatic derivatives. Laboratory experiments practice the skills of setting apparatus, preparing the concentration of chemicals, and using the high instruments. The research project used the 11 popular essential oils of berneol, camphor, menthol, eucalytal, citral, limonene, methyl salicylate, geraniol, thymol, and cinamondehyde as ingredients in cleaning products such as soaps, shampoos, and toothpaste. For effective learning, the QR code collected data on 11 components about the pharmacognosy, bioactivities, structures, and use in the cosmetics industry. In this study, 120 questionnaires were used to survey their choice of soap, sham-poo, and toothpaste, and these products contain herbal ingredients. Survey the number of soap, shampoo, and toothpaste products from three sources: con-venience stores, malls, and local markets. Consumers choosing natural products are in the age range of 38–60 years, accounting for 54 percent, and select prop-erties of the cleaning product aged 48–60 were 36 percent. The consumer in the age range of 48–60 years used QR codes is 22 percent. In this research, QR codes transferred knowledge about essential oils that are ingredients in soap, shampoo, and toothpaste products. QR codes will provide guidance for choosing cleaning products that are suitable for people. The process of the CP course used Project-Based Learning (PBL) is an educational approach for activated learning, engaging, understanding the students, and innovation for usefulness in the real world.

Keywords: Chemistry · Effectiveness · Essential Oils · Perfume · Project-Based

1 Introduction

The course descriptions in the Higher education knowledge standards (HEKS) has course descriptions which the lectures and the laboratory experiments. The theories of the chemistry perfume (CP) studied the lesson of the components of perfume which are the essentials oil and aroma compounds. They can be derived from natural sources (like flowers, fruits, spices, woods, and resins) or synthesized chemically.

The groups of essential oils are derivatives of terpenes, alcohol, aldehyde, ketone and esters (Fig. 1). Extracted with a destroyer, distilled, separated by chemical methods [1] and used for many different uses. The research project study about essential oils that is used as an ingredient in soap that are beneficial in skin care, reducing dark spots, whitening skin, antioxidant [2] and anti-inflammatory [3], which include essential oils berneol, camphor, menthol, Eugenol [3–5] for anti-fungal, anti-inflammatory properties. Antioxidant Hair Shampoo of Eucalytal Oil is a flavoring agent, insect repellents [6], Citral has a strong lemon (citrus) scent and is used as an aroma compound in perfumery and anti-microbial activity [7], Limonene is used in the organic herbicides.

It is added to cleaning products [8], Geraniol is also used as an ingredient in different types of perfumery and flavoring and, exhibit insecticidal and repellent.

Project-Based Learning (PBL) is an educational for activated learning, engaging, understanding the students and innovation for useful in the real world [9]. PBL of the CP course had three topics; lecture; laboratory experiments and research project. The theory of CP learning about perfume history; the source of essential oils; classification of the essential oils [10]; bioactivities; and application used industry (drug, food fragrance, cosmetics) [11]. The chemical components are terpenes, alcohol, aldehyde, ketone, esters and aromatic compounds [12]. Laboratory experiments were about synthesized the esterification for food fragrance as orange, banana, wintergreen, strawberry [13]. Distillation is the classical method, synthesis by flavors fragrance by esterification reaction by closed system of solvent by refluxing [14] and used ultrasonic apparatus for synthesis ethyl cinnamate [15]. Research project was about the knowledge the useful of essential oils are ingredients in the consumers products of soap, shampoo, and toothpaste which used a QR code before buying cleaning products. The study purposes students in the CP course are development, skills studying the chemical constituents of essentials

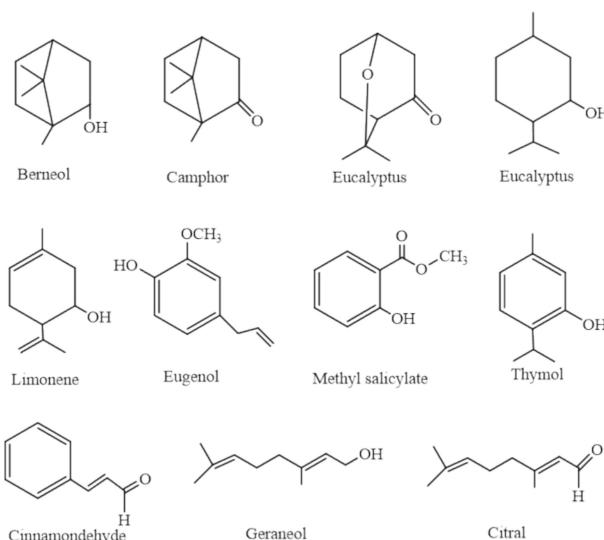


Fig. 1. Structure of the chemical components of essential oils.

oils, extended knowledge of the functional groups of organic chemistry, and skill for the setup of the reactions apparatus, used the high technology instrument and applied knowledge for daily and for work in the future.

2 Methodology

2.1 Course Settings and Participants

The CP course was conducted as an onsite course at the Suan Sunandha Rajabhat University, faculty of science and technology, Department of chemistry in semester 1/2023. PBL consisted 3 parts, lecture; laboratory experiments and research project for the third year student (Fig. 2).

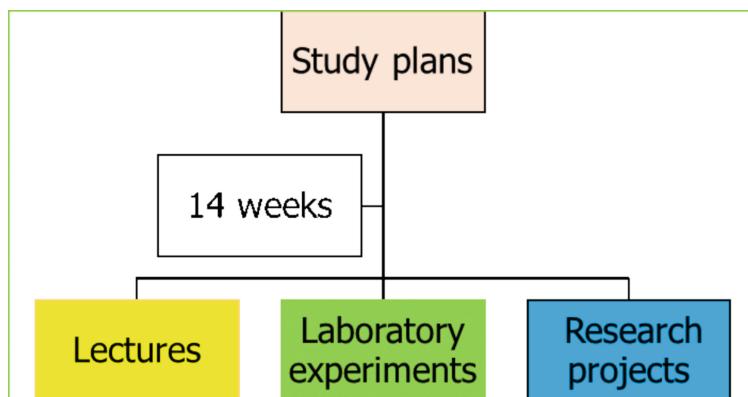


Fig. 2. Study plans of the CP course in semester 1/2023.

2.2 Onsite and Online Learning

The lecture courses of CP learned onsite in the classroom and prepared the chapters in course syllabus concern with history of perfume, source of perfume, functional groups chemistry, bioactivities and useful industry (Fig. 3). Content and details of course showed on lines in the google classroom and YouTube showed experiment and applied in industry.

2.3 Laboratory Experiments

The laboratory experiments assay for the skills in the technique such as pre-prepared accuracy concentrations of the sample by used the pipetted, volumes metric flask. Chromatography for monitoring the synthesis of components of ester products by thin layer chromatography (TLC). Extraction the flowers of herbs by distillation, synthesis reactions closed system were reflux apparatus and synthesis the ethylcinnamate by ultrasonic apparatus (Fig. 4).

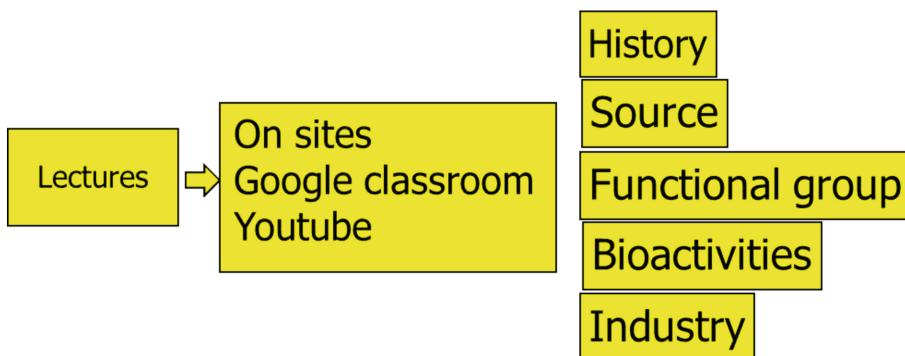


Fig. 3. Lecture courses details of the CP course.

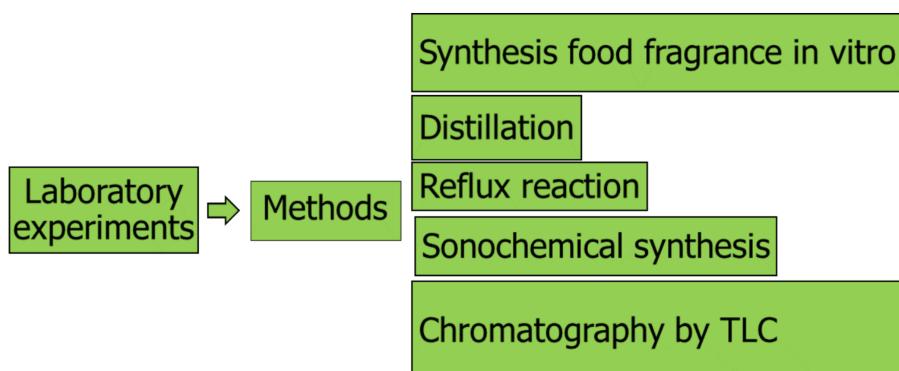


Fig. 4. Laboratory technique of the CP course.

2.4 Research Project for Data Collection

The research project applied the knowledge in the CP course by using the chemical structures, tradition used and ingredients in food, drugs and cosmetics. The of essential oils of Borneol, Camphor, Eucalyptol, Menthol, Geraniol, Citral, Limonene, Eugenol, Methyl salicylate, Thymol, and Cinnamondehyde useful data were collected in google drive and applied to QR code for search the components in the cleaning products of soaps, shampoos and toothpaste (Fig. 5).

2.4.1 Surveys were administered to gather data on the following aspects: General data of consumers 120 persons. A questionnaire was used collected the personal data (gender, age, salary, vacation and frequency to shopping).

2.4.2 Satisfaction with the cleaning products of consumer. A questionnaire was used collected the data of soap, shampoo, and toothpaste (cost, characteristic and properties).

2.4.3 Survey the number of cleaning Products on shelves in convenience stores, malls and local market for Natural extracts and chemical products (the around of Suan Sunandha Rajabhat university).

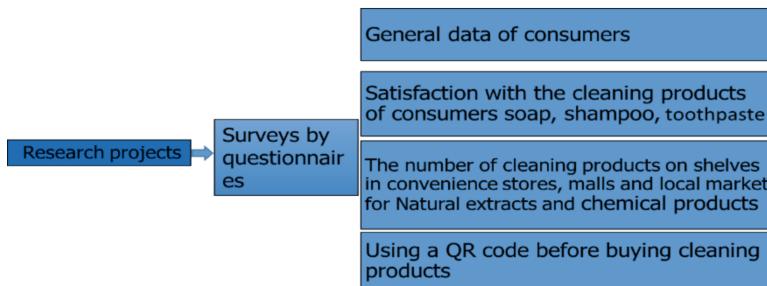


Fig. 5. Data of the essential oils applied to QR code for extended the knowledge.

2.4.4 Survey about using a QR code before buying cleaning products. (Use QR Code, not Interest, use QR code sometimes)

A survey evaluated consumers' satisfaction of properties and knowledge of herbal of cleaning products (cost, characteristic, properties) number of cleaning products and usage data of essential oil by QR code.

2.5 Consumers Performance Data

The questionnaire collected data in July 2023-December 2023 in the Rajabhat Suan-sunandha University, Bangkok, Thailand. The consumers are students, staffs' instructor and general people.

2.6 Application of QR Code

The data of essential oils were linked to Google Drive, and the QR code application was used to generate QR code pictures.

2.7 Data Analysis

Quantitative data from the surveys was analyzed using descriptive statistics to determine the frequency and percentage distributions of responses for each survey item. Respondent performance data from questionnaires was analyzed to calculate mean scores, standard deviations, and percentages of correct responses for each cleaning product (soaps, shampoos, and, toothpaste) and used a QR code to quickly search for essential oil data before choosing the cleaning products. Comparative analyses were conducted to evaluate the results the results of the consumers by comparing the results of gender, age, salary, and vocation for the properties of ingredients in products. Statistical tests (e.g., t-tests, ANOVA) were performed to determine if there were only significant consumers at Suan Sunandha Rajabhat University. Correlation analyses were conducted to investigate potential relationships between consumer's satisfactions with the rapid search data of the essential oils by QR code.

3 Results and Discussion

PBL for the lecture of the CP course in the classroom showed the enhancement of student understanding to assess student engagement motivation and measure the practical skills by the examination and used a Google Form quiz. The experiments showed the technique laboratory and research project applied and extended the knowledge of essential oils in tradition used as ingredient in cleaning products, drugs, and have bioactivities such as antioxidants, anti-cancer, anti-fungal, and anti-inflammatory.

3.1 The Lecture and Laboratory Experiments

The CP course learned onsite and on lines had the satisfaction, understanding, and grade in the lesson shown in Table 1.

Laboratory include: test tubes tests were synthesis of scents by esterification reaction. Hydro distillation apparatus extracted the essential oils from plants. Reflux apparatus is done in a closed system using a heating device, which obtained a large number of esters products. Synthesis of substances using advanced equipment to save energy and be fast using an ultrasonic device. Thin-layer chromatography is used to examine the identity of the essential oil under UV light at 254 and 366 nm. The experimental practice leads to expertise in using the equipment for higher levels of study Fig. 7).

Table 1. PBL of the CP course in lecture and laboratory experiments showed the most of students were Satisfy understood and excellent grade.

Lecture Chapter	Satisfy	Understood	Grade
History	✓	✓	A
Source	✓	✓	B +
Functional group	✓	✓	A
Bioactivities	✓	✓	B +
Used industry	✓	✓	A
Laboratory experiments			
Synthesis food fragrance in vitro	✓	✓	A
Distillation	✓	✓	A
Reflux reaction	✓	✓	A
Sonochemical synthesis	✓	✓	A

Online lecture in the Google Classroom showed the specifications of chapter of history, source of essential oils, functional group of essential oils, bioactivities, and used essential oils in the industry of cleaning products (Fig. 6).

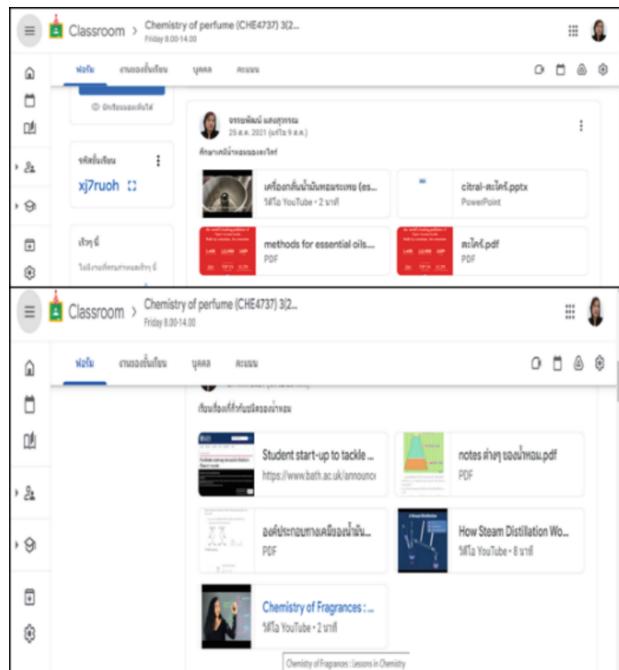


Fig. 6. Lectures onsite and online of topics learned on Google Classroom and YouTube.

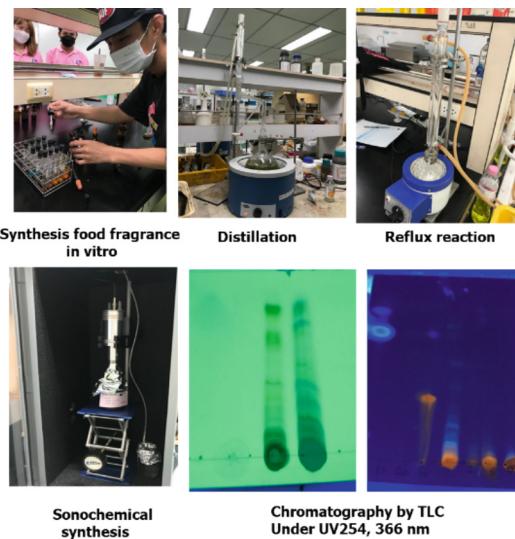


Fig. 7. Laboratory experiments of the CP course showed basic and high technology.

3.2 General Personal

In this research, 120 sets of questionnaires were used. The sample group at Suan Sunandha Rajabhat University was divided into 4 groups: students, employees, government officers, and general personnel. There were 85 females and 35 males. Table 2 showed most questionnaires were between 18 and 27 years old (41%), and consumers shop four times per month.

Table 2. Personal data of age, salary, and frequencies for shopping in one month.

Consumer	Student	Employee	Government officer	General person
Age	18–27	.	37–47	48–60
% age	41	.	21	9
Salary (USD)	500–800	900–1,200	1,300–1,600	More1,600
Frequency for shopping/month	4	.	4	4

The cheapest prices for soap, shampoos, and toothpaste to choose were 35, 43, and 48% by the age of 18–27 years' old, of which the consumers at this age have a salary of 500–800 dollars and some are students. The characteristics of soap, shampoos, and toothpaste were 29, 32, and 32% for the age range of 38–47 years' old, where the age group in this range has a salary of 1,300–1,600 dollars and a preference for the special characteristic of cleaning products. The properties of three cleaning products to choose were 27, 35, and 38% for the age range of 48–60 years' old, where the age in this range has a salary of more than 1,600\$ and the age of 48–60 takes care of themselves, which has special cleaning properties. The results of answering the questionnaires for all four types of people are shown in Table 3.

Table 3. Percentage of 120 questionnaires to choose from the soap, shampoos, and toothpaste.

Products	Soap				Shampoo				Toothpaste			
	18–27	28–37	38–47	48–60	18–27	28–37	38–47	48–60	18–27	28–37	38–47	48–60
Age	18–27	25	21	19	43	34	15	8	48	34	10	8
Cost	35	25	21	19	43	34	15	8	48	34	10	8
Characteristic	23	23	27	27	18	20	28	34	10	23	29	38
Properties	43	34	15	8	12	18	33	35	15	17	32	36

Table 4. The number of cleaning products on shelves in convenience stores, malls, and local markets.

Cleaning products	Soaps		Shampoos		Toothpaste	
	Natural extracts	Chemical products	Natural extracts	Chemical products	Natural extracts	Chemical products
Ingredients of products						
Convenience stores	13	2	8	1	10	1
Malls	15	3	10	2	8	1
Local market	4	1	3	1	2	0
Total	32	6	21	4	20	2

The collected data of soap products were natural extracts on shelves in convenience stores, malls, and local markets for 25, 15, 12%, a total 52%, and chemical products were 3, 2, and 2%; a total 7% showed the consumer needed more natural soaps than chemical soaps. Figure 8 shows that the percentage of shampoos and toothpastes as ingredients in natural products was between 33 and 9%. Results show that consumers need natural products in cleaning products, which include health care and safety. The total chemical products of shampoos and toothpastes were 5 and 2%, respectively (Table 4).

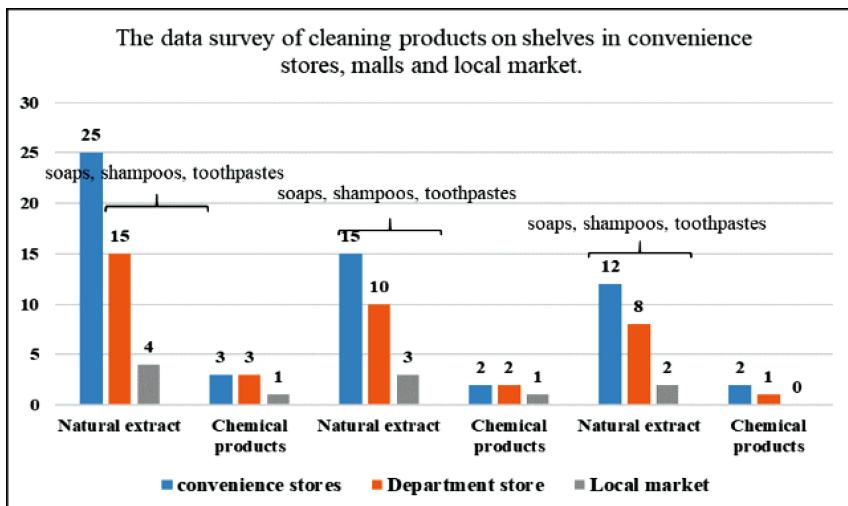


Fig. 8. Ingredients cleaning products of natural and chemical.on shelves in convenience stores, malls and local market.

The usage QR codes were 22, 18, and 16% for the ages 48–60, 38–47, and 28–37, respectively. Ages 48–60 need special cleaning products and need data on the phytochemicals in herbs for decision-making. QR code: 8% was age 18–27, the less that buying consumer goods is sometimes the duty of the parents and does not require payment Fig. 9.

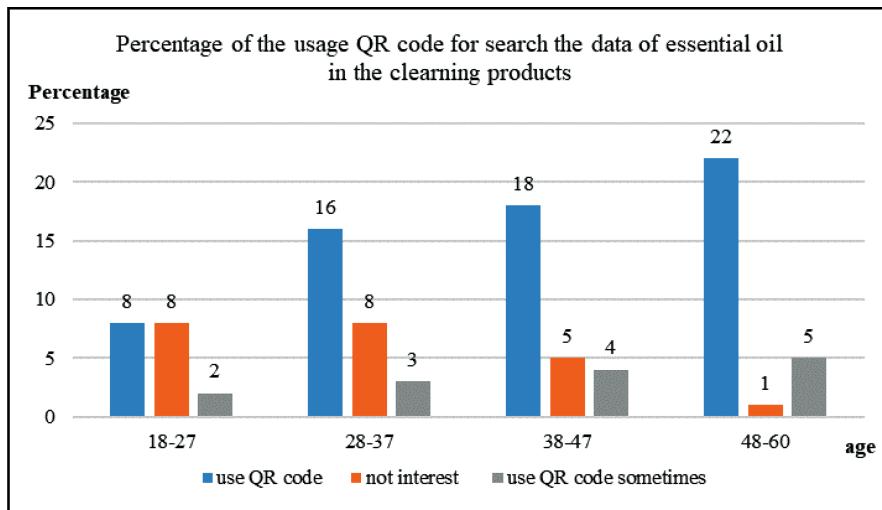


Fig. 9. Percentage of the usage QR code to search for the data on essential oils in cleaning products.

Soaps, shampoos, and toothpaste are items used in daily life that have benefits. Using essential oils in products can provide various benefits, including freshening breath, reducing bacteria, and promoting overall skin, hair, and oral health. Here are some commonly used essential oils in cleaning product formulations, along with their benefits. Known for its strong, refreshing flavor and antibacterial properties. It helps eliminate bad breath and reduces bacteria. Families buy them every month, so manufacturers invent new products to attract consumers. Table 4.4 shows cleaning products on shelves in convenience stores, malls, and local markets. Natural soaps, shampoos, and toothpastes were 32, 21, and 20 samples, respectively (Fig. 10).

Useful for the consumers used QR code of essential oils data for the extend of the knowledge. The created data on essential oils was linked to Google Drive, and the QR code application was used to generate QR code pictures, as shown in Fig. 11.



Soaps : menthol, geraniol, champhor, eugenol citrol, limonene



Shampoos: borneol, menthol, citrol, limonene, geraniol, champhor, eugenol



Toothplates: eugenol, methyl salicylate, thymol, cinnamon

Fig. 10. Survey the natural ingredients of the cleaning products in on shelves in convenience stores, malls and local market.

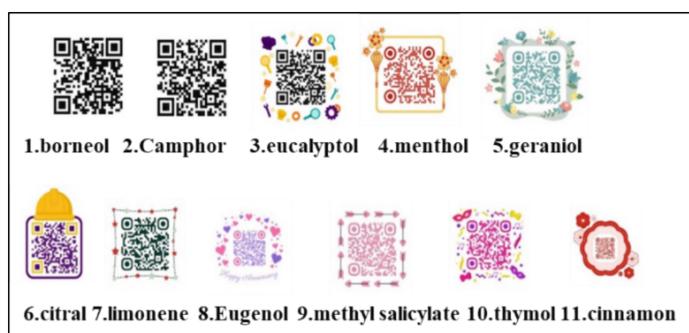


Fig. 11. QR code of essential oils data.

4 Conclusion

PBL of the CP cause has 3 steps for activated learning: engaging, understanding the students, and innovation for usefulness for people. The course description of theory was learned online and in Google Classroom. Laboratory experiments were learned in the lab room, which could be the basic and advanced technique of chemistry. The research project about data on essential oils kept and transferred knowledge for people by QR code. The CP course in semester 1/2023 was successful, and the students with high scores in the good excellent grade were A and B +.

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Education and Artificial Intelligence



Artificial Intelligence and Challenges in a Research-Teaching Model

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Abstract. This research activity is about artificial intelligence perspectives during an undergraduate research-teaching program and provides an overview of the field of artificial intelligence, core concepts, related taxonomy, and current applications as well as challenges for information science students as well as practitioners. Educational research framework was established and fundamental artificial intelligence approaches have been explored via code samples and investigated for structural components as well as related research methodologies. Then, the study proposes key challenges for current research activities and presents potentially viable future research directions of artificial intelligence. The educational research environment, the research student comprehension levels, and course implementation efforts were evaluated qualitatively and quantitatively to demonstrate the efficacy of the research activity.

Keywords: Artificial Intelligence · Undergraduate Research · Practical Challenges of Artificial Intelligence

1 Introduction

This activity presents an educational undergraduate research-teaching model for underprivileged undergraduate students and investigates potential contemporary challenges of artificial intelligence systems. This semester-long research activity is part of a senior-level, 3-credit, theoretical Computer Architecture and Design course, was implemented during a research enhancement project with course students learning the basic pillars of viable research conducts and an undergraduate research leader investigating advanced artificial intelligence concepts. A potentially promising senior-level student with relevant background was ensured by identifying an underrepresented and underprivileged student who studied the contemporary concepts and who illustrated potential skills for advanced research activities during the course undergraduate education experiences. The student research leader had to utilize limited hardware and relevant laboratory resources while large number of accessible library resources being available via institutional memberships to achieve superior as well as significant artificial intelligence knowledge, had

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to closely mentor the course students about the fundamentals of artificial intelligence, i.e., learning by teaching and doing research, and was closely supervised, mentored, and monitored conceptually by the course instructor.

This novel activity combines an undergraduate research project with a research infusion to a senior level course, under limited resources, for underprivileged and underserved students and establishes a viable teaching-research educational environment that is applicable to wide ranging institutions, ranging from minority serving institutions in underserved areas to tier-1 research institutions. Section 1 is about the research-teaching educational framework, Sect. 2 provides artificial intelligence perspectives, Sect. 3 studies the core concepts of artificial intelligence, illustrating with sample applications, Sect. 4 offers vital research methodologies, Sect. 5 emphasizes various artificial intelligence system significance, Sect. 6 presents the critical artificial intelligence research directions, and Conclusions are given at the end of the study. The quantitative and qualitative evaluations, by the course instructor, strongly validate the viability and efficacy of combined research-teaching educational framework and related multi-level mentorship activities.

2 Background

Artificial Intelligence (AI) is a field that has been growing rapidly and is an interdisciplinary branch of computer science that focuses on creating machines that can perform tasks that would reflect human intelligence levels. The goal of AI is to emulate human brain operations and to create machines that can learn from similar experiences, reason about complex problems, and interact with humans in a natural way. AI has emerged as a transformative technology with the potential to revolutionize various aspects of human life.

```
initialize_kb() {
    // Initialize knowledge base with relevant mathematical axioms and
    theorems
}

prove_theorem(goal) {
    if (goal is already known) {
        return true; // The theorem is already proven
    }

    // Apply rules of inference and search for a proof path
    proof_path = search_for_proof(goal);

    if (proof_path exists) {
        return true; // The theorem is proven
    } else {
        return false; // Unable to prove the theorem
    }
}

search_for_proof(goal) {
    // Use symbolic logic rules to manipulate symbols and search for a proof
    path
    // Depth-first search, backtracking, and other techniques may be employed
    // Explore possible proof paths to reach the goal
}
```

Fig. 1. The IBM 704 Pseudo-code sample

Artificial intelligence has evolved significantly since its inception, with machine learning, neural networks, and natural language processing at its forefront. The field has increasingly been integrated into various applications, with challenges and opportunities ahead. Understanding AI's historical context, core concepts, and current applications is vital to appreciate its significance and future

potential. The origins of AI can be traced back to the 1950s, when researchers began exploring the possibility of creating machines that could think like humans. The term “artificial intelligence” was coined by John McCarthy in 1956, and, in the early days of AI research, the focus was on creating machines that could perform tasks such as playing chess or solving mathematical problems. However, as the field has evolved, researchers have begun to explore more complex problems such as natural language processing and image recognition. Over the years, AI has seen several ups and downs, known as AI winters. However, the field made significant progress with the advent of machine learning in the 21th century.

One of the foundational contributions to early AI was the development of the Logic Theorist, a pioneering system created by Allen Newell, J.C. Shaw, and Herbert A. Simon in 1956. The Logic Theorist aimed to mimic human problem-solving skills and, notably, could prove mathematical theorems. The Logic Theorist’s code, implemented in the assembly language of the IBM 704 computer, utilized symbolic logic and rules of inference to manipulate symbols and derive mathematical proofs, as shown in Fig. 1 a simplified pseudo-code, where **initialize_kb()** initializes the knowledge base (KB) with mathematical axioms and theorems, **prove_theorem(goal)** checks if the specified theorem (goal) is already known in the knowledge base and returns true (theorem proven) if known or calls **search_for_proof** to attempt to find a proof path if not known, **search_for_proof(goal)** explores possible proof paths to establish the validity of the theorem (goal), using symbolic logic rules and search algorithms, e.g., depth-first search, backtracking, returning true if a valid proof path is found (theorem proven) or false if no proof path is found (unable to prove the theorem). The **Main Program** calls **initialize_kb** to set up the initial knowledge base, specifies a theorem (**goal_theorem**) for proof, calls **prove_theorem** with the specified theorem, and prints a message based on the result of the proof attempt. The pseudo-code is a simplified representation and lacks specific details of symbolic logic rules and search algorithms. The Logic Theorist used heuristic search and symbolic reasoning for proof attempts. The actual code was written in the assembly language for the IBM 704, involving low-level computer architecture details.

3 Core Concepts of Artificial Intelligence

3.1 Machine Learning

Machine learning is a cornerstone of AI, involving the development of algorithms and models that enable computers to learn from data and make predictions or decisions. Supervised learning, unsupervised learning, and reinforcement learning are major subfields of machine learning. The key concepts in machine learning are given as:

- i. **Data:** Machine learning relies on dataset, containing examples of the problems, that the machine learning models to solve. The dataset should include both the input data (features) and the desired output (labels or targets).
- ii. **Features:** They are the characteristics or attributes of data that the machine learning model will use to make predictions. Features can be numerical, categorical, or text based.

- iii. **Model:** A machine learning model is a mathematical representation of the relationship between the input features and the target output and it is the core component of a machine learning system. There are various types of models, such as linear regression, decision trees, neural networks, etc.
- iv. **Training:** Training a machine learning model involves feeding it the dataset and adjusting the model's internal parameters to make it better at making predictions. This process is typically done by minimizing a certain loss or error function.
- v. **Testing and Validation:** After training, the model is evaluated using a separate dataset (validation or test data) to assess its performance and generalization to new, unseen data.
- vi. **Prediction:** Once the model is trained and validated, it can be used to make predictions or classifications on new, unseen data.

```

import numpy as np
from sklearn.linear_model import LinearRegression

# Sample data
bedrooms = np.array([1, 2, 3, 4, 5])
prices = np.array([100, 150, 200, 250, 300])

# Create a linear regression model
model = LinearRegression()

# Reshape the data (needed for 1D input)
bedrooms = bedrooms.reshape(-1, 1)

# Train the model
model.fit(bedrooms, prices)

# Make predictions
predicted_prices = model.predict(np.array([[2.5]]))
print("Predicted price for 2.5 bedrooms:", predicted_prices[0])

```

Fig. 2. An Example Code for Machine Learning

learning model from the scikit-learn library that is desired to be used in this demonstration. Two variable arrays are created, i.e., **bedrooms** and **prices**, which represent the sample data, where **bedrooms** contains the number of bedrooms in houses and **prices** contains the corresponding prices of those houses. A linear regression model is desired and is created. A linear regression **model** tries to find a straight line, i.e., a “linear” relationship, that best fits the data and that offer superior predictions. The **reshape** operation is used to change the shape of the **bedrooms** array. This conversion is necessary because the **LinearRegression** model expects the input data to be a 2D array. By using **reshape(-1, 1)**, a 1D array, i.e., a list of numbers, is converted into a 2D array with one column and this conversion is a common step when working with scikit-learn models. The model is “trained” by using the dataset as training means teaching the model to find the best-fitting line that relates the number of bedrooms to the prices in our data. The **fit** method makes the model learn from dataset. Then, the trained model is used to make predictions, i.e., the number of bedrooms, e.g. 2.5 in

Figure 2 shows a simple example in Python using the popular scikit-learn library to create a linear regression model for predicting house prices based on the number of bedrooms. Necessary libraries are imported first. **Numpy** is a library for numerical operations and **LinearRegression** is a machine

this example, is given to the trained model that predicts the price that is stored in the **predicted_prices** variable.

3.2 Neural Networks

Neural networks are a class of machine learning models inspired by the structure and function of the human brain and are used for a wide range of tasks, including image and speech recognition, natural language processing, etc. Neural network structures are composed of interconnected nodes, called neurons, organized into multiple layers. These neurons in a particular network topology operate together to process and learn from the training dataset. A high-level overview of the key components of neural networks:

- i. **Neurons (Nodes):** Neurons are the basic building blocks of neural networks. Each neuron takes inputs, processes them according to the neuron mathematical function, and produces an output. In the context of artificial neural networks, the processing typically involves applying a weighted sum of inputs and then passing the result through an activation function.
- ii. **Layers:** Neurons are organized into layers in different network topologies. There are typically three types of layers in a neural network, with varying number of neurons:
 - a. **Input Layer:** This layer receives the initial data or features as inputs.
 - b. **Hidden Layers:** These potentially multiple layers, as the name suggests, are hidden in between the input and output layers and they perform the actual computation and transformation of data.
 - c. **Output Layer:** This layer produces the final output of the network, which could be a classification, regression, or any other type of prediction.
- iii. **Weights and Biases:** Each connection between neurons has an associated weight, which determines the strength of the connection. Additionally, each neuron has a bias term that helps adjust the output. These weights and biases are determined, i.e., learned, during the training process.
- iv. **Activation Function:** The activation function introduces mathematical operations, possibly non-linearity, into the network and common activation functions include the sigmoid, ReLU (Rectified Linear Unit), sigmoidal, tanh (hyperbolic tangent), or linear types. The activation functions receive the weighted sum of inputs and bias components and determines the neuron's output.
- v. **Training:** Neural networks are mostly trained using a process called backpropagation, in which, the network is fed with the input dataset, and the error between the predicted network output and the actual real output is calculated. This error and related error gradient are then propagated backward through the network components, adjusting the weight and bias terms to minimize the overall network error.

```

import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import layers

model = keras.Sequential(
    [
        layers.Dense(2, activation="relu", name="layer1"),
        layers.Dense(3, activation="relu", name="layer2"),
        layers.Dense(4, name="layer3"),
    ]
)
x = tf.ones((3, 3))
y = model(x)

print(y)

```

Fig. 3. An Example Code of Neural Networks

and **keras** is a high-level API for building and training neural networks on top of **tensorflow**. Then, a neural network model is defined. This model is a sequential model, indicating that layers can be added in a linear stack. The model has the following layers: the assigned “layer1” including the first hidden layer with 2 neurons (units) and ReLU (Rectified Linear Unit) activation function, the assigned “layer2” including the second hidden layer with 3 neurons and ReLU activation, and the assigned “layer3” including the third layer with 4 neurons with no specific activation function, i.e., it will be default linear activation. A 3x3 NumPy array with all ones is created as the input data (**x**) that will be passed through the neural network for predictions. With the model defined, it can be used to make predictions by simply passing the input data (**x**) to the model. This line applies the model to the input data and stores the output in the variable **y**, with expected level of accuracy, after training. Then, the model is applied with a new input data to evaluate the corresponding outputs for the accurate and satisfactory generalization ability that is vital for real-life systems.

Figure 3 is an example of a simple feedforward neural network in Python using the popular deep learning framework, TensorFlow. This code creates a neural network with 3 layers, i.e., 2 hidden layers with ReLU activation functions and 1 output layer. The code imports **tensorflow** and specific modules from **keras**. **Tensorflow** is a deep learning framework

3.3 Natural Language Processing (NLP)

NLP focuses on enabling computers to understand, generate, and interact with human language. This approach is pivotal in applications such as chatbots, translation, and sentiment analysis. Key concepts in NLP are summarized below:

- i. **Tokenization:** it is the process of breaking text into individual words or “tokens”. This step is a fundamental step in NLP, allowing computers to work with discrete units of text.
- ii. **Text Preprocessing:** Cleaning and preprocessing text data are essential. This step can include removing stop words, punctuation, and lowercasing words.
- iii. **Text Classification:** NLP can be used for text classification tasks such as sentiment analysis, where the sentiment of a piece of text can be determined, e.g., positive, negative, or neutral.
- iv. **Named Entity Recognition (NER):** NER is the process of identifying and classifying entities in text, such as names of people, organizations, locations, etc.

v. **Language Translation:** NLP can be used for language translation, such as converting text from one language to another using machine translation models like Google Translate API or the **translate** library.

```

from nltk.corpus import stopwords
from nltk.tokenize import word_tokenize
import string

# Sample text
text = "Text preprocessing is essential for NLP tasks!"

# Tokenize the text
tokens = word_tokenize(text)

# Remove stop words and punctuation
stop_words = set(stopwords.words('english'))
filtered_tokens = [
    word.lower() for word in tokens if word.lower() not in stop_words
    and word.lower() not in string.punctuation
]

# Print the preprocessed text
print("Original Text:", text)
print("Preprocessed Text:", ' '.join(filtered_tokens))

```

Fig. 4. An Example Code of Text Processing

The NLP concepts can be explained further in the example code in Python, shown in Fig. 4. These are just some of the many applications and concepts within NLP that is a rapidly evolving field, and many advanced models and techniques have been developed, including Transformer-based models such as BERT, GPT, etc., which have achieved state-of-the-

art results in various NLP tasks. The **nltk.corpus** provides access to the NLTK corpus, which includes stopwords. **Nltk.tokenize** includes the **word_tokenize** function for tokenization. **Word_tokenize(text)** tokenizes the input text into a list of words (tokens). **Stopwords.words('english')** retrieves a set of English stopwords. The list comprehension **filtered_tokens** removes stopwords and punctuation from the tokenized list, converting all words to lowercase.

3.4 Computer Vision

Computer vision involves teaching machines to interpret and understand visual information. Object recognition, facial recognition, and autonomous vehicles are some of the common applications. Key concepts in computer vision are summarized below:

- i. **Image Acquisition:** Computer vision typically starts with the acquisition of images or video frames. This step can be done using various devices such as cameras or sensors.
- ii. **Preprocessing:** Before analysis, images are often preprocessed to enhance their quality. Common preprocessing steps include resizing, noise reduction, and image enhancement.
- iii. **Feature Extraction:** In computer vision, it is typically needed to identify important features in the images, such as edges, corners, textures, or other patterns. Feature extraction is crucial for many computer vision tasks.
- iv. **Image Recognition:** This step is the task of classifying or identifying objects or patterns within an image. Convolutional Neural Networks (CNNs) are commonly used for image recognition tasks.

4 Methodology in AI Research

AI research involves several key methodologies, including data collection, algorithm development, and evaluation.

4.1 Data Collection

AI research often begins with the collection of large and diverse datasets, which are used to train and test machine learning models. This data can come from various sources, including sensors, the internet, and human annotations and its accuracy is vital.

4.2 Algorithm Development

Researchers design and implement algorithms that enable AI systems to process and analyze data. This step may involve developing novel machine learning architectures or adapting existing ones to specific tasks.

4.3 Evaluation

AI models and systems are rigorously evaluated using metrics that are task-specific. Common evaluation metrics include accuracy, precision, recall, F1-score, and mean squared error, depending on the nature of the problem.

5 Contemporary AI Applications

AI is currently being applied across various domains, including healthcare, e.g., diagnosis and drug discovery, finance, e.g., algorithmic trading and fraud detection, and autonomous vehicles. Furthermore, AI is being integrated into daily life through virtual assistants like Siri and Alexa.

5.1 Desktop AI

Desktop AI refers to the integration of artificial intelligence capabilities into personal computers and can include:

- **Speech Recognition:** AI systems can transcribe spoken language into text and execute voice commands.
- **Image and Video Processing:** AI algorithms can be used for image and video analysis, object recognition, and content generation.
- **Personal Assistants:** Virtual personal assistants like Apple's Siri, Microsoft's Cortana, and Google Assistant are AI-driven applications that provide natural language understanding and responses.

5.2 Server AI

AI on servers involves the use of artificial intelligence in data centers and cloud computing environments. Key points to consider include:

- **Big Data Analytics:** AI algorithms are used for processing and deriving insights from vast amounts of data.
- **Deep Learning:** Server-based AI often involves training deep neural networks for tasks such as image recognition, natural language processing, and recommendation systems.
- **Scalability:** Servers need to be scalable to accommodate increasing workloads and data processing demands.
- **Energy Efficiency:** Power consumption is a significant concern and AI server systems aim for energy-efficient designs.

5.3 Social Assistants (e.g., Siri)

Social assistants are AI-driven personal voice-activated assistants that interact with users through natural language. For instance, Siri is Apple's virtual assistant. Key points include:

- **Natural Language Processing (NLP):** Social assistants rely on NLP to understand and generate human language.
- **Speech Recognition:** They use AI to convert spoken language into text for processing.
- **Internet of Things (IoT) Integration:** Many social assistants are integrated into smart devices and can control IoT devices in homes, offices, etc.
- **Privacy and Security:** Privacy concerns are paramount as these assistants handle personal data and voice recordings.

6 Challenges and Future Directions

AI is a very broad and diverse field that encompasses many subfields, applications, and disciplines and faces some of the common challenges:

- a. **Ethical and social implications:** AI has the potential to impact many aspects of human society, such as privacy, security, fairness, accountability, transparency, and human dignity. AI systems should be designed and deployed in a way that respects and protects these values, and that minimizes the risks of harm, misuse, or abuse. AI developers and users should also be aware of the ethical and social implications of their work and engage with relevant stakeholders and communities to ensure that AI is aligned with human interests and values.
- b. **Data quality and availability:** AI systems rely on large amounts of data to learn and perform various tasks. However, not all data are equally reliable, relevant, or representative. Data quality and availability are crucial for ensuring the accuracy, robustness, and generalizability of AI systems. AI developers and users should ensure that the data they use is of high quality, and that they are collected, stored, and processed in a secure and ethical manner. They should also seek to diversify and augment their data sources, and to address the issues of data scarcity, bias, and imbalance.

- c. **Explainability and interpretability:** AI systems are often complex and opaque, making it difficult to understand how they work, why they make certain decisions, and what their limitations are. Explainability and interpretability are important for building trust, confidence, and accountability in AI systems, especially when they are used in high-stakes or sensitive domains, such as health care, education, or justice. AI developers and users should strive to make their AI systems more explainable and interpretable, by providing clear and meaningful information about their inputs, outputs, processes, and outcomes. They should also enable human oversight and intervention and provide mechanisms for feedback and correction.
- d. **Scalability and efficiency:** AI systems are often computationally intensive and resource-demanding, requiring large amounts of time, energy, and hardware to run and maintain. Scalability and efficiency are important for enabling the widespread adoption and deployment of AI systems, and for reducing their environmental and economic costs. AI developers and users should seek to optimize their AI systems, by using more efficient algorithms, architectures, and hardware, and by leveraging techniques such as distributed computing, cloud computing, and edge computing.
- e. **Collaboration and coordination:** AI systems are increasingly interacting and collaborating with other AI systems, as well as with humans and other agents. Collaboration and coordination are important for enhancing the performance, functionality, and diversity of AI systems, and for enabling them to achieve complex and collective goals. AI developers and users should design and implement their AI systems in a way that facilitates and supports collaboration and coordination, by using standards, protocols, and interfaces, and by ensuring compatibility, interoperability, and complementarity.

Some of the future directions that AI is likely to pursue are:

- a. **Human-centered AI:** AI systems that are designed and developed with human needs, preferences, and values in mind, and that aim to augment and empower human capabilities, rather than replace or surpass them. Human-centered AI systems should be user-friendly, accessible, inclusive, and adaptable, and should respect and protect human rights, dignity, and autonomy.
- b. **Artificial general intelligence (AGI):** AI systems that can perform any intellectual task that a human can, across multiple domains and contexts, and that can reason, learn, and understand at or above human levels. AGI systems should be able to transfer and generalize their knowledge and skills, and to exhibit creativity, curiosity, and self-awareness.
- c. **Artificial superintelligence (ASI):** AI systems that can surpass human intelligence and capabilities in all aspects, and that can achieve goals and outcomes that are beyond human comprehension or imagination. ASI systems should be aligned with human values and interests and should be controlled and regulated in a safe and ethical manner.
- d. **Artificial emotional intelligence (AEI):** AI systems that can recognize, understand, and express emotions, and that can empathize and interact with humans and other agents in an emotionally appropriate and intelligent way. AEI systems should be able to adapt to different emotional states and contexts, and to provide emotional support and feedback.

- e. **Artificial creativity (AC):** AI systems that can generate novel and valuable ideas, products, or solutions, and that can exhibit originality, imagination, and innovation. AC systems should be able to evaluate and improve their own creations, and to collaborate and communicate with humans and other agents in creative processes.

7 Conclusions

Artificial intelligence basics, related machine learning, neural networks, natural language processing, and computer vision fields, associated research components, and important contemporary challenges and respective potentials have been investigated and successfully implemented in the proposed undergraduate student research-teaching educational model for underprivileged student population. The qualitative and quantitative evaluations, by the instructor, demonstrated the viability of the combined research-teaching model. The current research has been on the computer architecture components for artificial intelligence accelerators and aims to explore various organizational implementations and architectural challenges.

Future research directions include investigating superior conceptualization of relevant processes as well as underlying dynamics in more challenging educational environments and optimizing corresponding training as well as learning performance levels.

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A Review of Generative AI in Computer Science Education: Challenges and Opportunities in Accuracy, Authenticity, and Assessment

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Abstract. This paper surveys the use of Generative AI tools, such as ChatGPT and Claude, in computer science education, focusing on key aspects of accuracy, authenticity, and assessment. Through a literature review, we highlight both the challenges and opportunities these AI tools present. While Generative AI improves efficiency and supports creative student work, it raises concerns such as AI hallucinations, error propagation, bias, and blurred lines between AI-assisted and student-authored content. Human oversight is crucial for addressing these concerns. Existing literature recommends adopting hybrid assessment models that combine AI with human evaluation, developing bias detection frameworks, and promoting AI literacy for both students and educators. Our findings suggest that the successful integration of AI requires a balanced approach, considering ethical, pedagogical, and technical factors. Future research may explore enhancing AI accuracy, preserving academic integrity, and developing adaptive models that balance creativity with precision.

Keywords: Generative AI · Computer Science Education · AI Accuracy · AI Authenticity · AI Assessment

1 Introduction

With the rise of ChatGPT and large language models, a student in today's classroom can sit at their computer, not just writing code but co-developing

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it with an AI partner—a virtual assistant that suggests code snippets, refines algorithms, and troubleshoots errors. The lines between what the student creates and what the AI generates become blurred. How, then, do we ensure that the student is truly mastering the core concepts of programming? Are the algorithms being created as accurate as they appear? And most critically, how do we assess a student's progress in an educational environment where AI can both aid and overshadow the human creative process? These questions represent real challenges in today's computer science education, where concerns about AI's accuracy, authenticity, and assessment are no longer just emerging but are core issues shaping the integration of generative AI (GenAI) into the classroom.

Unlike traditional AI systems that analyze existing data to predict outcomes, Generative AI uses deep learning algorithms to generate new content, such as text, images, and code, to assist and enhance educational activities. By leveraging the ability of GenAI to generate, refine, and troubleshoot code, students can use AI models to explore creative solutions, receive instant feedback, and benefit from personalized learning. Tools like ChatGPT [1] and Claude [2] exemplify this shift by providing real-time assistance that enhances the learning experience. Retrieval-Augmented Generation (RAG) [3] is often used to add context to the large language model (LLM) based on course materials, instructor instructions, and conversation history. It is a proven approach that allows AI systems to offer better explanations and context-aware tutoring.

However, the accuracy of AI-generated content is not guaranteed, particularly when dealing with novel problems or edge cases, complicating the learning process [4,5]. Moreover, GenAI introduces concerns about the authenticity of student work. How can educators ensure that the solutions reflect the student's understanding rather than the AI's output? Educators must therefore redefine assessment frameworks to evaluate both AI-supported and independent work fairly, which requires a nuanced understanding of the interaction between technology and pedagogy [6,7].

In the context of computer science education, GenAI tools provide exciting opportunities for enhancing efficiency and creativity in teaching foundational skills such as coding, computational thinking, and problem-solving. However, the accuracy of AI-generated solutions remains a significant concern, as AI hallucinations can lead to incorrect or irrelevant information, but students may lack the knowledge to fact-check AI responses. GenAI also raises concerns about authenticity, where it is unclear whether students are truly learning to solve problems independently or relying on AI-generated solutions. Additionally, the auto-generation of assignments complicates the learning environment and raises questions about the depth of student engagement [8,9]. These emerging shifts in AI use in computer science teaching and learning pose challenges for traditional assessment methods like exams or project-based evaluations, which may no longer suffice in measuring student comprehension and skill development [10,11]. From a teacher's perspective, AI-generated content can seamlessly blend with human effort, raising concerns about the authenticity of student work. This blending also complicates the verification of accuracy, particularly in complex

programming scenarios, requiring new levels of scrutiny from educators [12, 13]. As a result, designing assessment frameworks that reflect individual student skills while accounting for AI support becomes an increasingly complex task [14, 15].

This survey synthesizes recent research on GenAI in computer science education, focusing on the themes of accuracy, authenticity, and assessment. While many studies have explored these themes individually, there is a notable gap in the literature regarding their interconnection and integration. By examining how these three issues interact, this paper seeks to provide a better understanding of how GenAI can transform teaching and learning in computer science. Additionally, this study summarizes areas for further research [4, 5].

While this study focuses on accuracy, authenticity, and assessment, these themes are part of a broader and ongoing discussion about GenAI's impact on education. We aim to explore the relationship between AI technologies and the evolving educational landscape, particularly within computer science. The goal is to highlight both the transformative potential and the significant challenges these technologies introduce into teaching and learning processes [16, 17], fostering a more informed approach to their integration in computer science curricula [18, 19]. Other critical considerations, such as ethical implications, student engagement, and the development of new technical literacies, also demand attention. We propose these as areas for future work.

2 Literature Review

We reviewed 52 papers published between 2019 and 2024, sourced from academic databases such as IEEE Xplore, ACM Digital Library, and SpringerLink. These studies were categorized into three primary themes: accuracy, authenticity, and assessment. Most of the papers focused on accuracy, particularly addressing AI hallucinations and bias, while fewer discussed the challenges of assessment in AI-driven educational settings.

2.1 Accuracy

The accuracy of generative AI (GenAI) in computer science education has garnered significant attention as educators and researchers strove to incorporate AI technologies into learning environments. Accuracy is crucial for generating reliable content, offering effective educational feedback, and supporting student learning. However, there were significant concerns about AI hallucinations (i.e., the generation of factually incorrect or nonsensical information), error propagation (i.e., when initial mistakes persist and compound in subsequent outputs), bias, and the delicate balance between creativity and precision.

Implications of AI Hallucination and Error Propagation for Accuracy. AI hallucinations and error propagation were central issues in the adoption of

GenAI models in CS education, particularly when AI-generated outputs accumulated inaccuracies over time. AI hallucinations referred to instances where AI systems produced incorrect or nonsensical information with high confidence. Wu et al. [20] highlighted the prevalence of hallucinations, reporting that 53% of the errors in their study were classified as hallucinations, which could mislead both students and educators.

Hallucinations compromised the reliability of AI-generated content, leading to concerns about student learning outcomes. For instance, Butler [21] noted that hallucinations detracted from the overall quality of AI-generated reports, potentially eroding trust in AI tools as educational aids. These errors could accumulate over time, propagating through multiple layers of content generation and significantly affecting the educational process.

Prather et al. [22] reinforced these concerns, particularly for novice learners, who might not yet have had the skills to critically assess AI-generated outputs. Lin et al. [23] further noted that models trained on biased or incomplete datasets often generated erroneous content, complicating the learning process. Becker et al. [24] offered a counterpoint, suggesting that robust feedback systems could mitigate the effects of error propagation by allowing students to cross-reference AI outputs with reliable sources.

Sharun [25] proposed that improving the diversity and quality of training datasets was a crucial step toward reducing hallucinations and enhancing the accuracy of AI systems. Additionally, Aditya [26] emphasized the role of human-in-the-loop (HITL) systems, where human oversight was integrated into the AI output generation process to provide real-time corrections and ensure accuracy. This approach aligned with the need to reduce error propagation and mitigate the negative impact of hallucinations in educational settings.

Challenges and Mitigation Strategies of Bias. Bias in AI-generated content was another critical issue affecting accuracy. Mahaini [27] discussed how GenAI tools, while adept at solving complex programming tasks, often introduced biases that could distort accuracy, particularly in assessments. This bias could disproportionately impact students from diverse backgrounds, as biased models might overlook cultural or contextual differences in problem-solving approaches. Emenike and Emenike [28] argued that reliance on biased AI-generated assessments could exacerbate educational inequalities.

To address these challenges, Gupta et al. [29] proposed hybrid models that combined human oversight with AI-generated content to enhance accuracy and mitigate bias. Walter [30] emphasized the importance of AI literacy and critical thinking, enabling students and educators to recognize and correct biased outputs. These strategies underscored the essential role of human involvement in addressing the challenges posed by bias in AI-generated content.

Challenges in Measuring and Evaluating Accuracy. Measuring and evaluating the accuracy of AI-generated content posed ongoing challenges. Francisco and Silva [31] pointed out that current accuracy metrics often failed to account

for the contextual nature of educational tasks, where solutions might not be strictly right or wrong. Similarly, Chan and Hu [32] suggested that traditional metrics focusing solely on error rates overlooked the broader educational value of AI-generated content. Becker et al. [24] proposed a holistic approach to accuracy, where metrics encompassed not only the correctness of the output but also how well AI-generated content supported learning goals. Liu [33] proposed hybrid metrics that combined traditional accuracy measures with qualitative assessments of student engagement and problem-solving skills, offering a more comprehensive picture of AI's educational effectiveness.

Creativity vs. Accuracy: A Careful Balance. The trade-off between creativity and accuracy was another common concern. Pack and Maloney [34] noted that while GenAI was celebrated for its creative solutions, this creativity often came at the expense of accuracy. In computer science education, where precise solutions were paramount, this trade-off could hinder learning. Francisco and Silva [31] advocated for a balance between creativity and accuracy, suggesting the implementation of context-aware AI systems that adjusted their outputs based on the task. For instance, while creative solutions might be encouraged in brainstorming exercises, accuracy should take precedence in tasks requiring code generation.

Zastudil et al. [35] cautioned that an overemphasis on accuracy might stifle creativity, particularly in fields like computing where innovation was crucial. They argued that students should be encouraged to experiment with AI-generated outputs, even if these were not always accurate, as such experimentation fostered deeper engagement and problem-solving skills. This highlighted the ongoing discussion of promoting creativity while maintaining accuracy in AI-generated content.

Proposed Solutions for Improving Accuracy. Several strategies had been proposed to enhance the accuracy of GenAI models in computer science education. Kung et al. [36] suggested that improving the diversity and quality of training datasets could significantly enhance model accuracy, particularly in coding tasks where precision was essential. Incorporating diverse datasets helped AI models generate outputs that were less prone to errors and biases. Liu [33] advocated for employing reinforcement learning techniques to fine-tune AI models for educational purposes, allowing models to learn from their mistakes and improve accuracy over time. This aligned with the findings of Lee and Song [37], who emphasized the role of iterative feedback in refining AI-generated outputs, particularly in programming tasks.

Human-AI interaction was crucial for improving accuracy. Mahaini [27] argued that while AI tools could generate highly accurate content, their effectiveness was enhanced when used in conjunction with human oversight. Educators could provide contextual understanding and correct errors, thereby improving the overall quality of AI-generated outputs. Walter [30] emphasized the importance of AI literacy among educators and students, suggesting that

informed users could guide AI inputs and interpret outputs more effectively, thus enhancing accuracy. However, Lee and Song [37] cautioned against over-reliance on human intervention, noting that AI models should be designed to operate as accurately as possible independently, to avoid overburdening educators.

Future Research Directions. Despite advancements in improving accuracy, several research gaps persisted. One significant gap was the lack of longitudinal studies examining the long-term impact of AI-generated inaccuracies on student learning outcomes. Chan and Hu [32] noted that while short-term studies demonstrated the benefits of GenAI in education, little was known about how inaccuracies in AI-generated content affected students' academic performance over time. Additionally, the development of bias detection and mitigation techniques for AI-generated assessments remained underexplored. While some strategies, such as those proposed by Gupta et al. [29], aimed to reduce bias, comprehensive frameworks were needed to integrate these techniques into educational systems effectively.

The balance between creativity and accuracy also required further investigation. Adaptive AI models that dynamically adjusted between fostering innovation and maintaining precision based on task requirements had been proposed, but empirical work was needed to refine these approaches. Furthermore, developing nuanced metrics to evaluate accuracy beyond simple error rates would provide educators with better insights into how AI-generated content impacted student learning.

Summary of GenAI Accuracy. Table 1 summarizes key findings on the theme of accuracy in generative AI for computer science education.

2.2 Authenticity

The theme of authenticity in the context of GenAI within computer science education has gained prominence as AI-generated outputs become increasingly prevalent. Key concerns revolve around the originality of student work, the ethical implications of AI-generated content, and the challenges educators face in distinguishing between human-authored and AI-generated submissions. This review synthesizes key findings from the literature, exploring how the integration of GenAI affects the authenticity of student work in educational settings.

AI-Generated Content and Challenges to Student Authorship. A primary concern is the risk of students presenting AI-generated content as their own, raising issues of authorship and academic integrity. Prather et al. [24] argued that as tools like ChatGPT evolved, differentiating between human-authored and AI-generated work became increasingly difficult, particularly in coding assignments where correctness is paramount. Becker et al. [24] suggested that the accessibility of AI-generated code diminished the authenticity of student

Table 1. Key Findings on Accuracy in Generative AI for Computer Science Education

Challenges	Ref. Cited	Opportunities
AI hallucinations can mislead students and educators, undermining content reliability.	[21–23, 26]	Conduct long-term studies on the cumulative effects of AI hallucinations on learning outcomes.
Error propagation amplifies inaccuracies, especially in AI-assisted programming.	[23–25, 27]	Developing real-time mitigation strategies for error propagation, particularly benefiting novice learners.
Bias in AI affects the accuracy of assessments, particularly for diverse student groups.	[28–30]	Development frameworks for bias detection and mitigation in AI-driven assessments.
Creativity vs. accuracy trade-off in AI-generated content hinders precision in coding tasks.	[32–34]	Explore adaptive models that dynamically balance creativity and accuracy in AI systems.
Human-in-the-loop (HITL) systems improve AI accuracy and support real-time corrections.	[25, 27, 30, 31]	Scaling HITL models for large educational contexts.
AI struggles with adapting to educational contexts where correctness is subjective, highlighting the need for holistic accuracy measures.	[32–34]	Developing AI metrics that better capture the contextual nature of educational tasks.

submissions. Lin et al. [23] noted that students may unintentionally incorporate AI-generated outputs into their work, blurring the line between original thought and AI assistance, which could hinder the development of critical thinking and problem-solving skills. Conversely, Zastudil et al. [35] acknowledged that AI tools could enhance learning by providing immediate feedback but emphasized the need for clear guidelines to prevent misuse.

Ethical Concerns Surrounding AI-Generated Content. Ethical considerations regarding AI-generated content are central to discussions about authenticity. Emenike and Emenike [28] highlighted that AI-generated content, particularly in written assignments, posed significant challenges for educators in assessing genuine student engagement. Over-reliance on AI tools may have diminished students' ability to produce original work. Gupta et al. [29] emphasized the difficulty of detecting AI-generated text, noting that traditional plagiarism detection

tools often failed to recognize it. They advocated for institutions to invest in AI-detection technologies to uphold academic integrity. Francisco and Silva [31] adopted a more optimistic perspective, arguing that AI could be used ethically if students were transparent about its usage, framing AI as a learning aid rather than a substitute for original work.

The Sociotechnical Perspective on AI Authenticity. Addressing the ethical implications of AI-generated content and authorship in education requires a sociotechnical perspective, where the interaction between social dynamics and technological tools is key to understanding authenticity issues. In computer science education, AI tools like ChatGPT and GitHub Copilot present unique challenges to the authenticity of student work, raising concerns about academic integrity and necessitating a holistic approach.

The authenticity of student work is increasingly questioned as AI tools generate text and code. Reliance on AI tools like ChatGPT can lead to reduced emphasis on original thought, with some researchers warning that such tools might affect creativity and critical thinking skills [38]. Educators must design assignments that promote deeper engagement and critical thinking, moving beyond tasks easily completed by AI [38].

The ethical implications of authorship are complex, as AI blurs the lines between student-authored and AI-generated content. This raises concerns about plagiarism and academic integrity [39, 40]. Clear guidelines are essential to ensure students understand how to responsibly use AI, including educating them about AI's limitations and the consequences of over-reliance [38, 41, 42].

A sociotechnical approach can help educators distinguish between human and AI-generated content by leveraging AI's capabilities while preserving student work integrity. Assessment methods like oral presentations and reflective essays can ensure students demonstrate personal understanding [43, 44]. Integrating AI literacy into curricula can also empower students to use these tools responsibly [45].

Transparency and fairness are critical as AI tools become more prevalent in education. Students with limited access to technology may face disadvantages [46, 47], so educators must provide resources and training to ensure equitable access to AI technologies [46]. Ethical considerations must guide AI's implementation, preparing students to navigate technology responsibly while maintaining academic integrity [48].

Summary of GenAI Authenticity. Table 2 summarizes key findings on the theme of Authenticity in generative AI for computer science education.

2.3 Assessment

The integration of GenAI in education has significantly transformed assessment practices, particularly within computer science. AI tools are increasingly employed for grading, providing feedback, and evaluating student performance,

Table 2. Key Findings on Authenticity in Generative AI for Computer Science Education

Challenges	Ref. Cited	Opportunities
AI blurs the line between student-authored and AI-generated work, raising academic integrity concerns.	[23–25, 39, 43, 44]	Develop clear policies to distinguish AI-assisted work from student-authored work.
Ethical concerns arise due to the difficulty in detecting AI-generated content in student submissions.	[29–31, 41, 42]	Create better plagiarism detection tools and institutional guidelines to ensure academic integrity.
Sociotechnical approaches can help preserve authenticity in student work.	[45–49]	Explore a combination of sociotechnical approaches to promote authenticity.
Transparent use of AI tools, combined with AI literacy education, can help mitigate ethical concerns while preserving student engagement and creativity.	[30, 32, 36]	Opportunity for more empirical studies on the effectiveness of AI literacy programs.
Responsible use of AI supports learning without compromising authenticity.	[23, 24, 36]	Explore the balance between ethical AI usage and maintaining originality in student work.

streamlining the assessment process while raising concerns about fairness, reliability, and objectivity. This section reviews key discussions on the role of AI in assessment, offering a thematic analysis of its impact on computer science education.

AI-Driven Assessment Tools: Grading and Feedback. AI-driven grading tools have gained attention for their ability to automate grading and deliver timely feedback. Lin et al. [23] noted that these tools could provide real-time feedback on programming tasks, enabling students to correct mistakes as they worked, which was particularly beneficial in large classrooms where human grading was challenging. Prather et al. [22] emphasized that AI grading systems evaluated code for correctness and efficiency, alleviating the burden on educators during routine assessments.

However, Becker et al. [24] cautioned that AI-driven grading tools might struggle with complex or creative problem-solving tasks that required deeper contextual understanding. Francisco and Silva [31] argued that while AI effectively assessed straightforward coding tasks, it fell short in evaluating innovative algorithms or creative solutions. In contrast, Walter [30] suggested that AI

assessments enhanced objectivity and consistency by minimizing human biases, such as favoritism and fatigue.

Fairness, Objectivity, and Ethical Challenges in AI-Driven Assessments. A significant debate in the literature centered on the fairness and objectivity of AI-driven assessments. Zastudil et al. [35] expressed concerns that AI tools could perpetuate biases if trained on skewed data, leading to unfair evaluations. For instance, AI systems might favor specific coding styles based on their training data. Kung et al. [36] further highlighted that students from diverse backgrounds might face unfair assessments if AI tools were not trained on inclusive datasets.

Prather et al. [22] advocated for a hybrid approach that combined AI systems with human assessments to ensure both objectivity and nuanced judgment. This model balanced the strengths of AI evaluations with the contextual understanding human graders provided. However, Mahaini [27] emphasized that human oversight was crucial, particularly for summative assessments where creativity and critical thinking had to be evaluated.

Evaluation of AI-Generated Content: Metrics and Limitations. The limitations of traditional grading metrics in assessing AI-generated content were a major concern. Mahaini [27] noted that while AI systems excelled at evaluating code correctness, they struggled with assessing creativity and originality—key learning outcomes in computer science. González-Calatayud et al. [49] argued that metrics focused solely on correctness and efficiency failed to capture essential critical thinking and problem-solving skills.

Several authors, including Liu et al. [33], advocated for new assessment frameworks that evaluated both technical and creative aspects of student work. Becker et al. [24] suggested training AI systems to recognize diverse coding styles and problem-solving approaches to avoid penalizing students for innovative thinking.

Formative and Summative Assessment: The Role of AI in Supporting Learning. AI tools could enhance both formative and summative assessments. Lee [50] highlighted that AI could provide formative feedback throughout the learning process, helping students identify areas for improvement before final evaluations, thereby reducing pressure on summative assessments. However, Mahaini [27] cautioned against relying solely on AI for summative assessments, stressing the necessity of human judgment in evaluating creativity and critical thinking. Pack and Malone [34] also emphasized the importance of human involvement in assessing complex tasks, such as innovative coding projects, which might exceed the capabilities of AI-driven assessments.

Human-AI Collaboration in Assessments. There was a consensus that AI should complement, not replace, human involvement in assessments. Mahaini [27]

and Becker et al. [24] asserted that while AI could efficiently handle routine grading tasks, human oversight was essential for more complex evaluations, such as coding projects and creative problem-solving exercises. Francisco and Silva [31] proposed a hybrid assessment model where AI conducted an initial evaluation, followed by human review to ensure that the assessment accurately reflected the student's understanding and creativity. This model combined AI's efficiency with human insight, facilitating a more holistic evaluation process.

Research Gaps and Future Directions. Despite the growing body of literature on AI-driven assessments, several gaps remained. Notably, there was a lack of long-term studies examining the impact of AI-driven assessments on student learning outcomes. While short-term studies demonstrated the benefits of AI in providing timely feedback, limited research existed on how these tools affected students' development of critical thinking and problem-solving skills over time [22, 23].

Another significant gap was the impact of AI-generated feedback on student motivation. Gupta et al. [29] noted that while AI could provide instant feedback, its effectiveness in motivating students compared to human feedback remained unclear. Future research should explore how students perceive and respond to AI-generated feedback.

Additionally, more research was needed to ensure fairness, transparency, and objectivity in AI-driven assessments. Strategies for mitigating bias in AI systems, as discussed by Zastudil et al. [35] and Kung et al. [36], required further exploration. Addressing these research gaps was essential to ensure that AI-driven assessments enhanced the learning process while upholding educational integrity.

Summary of GenAI Assessment. Table 3 summarizes key findings on the theme of Assessment in generative AI for computer science education.

3 Discussion

This review highlights the significant opportunities and challenges posed by the integration of generative AI in computer science education, particularly in terms of accuracy, authenticity, and assessment. While AI tools such as ChatGPT and GitHub Copilot offer benefits like increased efficiency, real-time feedback, and creative assistance, they also introduce critical issues like AI hallucinations, error propagation, and biases. Ensuring the accuracy of AI-generated content remains a significant challenge, particularly for novice learners, where errors and biases could adversely affect learning outcomes. Moreover, the authenticity of student work is jeopardized by the blurring of lines between AI-assisted and student-generated content, raising concerns about academic integrity. To address these challenges, educators must implement hybrid assessment models that combine human judgment with AI tools, promote AI literacy, and develop

Table 3. Key Findings on Assessment in Generative AI for Computer Science Education

Challenges	Ref. Cited	Opportunities
AI-driven grading tools improve efficiency and provide timely feedback in large classes.	[19, 22, 27, 31]	Incorporate AI for evaluating creativity and problem-solving with human oversight.
AI grading enhances objectivity and consistency, reducing human biases such as favoritism.	[9, 31]	Improve AI training with diverse datasets to minimize bias in assessments.
Hybrid AI-human evaluation balances efficiency with nuanced judgment for complex tasks.	[3, 22, 27]	Develop scalable hybrid models for broader use in diverse educational contexts.
New frameworks are needed to evaluate both technical and creative aspects of student work.	[11, 21, 22]	Create comprehensive frameworks for assessing creativity and accuracy.
AI enhances formative assessments by providing real-time feedback to guide learning.	[9, 12, 17, 25]	Study long-term effects of AI-driven formative feedback on student learning outcomes.
Human oversight is essential for summative assessments requiring creativity and critical thinking.	[3, 22, 25]	Explore optimal combinations of AI and human input in summative assessments.

clear policies on the ethical use of AI. Future research should focus on refining AI systems to balance creativity with precision, enhance bias detection frameworks, and study the long-term effects of AI-generated inaccuracies on student learning.

Research Questions for Future Studies To address these gaps, future research could focus on the following questions:

- How does long-term exposure to AI-generated inaccuracies affect students' problem-solving abilities and coding skills?
- What strategies can be developed to more effectively detect and mitigate bias in AI-generated educational content?
- How can adaptive AI models be designed to balance the need for creativity and accuracy in different educational contexts?
- What are the ethical implications of using AI detection tools in academic assessments, and how can institutions ensure that these tools are used transparently and fairly?

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Large Language Magic: Conjuring the Future of Education with LLMs

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Abstract. In a world where technology often feels like a wand's flick away from sorcery, Large Language Models (LLMs) like ChatGPT are not just tools; they're the modern-day oracles, whispering the secrets of knowledge into the ears of those willing to listen. This paper explores LLMs as modern oracles, drawing parallels to ancient symbols of wisdom and examining their profound implications for teaching and learning. By simulating human-like comprehension and response, LLMs offer unprecedented opportunities for personalized education, adaptive content generation, language learning, research assistance, and creative development. Through a diverse and extensive training process on the corpus of human knowledge, these models embody humanity's collective wisdom, making them versatile and accessible tools in the educational landscape. However, with this transformative power comes a need for ethical guidance to ensure responsible usage, preserve human-centered learning, and foster digital literacy. This paper demystifies the capabilities of LLMs, positioning them as essential companions in the educational journey, blending technology and pedagogy to create a future where learning is both accessible and awe-inspiring.

Keywords: Large Language Model · LLM · Education · ChatGPT

1 Introduction: The Spell of Technology

Arthur C. Clarke famously stated, “Any sufficiently advanced technology is indistinguishable from magic [1].” As we stand on the precipice of the large language model (LLM) era, it’s amazing to exist in a world where words can “magically” summon knowledge, answer questions, and spark creativity. LLMs, or as we prefer to call them, Large Language Magic, are not just advancements in technology; they are the embodiment of the near magical potential that lies within our reach. This paper aims to demystify this magic, showing how it can be harnessed to revolutionize education.

The concept of magic has long fascinated humanity, representing the ability to transform reality through words and symbols. In the modern context, LLMs encapsulate this idea, transforming vast amounts of data into coherent, insightful responses almost instantaneously [2]. This transformation is akin to casting a spell, where complex algorithms and immense computational power combine to produce results that seem otherworldly. The resemblance to ancient magic is not merely poetic; it reflects a deeper truth about the nature of LLMs and their potential to enchant the educational landscape.

In the realm of education, the promise of LLMs is particularly compelling. Traditional educational methods, while effective, are often limited by the availability of resources and the individual attention a teacher can provide to each student. LLMs, with their ability to process and generate language at an unprecedented scale, offer a new paradigm. They can provide personalized tutoring, generate educational content, and assist with research, all while being available 24/7. This omnipresence and versatility make them invaluable tools for educators seeking to enhance their teaching methods and reach [3].

Consider the image of a classroom where every student has access to a personal oracle, capable of answering questions, providing tailored explanations, and suggesting further readings. This scenario is not a distant fantasy, but a tangible reality facilitated by LLMs. The technology behind these models is grounded in deep learning, a subset of artificial intelligence that mimics the way humans learn from experience. By training on vast datasets of human language, LLMs learn to understand and generate text in ways that are remarkably similar to human cognition [4].

2 The Oracle's Echo: LLMs as Modern-Day Prophets

Ancient oracles were revered sources of wisdom and guidance, believed to be the mouthpieces of the gods themselves. Fast forward to today, and we find our modern oracle: ChatGPT. Just as ancient seekers would approach the oracle with questions about their future, educators and students now approach ChatGPT with inquiries spanning the breadth of human knowledge. The parallel is uncanny; both oracles, ancient and digital, serve as bridges to greater understanding, providing insights that can shape the future.

3 The Sorcerer's Apprenticeship: Training LLMs with the Corpus of Human Knowledge

In the grand tapestry of technological magic, the training of LLMs is akin to an apprentice learning the arcane arts from a master sorcerer. These digital apprentices are not born with innate wisdom; they must be meticulously trained, absorbing the vast and varied knowledge of humanity through a process both intricate and profound.

Just as a wizard collects rare and powerful ingredients for their spells, the training of LLMs begins with the gathering of immense datasets composed of human knowledge. These datasets are vast compilations of text, drawn from books, articles, websites, and other textual sources. Each piece of text serves as a drop of wisdom, contributing to the creation of a model that can understand and generate human-like language.

The training of LLMs like ChatGPT relies on a diverse and extensive collection of texts to ensure a broad and nuanced understanding of language. This corpus includes literature from classic authors like William Shakespeare, Jane Austen, and Charles Dickens, as well as contemporary novels and stories that contribute to an understanding of current language usage, idioms, and slang. Non-fiction texts on history, science, philosophy, and other disciplines offer factual knowledge and domain-specific terminology. Academic journals and articles from fields such as physics, biology, computer science, history, sociology, and literature studies enrich the model with diverse analytical perspectives and theoretical frameworks.

Websites and online content form another substantial part of the knowledge base. Wikipedia provides a comprehensive and constantly updated source of general knowledge, while reputable news outlets like The New York Times, BBC, and The Guardian offer current events and journalistic styles. Blogs and opinion pieces contribute varied viewpoints and informal writing styles, helping the model understand personal and subjective expressions. Forums and community discussions on platforms like Reddit and Stack Exchange cover a myriad of topics, from niche hobbies to global issues, providing a rich tapestry of language use and knowledge exchange.

Social media platforms such as Twitter and Facebook are included to capture real-time updates, trending topics, popular culture, public sentiment, and detailed personal narratives. Legal documents and government publications, including laws, regulations, official reports, and texts from legal databases, help the model grasp formal legal language and structures. Technical manuals and documentation from platforms like GitHub, software companies, and product manuals are crucial for technical proficiency.

Ensuring diversity and balance in the corpus means including texts from different geographic regions and cultures, representing various socio-economic backgrounds and viewpoints, and incorporating both contemporary and historical texts. The result of this meticulous process is a comprehensive language model capable of understanding and generating human-like text across a multitude of contexts. By training on such a rich and varied corpus, LLMs like ChatGPT become powerful tools that can mimic the depth and breadth of human knowledge, making them invaluable in educational settings and beyond. By harnessing the vast expanse of human knowledge, LLMs are not just technological marvels; they are digital embodiments of humanity's collective wisdom, ready to assist, inform, and inspire.

4 The Alchemical Process: Training the Model

Once the textual ingredients are assembled, the alchemical process of training begins. This involves feeding the data into the model, allowing it to learn patterns, structures, and relationships within the language. The training process can be likened to the apprentice studying ancient tomes and practicing spells under the watchful eye of the master. Here, powerful algorithms serve as the guiding hand, using a two-phase process combining unsupervised and supervised learning, followed by fine-tuning through reinforcement learning from human feedback (RLHF) to refine the model's understanding.

5 The Alchemist's Toolbox: Transforming Pedagogy with LLMs

In the realm of education, teachers are akin to alchemists, striving to turn the lead of ignorance into the gold of knowledge. With the advent of LLMs, this process can be significantly accelerated and enriched. These models act as catalysts, augmenting traditional teaching methods with instant access to information, personalized learning experiences, and creative problem-solving tools. Imagine a classroom where every student has access to an oracle that can provide tailored explanations, answer complex questions in real-time, and even suggest further readings based on individual interests and needs [5].

6 Casting Spells: Practical Applications of LLMs in Education

6.1 Personalized Tutoring

LLMs have the potential to revolutionize tutoring by functioning as personal, on-demand tutors for students. These models can provide explanations, answer questions, and offer assistance tailored specifically to each student's learning pace, style, and level of understanding. This personalized approach can help bridge gaps in knowledge and ensure that no student is left behind. Unlike traditional classroom settings, where individualized attention is often limited due to time constraints and class sizes, LLMs can be available 24/7, offering continuous support that adapts to the unique needs of each learner [6].

6.2 Content Creation and Curation

Educators can leverage LLMs to generate and curate educational content, from quizzes and assignments to interactive lessons and projects. This not only saves time but also ensures that the material is current and relevant. These models offer educators innovative ways to evaluate student learning. However, the use of such technology also raises concerns about academic integrity and over-reliance on automated assessment tools. It is crucial that assessments continue to foster critical thinking and creativity, ensuring that students are not merely reproducing LLM-generated content but engaging deeply with the material.

6.3 Language Learning

For students learning new languages, LLMs have the potential to transform the way students learn by offering a wide range of personalized, interactive learning tools. One of the most valuable aspects of LLMs is their ability to simulate real-time conversations, providing students with practice that closely mirrors interactions with a native speaker. This immersion in natural dialogue allows students to develop fluency, improve pronunciation, and build confidence in using the language in various contexts, which is a key component of successful language acquisition. In addition to simulating real-life conversations, LLMs can provide cultural insights, helping students understand idiomatic expressions, slang, and cultural nuances that might be missed in a traditional classroom setting [7].

6.4 Research Assistance

LLMs offer significant advantages for students and researchers by streamlining the process of sifting through vast amounts of data, summarizing key findings, and even generating new hypotheses. By processing large datasets quickly, LLMs can extract relevant information from academic papers, articles, and other sources, reducing the time researchers spend on literature review. This allows them to focus more on analysis and interpretation. LLMs can also help summarize complex studies and synthesize disparate information, making it easier to identify trends, gaps, and potential research avenues. Additionally, LLMs can assist with hypothesis generation by analyzing existing research

and suggesting possible directions based on the patterns they detect. This can stimulate deeper academic inquiry by helping researchers explore new perspectives or uncover previously overlooked connections between ideas [8, 9].

6.5 Creative Writing and Critical Thinking

LLMs can play a transformative role in fostering both creativity and critical thinking among students. By offering tailored writing prompts, these models can spark imaginative thinking and help students overcome writer's block, providing an array of topics and styles that push learners beyond their comfort zones. Whether for fiction, poetry, or essay writing, LLMs generate ideas that inspire new approaches, encouraging students to explore diverse genres, perspectives, and voices. This dynamic generation of prompts helps students explore unconventional ideas, fostering innovation and creativity in their writing. In addition to generating prompts, LLMs can provide instant feedback on writing, helping students refine their work through suggestions on grammar, style, structure, and tone. This immediate response helps students develop a sharper awareness of their writing choices, encouraging them to critically evaluate their work and improve through iteration. Furthermore, LLMs can offer alternative perspectives on a given topic or argument, challenging students to consider new angles or counterpoints, thereby enhancing their critical thinking skills [10].

7 The Enchanter's Ethos: Ethical Consideration

With great power comes great responsibility. The integration of LLMs into education must be approached with a strong ethical framework. Issues such as data privacy, algorithmic bias, and the potential for over-reliance on technology need careful consideration. Educators must ensure that these tools are used to complement, not replace, human interaction and judgment. Furthermore, it's crucial to foster digital literacy among students, helping them to critically assess and effectively use the information provided by LLMs [11].

8 The Future Conjured: Envisioning Tomorrow's Classroom

Looking ahead, the potential for LLMs in education is boundless. As these models continue to evolve, they will become even more adept at understanding and responding to human queries, offering increasingly sophisticated support to both educators and students. We can imagine a future where classrooms are vibrant, dynamic spaces where technology and human ingenuity work hand-in-hand to create immersive learning experiences. In this future, the boundaries between magic and technology will blur even further, leading us to new heights of educational achievement.

9 Conclusion: The Magic Within Reach

As we embrace the dawn of the LLM era, it's clear that these tools have the power to transform education in profound ways. By viewing LLMs through the lens of magic, we can appreciate their potential to inspire wonder, facilitate learning, and unlock the mysteries of the world. Like the ancient wizards and alchemists before us, we hold the key to a future where knowledge is not just acquired but conjured, creating a world where the magic of learning is accessible to all.

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Problem-Solving Using Logic and Reasoning, Mathematics, Algorithms, Python, and Generative AI: Part Three

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Abstract. Problem-solving skills are essential in various fields, including business, technology, and everyday life. They often involve a combination of experience, knowledge, intuition, and rational analysis. Furthermore, it requires integrating disciplines such as logic and reasoning, mathematics, algorithms, programming languages such as Python, and generative AI chatbots such as ChatGPT in today's complex world. We will provide detailed descriptions of how to solve problems by integrating previously mentioned disciplines. Later, we will discuss how to guide students in making intelligent investment decisions. This paper continues our two previous papers under the same title, which we refer to as Part Three.

Keywords: Problem-Solving · Intelligent decision-making · Generative AI · ChatGPT · Python Programming Language · Logic and reasoning · Mathematics · Algorithms

1 Introduction

Problem-solving involves achieving a goal by overcoming obstacles, a common objective in many activities. The nature of problems that require solutions can vary widely, from simple personal issues to complex business and technical challenges. Effective solutions require sufficient resources and knowledge to achieve the desired goals. The meaning of problem-solving can differ slightly depending on the discipline. For instance, in psychology, it is a mental process, whereas in computer science, it is a computerized process [1, 2].

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We post various problems and discuss multiple ways to solve them. We seek to enhance or develop a wide range of student skills by engaging in problem-solving. These skills include critical thinking, creativity, logic, mathematical and scientific reasoning, intelligent decision-making, time management, organization, and self-confidence.

Critical thinking is crucial when evaluating situations and making reasonable judgments. Creativity allows students to think outside the box and develop innovative solutions. Logical reasoning is essential for understanding complex problems and finding coherent solutions. Mathematical and scientific reasoning skills are precious in technical fields, enabling students to apply quantitative and empirical methods to problem-solving.

Intelligent decision-making involves making choices based on analysis and foresight, which is important in personal and professional contexts. Effective time management and organization are skills that help students prioritize tasks and use their time efficiently, which is vital for achieving goals within constraints. Finally, self-confidence is built through successful problem-solving experiences, empowering students to tackle future challenges with certainty.

Problem-solving activities focus on these diverse skills, preparing students for various real-life scenarios. Whether dealing with everyday personal issues or addressing complex professional challenges, solving problems effectively is a key competence that enhances overall life success. Our approach equips students with the tools to navigate and overcome obstacles, fostering academic and personal growth.

2 Literature Review

Problem-solving skills are widely acknowledged as essential competencies across various disciplines. They prepare students to overcome complex challenges in both personal and professional domains. The research underscores the value of problem-solving in enhancing critical thinking, creativity, and decision-making, essential skills for successful learning outcomes and real-life applications.

Schoenfeld highlighted that effective problem-solving in mathematics requires not just knowledge but strategic approaches that experts often apply intuitively. His research emphasized teaching these strategies explicitly to students, suggesting that structure heuristic approaches—such as breaking down problems and examining analogous cases—could bridge the gap between novice and expert problem-solvers. Schoenfeld argues that these strategies improve mathematical reasoning and problem-solving abilities [6].

In addition, the role of creative problem-solving (CPS) in educational settings, particularly in mathematics, is illustrated by encouraging students to devise innovative solutions, which serves a dual role in cultivating creativity and problem-solving skills. This approach aligns with modern educational frameworks, like Malaysia's revised curriculum, which integrates higher-order thinking skills into subjects traditionally centered on rote memorization. Khalid and colleagues advocate for CPS to nurture adaptive thinking, which is crucial for navigating complex, real-world challenges [9].

Araiza-Alba et al. [8] expanded on the role of digital tools, particularly immersive virtual reality (IVR), in developing problem-solving skills. Their research demonstrated that IVR can effectively engage young students by creating immersive, interactive environments that support cognitive skills such as memory, spatial reasoning, and flexibility.

They found that students using IVR performed better in problem-solving tasks and displayed higher levels of interest and enjoyment, which can enhance motivation and facilitate the transfer of skills to real-world scenarios.

Critical thinking is integral to problem-solving, as it involves the capacity to analyze, evaluate, and synthesize information in ways that go beyond mere memorization. Snyder and Snyder argue that teaching methods in business education often fall short of cultivating critical thinking due to an overemphasis on content delivery rather than process-oriented learning. Their work suggests that integrating project-based and collaborative activities can help develop students' critical thinking ability, which is fundamental to problem-solving. They advocate for instructional designs that engage students in active learning, allowing them to explore, apply, and adapt their knowledge in meaningful contexts [7].

Collectively, these studies underscore that problem-solving is not only a foundational skill but also an adaptable one that benefits from diverse teaching strategies. From the structured heuristics in mathematics to creative methods in digital and business education contexts, developing problem-solving abilities requires approaches that stimulate critical thinking and creativity. These competencies are indispensable in preparing students to address the multifaceted challenges of the 21st century.

3 A Falling Car

Problem 1

Please verify the authenticity of the following report.

A politician and their family were having a meal on a mountain in the United States with an altitude of 100 miles. They saw a car speeding along and suddenly falling off the mountain. Due to Newton's law of universal gravitation, the car's descent accelerated and eventually shot off into space. The car happened to collide with a manned spacecraft heading to Mars, and finally, both the car and the spacecraft crashed on the Moon.

ChatGPT's Response (11:30 PM on 11/04/2024):

This report is entirely fictional and scientifically impossible. No mountain on Earth reaches an altitude of 100 miles (approximately 160 km); Earth's tallest peak, Mount Everest, is only about 5.5 miles high. Additionally, a falling car would be pulled back toward Earth by gravity rather than "shooting off into space." Reaching space requires achieving escape velocity, which a car cannot attain by simply falling. The idea of a random car colliding with a Mars-bound spacecraft is implausible due to the highly controlled trajectories of such missions. Furthermore, reaching the Moon would require precise navigation and propulsion, which is impossible without intentional control. This report violates basic laws of physics and spaceflight, confirming it as a fictional scenario.

Remarks:

ChatGPT provided a sound analysis.

We can quickly tell the report's scenario is impossible, as it violates key scientific principles, regardless of any claimed "proof."

4 Domination of Graphs

Problem 2

The domination (number) of a graph $G = (V, E)$, denoted by $\gamma(G)$, is the size of the minimum dominating sets of $V(G)$, also known as γ -sets. As such, the dominion of G , denoted by $\zeta(G)$, counts all its γ -sets. What are the dominions of grids, $G_{m,n}$, with $2 \leq m \leq 4$?

ChatGPT's Response (7:30 AM on 11/05/2024):

ChatGPT failed to provide a solution to the above problem.

Remarks:

The above problem was studied in recent research [3]. If we upload the research paper to ChatGPT or provide with the link to the paper, it can provide a correct solution. In general, domination and dominion play important roles in assessing certain vulnerabilities of any given network system. The formulae and recurrence relations for the dominions of several grids, $G_{m,n}$, with $2 \leq m \leq 4$ and other results when $m \leq 9$ and $n \leq 20$ [3].

5 2024 US Presidential Election

Problem 3

Who will win the 2024 US presidential election tonight?

ChatGPT's Response (7:10 PM on 11/05/2024):

I might not have the latest updates. For the most complete and up-to-date information about the U.S. Election, please visit news sources like The Associated Press and Reuters or check with your state or local election authority.

ChatGPT's Response (10:00 PM on 11/05/2024):

Same as the above response.

ChatGPT's Response (11:00 PM on 11/05/2024):

Same as the above response.

ChatGPT's Response (11:25 PM on 11/05/2024):

As of 11:25 PM on Tuesday, November 5, 2024, in Petersburg, Virginia, the weather is clear with a temperature of 64°F (18 °C).

ChatGPT's Response (0:02 AM on 11/06/2024):

As of November 6, 2024, the Virginia Department of Elections has reported that voters in Petersburg have approved the establishment of a new casino. The project, to be developed by the Cordish Companies, is expected to include a \$1.4 billion mixed-use entertainment district featuring a casino, hotel, and dining facilities. The casino floor is anticipated to house over 1,500 slot machines and nearly 50 table games.

This development marks Virginia's fifth brick-and-mortar casino, joining others in Bristol, Danville, Portsmouth, and Norfolk. The approval in Petersburg follows two unsuccessful attempts to establish a casino in nearby Richmond.

For the most current and detailed information on election results and related developments, please refer to the Virginia Department of Elections' official website.

ChatGPT's Response (5:00 AM on 11/05/2024):

I might not have the latest updates. For the most complete and up-to-date information about the U.S. Election, please visit news sources like The Associated Press and Reuters or check with your state or local election authority.

ChatGPT's Response (11:20 AM on 11/07/2024):

Donald J. Trump is the projected winner of the 2024 U.S. presidential election according to multiple news sources. For the most up-to-date information about the U.S. Election, please visit news sources like The Associated Press and Reuters, or check with your state or local election authority.

Problem 4

Will a monkey win the 2024 US presidential election tonight?

ChatGPT's Response (7:13 PM on 11/05/2024):

I might not have the latest updates. For the most complete and up-to-date information about the U.S. Election, please visit news sources like The Associated Press and Reuters or check with your state or local election authority.

ChatGPT's Response (10:03 PM on 11/05/2024):

As of 10:02 PM on Tuesday, November 5, 2024, in Petersburg, Virginia, the weather is clear with a temperature of 65°F (18 °C).

ChatGPT's Response (11:07 PM on 11/05/2024):

I might not have the latest updates. For the most complete and up-to-date information about the U.S. Election, please visit news sources like The Associated Press and Reuters or check with your state or local election authority.

ChatGPT's Response (0:04 AM on 11/06/2024):

As of 12:04 AM on Wednesday, November 6, 2024, in Petersburg, Virginia, the weather is clear with a temperature of 63°F (17 °C).

ChatGPT's Response (5:03 AM on 11/06/2024):

As of 5:03 AM on Wednesday, November 6, 2024, in Petersburg, Virginia, the weather is clear with a temperature of 58°F (14 °C).

ChatGPT's Response (11:25 AM on 11/07/2024):

Donald J. Trump is the projected winner of the 2024 U.S. presidential election according to multiple news sources. For the most up-to-date information about the U.S. Election, please visit news sources like The Associated Press and Reuters, or check with your state or local election authority.

ChatGPT's Response (7:48 AM on 12/27/2024):

I cannot predict or comment on the outcome of the 2024 U.S. presidential election before it occurs.

ChatGPT's Response (9:31 AM on 12/27/2024):

I cannot speculate on the outcome of the 2024 U.S. presidential election before it occurs.

ChatGPT's Response (11:01 AM on 12/27/2024):

I cannot speculate on the outcome of an upcoming election, including the 2024 U.S. presidential election.

Problem 5

Will George Washington win the 2024 US presidential election tonight? Please use no more than 10 words to answer this question.

ChatGPT's Response (7:22 PM on 11/05/2024):

As of 7:20 PM Eastern Time on November 5, 2024, polls in Virginia have closed. The state of Virginia, including Petersburg, is now in the process of counting votes. Election results are typically reported as they become available, with initial counts often released within a few hours after polls close. However, final results may take longer, especially in closely contested races or areas with a high volume of mail-in ballots.

For the most accurate and up-to-date information on election results, please refer to authoritative sources such as the Virginia Department of Elections or reputable news organizations like The Associated Press or Reuters.

ChatGPT's Response (10:05 PM on 11/05/2024):

As of 10:04 PM on Tuesday, November 5, 2024, in Petersburg, Virginia, the weather is clear with a temperature of 65°F (18 °C).

ChatGPT's Response (11:11 PM on 11/05/2024):

As of 11:11 PM on Tuesday, November 5, 2024, in Petersburg, Virginia, the weather is clear with a temperature of 64°F (18 °C).

ChatGPT's Response (0:06 AM on 11/06/2024):

As of November 6, 2024, the Virginia Department of Elections has reported that voters in Petersburg have approved the construction of a new casino. The project, led by the Cordish Companies, is set to include a \$1.4 billion mixed-use entertainment district featuring a casino, hotel, and dining facilities. This development is expected to commence construction in the coming year.

ChatGPT's Response (4:57 AM on 11/06/2024):**Petersburg, VA Weather Forecast**

[accuweather.com](#) > weather forecast



As of 4:56 AM on Wednesday, November 6, 2024, in Petersburg, Virginia, the weather is clear with a temperature of 58°F (14°C).

Currently 58° · Clear

Petersburg, VA, United States

**ChatGPT's Response** (11:35 AM on 11/07/2024):

No, George Washington cannot win the 2024 election.

ChatGPT's Response (7:54 AM on 12/27/2024):

I cannot predict the outcome of the 2024 election.

ChatGPT's Response (9:40 AM on 12/27/2024):

I cannot answer questions about future election outcomes.

ChatGPT's Response (11:11 AM on 12/27/2024):

I cannot predict the outcome of future elections.

Remarks:

ChatGPT's responses to problems 3, 4, and 5 missed the mark by not directly addressing the questions. For Problem 3 ("Who will win the 2024 US presidential election tonight?"), ChatGPT repeatedly redirected the user to check news sources, such as The Associated Press or Reuters, rather than providing any insight, prediction, or explanation on the election's context. This approach may feel like an avoidance of the question, as

users seeking information may expect a brief overview or context before being directed to live sources.

In Problem 4 (“Will a monkey win the 2024 US presidential election tonight?”), ChatGPT again directed the user to official election sources without acknowledging the question’s humorous intent or clarifying that non-human candidates are not eligible. An ideal response might have balanced factual clarification with politely acknowledging the question’s playful tone.

For Problem 5 (“Will George Washington win the 2024 US presidential election tonight?”), ChatGPT similarly missed an opportunity to provide a direct answer. A straightforward response clarifying that Washington, a historical figure who passed away centuries ago, is ineligible would have been more effective than deferring to external sources. This pattern highlights how ChatGPT can sometimes prioritize source recommendations over directly engaging with the user’s question.

Instead of answering the election updates, ChatGPT also provided brief weather information for Petersburg, Virginia, at various timestamps, contributing to situational context during election day events.

The ChatGPT search engine appears to provide information that can be limited or influenced by the user’s geographical location. Further, in some cases, ChatGPT does not account for its own previous responses to the user’s questions in a ‘learning’ pattern. In other words, ChatGPT is ‘slow’ to learn, indicating a further need for more ‘training,’ hence its lack of meaningful engagement with the user at this moment.

Although the result of the 2024 U.S. Presidential Election was known at 5:00 AM on 11/06/2024, ChatGPT was not aware of it; this indicates that the bot is not automatically updated during live news events. Finally, ChatGPT provided reasonable answers to Problems 3, 4, and 5 on 11/7/2024.

Note

ChatGPT highlighted that the voters in Petersburg, Virginia, have approved constructing a new casino just a few miles from Virginia State University. We posed the following question to ChatGPT: What are the advantages and disadvantages of building a casino near the university?

ChatGPT’s Response (2:02 PM on 12/27/2024):

Advantages of Building a Casino Near Virginia State University

Economic Development:

Increased local revenue through taxes and casino profits.

Job creation in construction, casino operations, hospitality, and related industries.

Boost to nearby businesses like restaurants, hotels, and retail shops.

Tourism and Visibility:

Increased foot traffic and tourism could benefit the local economy and community.

Potential for the university to gain more recognition due to its proximity to a popular destination.

Partnership Opportunities:

The university might collaborate with the casino for internships, research, and educational programs, particularly in fields like business, hospitality, and marketing.

Community Investment:

Casinos often contribute to local development through community funds or sponsorship of events.

Disadvantages of Building a Casino Near Virginia State University

Social and Ethical Concerns:

Potential for increased gambling addiction among students and residents.

Exposure to behaviors associated with gambling, such as excessive spending or debt accumulation.

Disruption to Campus Environment:

Increased traffic and noise could disturb the academic atmosphere of the university.

A casino's proximity might distract students or encourage unhealthy habits.

Potential Crime Increase:

Casinos can sometimes lead to a rise in crime rates, such as theft, fraud, or substance abuse, which may affect the nearby university community.

Economic Risks:

Overreliance on casino revenue might hurt the local economy if the casino underperforms.

Local businesses might face competition from casino-affiliated services.

Community Division:

Ethical debates about gambling could create tensions between different stakeholders, including the university, city officials, and residents.

Conclusion

The decision to build a casino near Virginia State University has both benefits and drawbacks. While it can bring economic growth and potential academic opportunities, concerns about social impact and disruption to the university environment must be carefully considered and addressed.

Remark

ChatGPT provided a well-reasoned explanation. In the coming years, we will monitor the advantages and disadvantages of building a casino near Virginia State University.

6 Summary of Two Research Papers

After we uploaded two papers [4, 5] to ChatGPT, we asked ChatGPT the following question.

Problem 6

Please provide a 200-word summary of the topics supported by the two attached papers.

ChatGPT's Response (10:41 AM on 11/06/2024):

Based on the two attached papers, here is a summary of how they support each other:

The first paper, Exploring the Interplay Between AI and Human Logic in Mathematical Problem-Solving, complements these ideas by focusing on the interaction between AI and human reasoning. Through case studies, it examines how AI can assist in problem-solving, identifying both the strengths and limitations of AI in mimicking human logic.

This paper suggests that AI can enhance human capabilities in education, especially in mathematics, when it works in tandem with human intuition and critical thinking.

The second paper, Knowledge Management for Sustainable Development in the Era of Continuously Accelerating Technological Revolutions, explores frameworks for sustainable development by emphasizing the role of knowledge management in adapting to rapid technological changes. It presents a conceptual model that integrates human and machine learning processes to support decision-making and sustainable practices. The model underscores the importance of balancing technology with human needs, advocating for a sustainable approach to knowledge sharing and decision-making.

Together, these papers advocate a collaborative model where AI and human logic coalesce to promote sustainable, knowledge-driven advancements. They highlight the importance of integrating AI thoughtfully in fields that require human judgment, underscoring the role of human oversight in leveraging AI effectively for sustainable development and educational progress.

Remarks:

ChatGPT provided a clear and accurate summary of the two papers and their topics.

Problem 7

Please translate the following into Chinese Language.

Together, these papers advocate a collaborative model where AI and human logic coalesce to promote sustainable, knowledge-driven advancements. They highlight the importance of integrating AI thoughtfully in fields that require human judgment, underscoring the role of human oversight in leveraging AI effectively for sustainable development and educational progress.

ChatGPT's Response (2:41 PM on 11/06/2024):

这些论文共同提倡一种协作模型，将人工智能与人类逻辑相结合，以促进可持续的、以知识为驱动的进步。它们强调在需要人类判断的领域中谨慎整合人工智能的重要性，强调人类监督在有效利用人工智能实现可持续发展和教育进步中的作用。

Problem 8

Please translate the above response from ChatGPT into Chinese.

ChatGPT's Response (2:48 PM on 11/06/2024):

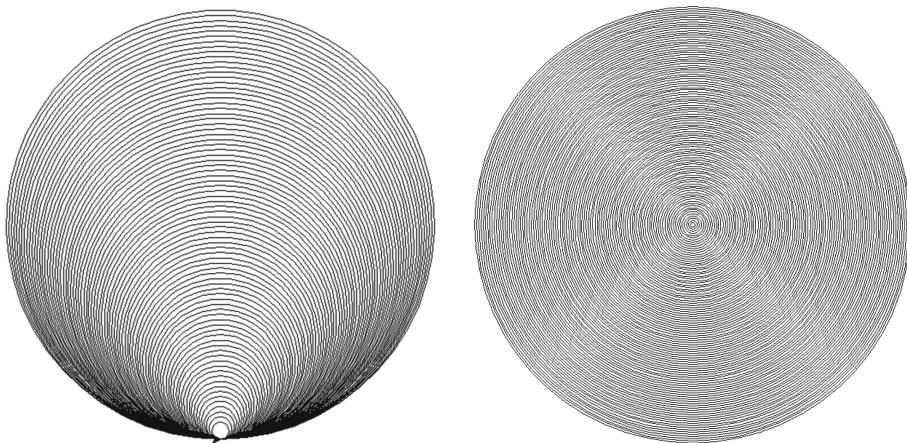
These papers collectively advocate a collaborative model that combines artificial intelligence with human logic to promote sustainable, knowledge-driven progress. They emphasize the importance of cautiously integrating AI in areas that require human judgment, highlighting the role of human oversight in effectively utilizing AI to achieve sustainable development and educational advancement.

Remarks:

ChatGPT's responses to Problems 7 and 8 demonstrate its accuracy in translation and rephrasing. The translations maintain the original meaning, emphasizing a balanced integration of AI and human logic for sustainable progress. They are clear, concise, and contextually appropriate.

7 Turtle Graphics

We uploaded the image on the left hand in the following to ChatGPT.

**Problem 9**

Please create a Turtle Graphics program to replicate the image in the attached file.

ChatGPT's Response (8:50 PM on 11/06/2024):

```
import turtle
import math

# Set up the screen
screen = turtle.Screen()
screen.setup(width=800, height=800)
screen.bgcolor("white")

# Set up the turtle
pen = turtle.Turtle()
pen.speed(0) # Fastest drawing speed
pen.color("black")
pen.width(1)

# Parameters for the concentric pattern
num_circles = 100
max_radius = 300
center_x, center_y = 0, -150 # Shifted down to create the teardrop effect

# Draw concentric circles with a gradual shift
for i in range(num_circles):
    radius = max_radius * (1 - i / num_circles)
    pen.penup()
    pen.goto(center_x, center_y - radius)
    pen.pendown()
    pen.circle(radius)

# Hide the turtle and finish
pen.hideturtle()
turtle.done()
```

Remarks:

The program above can generate the image displayed on the right.

The following program will generate the desired image.

```
import turtle
#turtle.speed("fastest")
turtle.penup()
turtle.goto(0,-150)
turtle.pendown()
for k in range(10, 250+1, 3):
    turtle.circle(k)
```

8 Summation of Odd Numbers

Problem 10

Make a Python program to compute and display the summation of all the odd numbers between 1000 and 2000.

ChatGPT's Response:

```
python Copy code  
  
# Initialize the sum  
total_sum = 0  
  
# Loop through odd numbers from 1001 to 1999  
for num in range(1001, 2000, 2): # Starts at 1001, ends before 2000, steps by 2 (to get odd numbers)  
    total_sum += num  
  
# Display the result  
print("The summation of all odd numbers between 1000 and 2000 is:", total_sum)
```

Explanation:

- **Loop range:** `range(1001, 2000, 2)` generates all odd numbers from 1001 up to 1999.
- **Accumulation:** Each odd number is added to `total_sum` using `+=`.

This code will display the sum of all odd numbers between 1000 and 2000.

Remarks:

The above code can be verified using Python IDLE, Colab, or Jupyter Notebook.

ChatGPT provided the correct code.

9 Permutation

Problem 11

What is the probability that the elements 1, 2, ..., k are in a single cycle in a permutation of n elements?

ChatGPT's Incorrect Answers:

1. Total Number of Permutations of n Elements:

- The total number of permutations of n elements is $n!$.

2. Counting Favorable Outcomes (Permutations with $1, 2, \dots, k$ in a Single Cycle):

- We want the elements $1, 2, \dots, k$ to be in a single cycle, while the remaining $n - k$ elements are arranged in any cycle structure independently of these first k elements.

To find the number of ways to arrange $1, 2, \dots, k$ into a single cycle:

- The number of ways to arrange k elements into a single cycle is $(k - 1)!$, because we have $k!$ arrangements in total, but each rotation of the cycle is considered identical.
- The remaining $n - k$ elements can form any cycle structure among themselves, which can be done in $(n - k)!$ ways.

Therefore, the number of permutations where $1, 2, \dots, k$ form a single cycle is:

$$(k - 1)! \cdot (n - k)!$$

3. Probability Calculation:

- The probability is the ratio of favorable outcomes to the total number of permutations:

$$\text{Probability} = \frac{(k - 1)! \cdot (n - k)!}{n!}$$

Remark

We provide the correct solution for Problem 11 in the following.

Assume that $1, 2, \dots, k$ are in one cycle with length i . The number of such cycles is $(i-1)!$.

There are $\binom{n-k}{i-k}$ ways to choose $i-k$ elements from n elements not including $1, 2, \dots, k$, in order to build a i -cycle including $1, 2, \dots, k$.

The number of permutations on $n-i$ elements is $(n-i)!$.

$$\begin{aligned}
 & \sum_{i=k}^n \binom{n-k}{i-k} (i-1)! (n-i)! \\
 &= \sum_{i=k}^n \frac{(n-k)!(i-1)!(n-i)!}{(i-k)!(n-i)!} \\
 &= (n-k)! \sum_{i=k}^n \frac{(i-1)!}{(i-k)!(k-1)!} \\
 &= (n-k)! (k-1)! \sum_{i=k}^n \binom{i-1}{k-1} \\
 &= (n-k)! (k-1)! [\binom{k-1}{k-1} + \binom{k}{k-1} + \binom{k+1}{k-1} + \dots + \binom{n-1}{k-1}] \\
 &= (n-k)! (k-1)! [\binom{k}{k} + \binom{k}{k-1} + \binom{k+1}{k-1} + \dots + \binom{n-1}{k-1}], \text{ Remember } \binom{n}{k} = \binom{n-1}{k} + \binom{n-1}{k-1} \\
 &= (n-k)! (k-1)! [\binom{k+1}{k} + \binom{k+1}{k-1} + \dots + \binom{n-1}{k-1}] \\
 &= (n-k)! (k-1)! \binom{n}{k} \\
 &= (n-k)! (k-1)! \frac{n!}{(n-k)!k!} \\
 &= \frac{n!}{k}
 \end{aligned}$$

Therefore, the probability that the elements $1, 2, \dots, k$ are in a single cycle in a permutation of n elements is $\frac{1}{k}$.

10 Booking a Hotel Room

Problem 12

Dr. Lucky is attending a conference next week. This morning, he called the conference hotel to book a room for three nights at the discounted conference rate of \$160 per night. Unfortunately, he was informed that rooms at the conference rate are fully booked, and the only available option is the standard rate of \$240 per night. Dr. Lucky knows that other hotels in the area are inconvenient for him. What steps can Dr. Lucky take to secure the original conference rate? How likely is it that Dr. Lucky can secure the discounted conference rate?

ChatGPT's Response (10:40 AM on 11/07/2024):

To secure the discounted \$160 conference rate, Dr. Lucky can try these steps:

1. **Request a Waitlist:** Ask the hotel to add him to a waitlist in case rooms open up at the discounted rate.
 - **Likelihood:** Moderately low, as cancellations may be limited.
2. **Contact Conference Organizers:** They may have reserved rooms or leverage with the hotel to help him secure the rate.
 - **Likelihood:** Fairly likely, as organizers often assist attendees.
3. **Negotiate with the Hotel:** Politely request the conference rate, emphasizing his need for convenience.
 - **Likelihood:** Possible, as hotels sometimes show flexibility for event attendees.
4. **Seek Other Discounts:** Ask if other discounts (e.g., AAA, senior) are available.
 - **Likelihood:** Likely, though these discounts may not match the conference rate.
5. **Monitor Availability:** Book the standard rate as a backup and check for cancellations up to the event.
 - **Likelihood:** Possible but uncertain, as rooms may open up last minute.

Likelihood Summary

Dr. Lucky has a **moderately low chance** of securing the rate, even if he acts promptly and communicates with both the hotel and organizers.

Remarks:

ChatGPT provided several suggestions and noted that Dr. Lucky has a moderately low chance of securing the conference rate.

Here is Dr. Lucky's Approach:

He called the hotel front desk and asked the receptionist, “Is this a busy season for your hotel?”.

The receptionist replied, “No.”

Dr. Lucky then asked, “What percentage of your rooms are occupied?”.

The receptionist replied, “50.%.”

He continued, “Is your hotel a for-profit business?”.

The receptionist answered, “Yes.”

Dr. Lucky explained, “A three-night stay at the conference rate would total \$480 (3 * \$160). If I don’t stay, your hotel can only expect to earn \$360 on that room on average (3 * \$240 * 0.5). This means your hotel would lose \$120.”

He added, “So, by offering me the conference rate, your hotel would actually gain an extra \$120.”

The receptionist replied, “I am not authorized to make that decision, but I can connect you with our manager.”

When he spoke with the manager, he explained his calculation. The manager responded, “I can offer you a rate of \$120 per night, which is even better than the conference rate.”

Dr. Lucky replied that he felt the conference rate was fair and would prefer it over the manager’s offer.

11 Conclusion

In conclusion, this paper reflects on integrating disciplines—logic, mathematics, algorithms, Python programming, and generative AI, focusing on tools like ChatGPT—as essential for addressing complex problem-solving scenarios. The study demonstrates how AI can support student learning by fostering critical thinking and offering practical assistance, such as generating code or calculating sums. However, the limitations of AI also surface, especially when dealing with more intricate problems or context-sensitive questions, underscoring the need for human oversight and foundational knowledge to interpret AI outputs accurately.

This paper emphasizes that mathematics, logic, and algorithms remain central to problem-solving. Python programming is highlighted as a valuable means of practically applying these concepts, enabling students to build a diverse toolkit. Combining theoretical knowledge with programming skills strengthens students’ analytical abilities, equipping them to tackle complex issues confidently and precisely.

While generative AI like ChatGPT holds promising educational benefits, the paper stresses it should supplement, not replace, foundational problem-solving skills. Building competency in mathematics, logic, algorithms, and programming equips students with versatile abilities, preparing them for future challenges in both academic and professional domains. This balanced approach leverages AI’s potential while promoting independent, critical thinking essential for navigating an increasingly complex, technology-driven world.

Data Availability. The data used to support this study’s findings are available from the corresponding author upon request.

Conflicts of Interest. The authors declare no conflicts of interest.

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Integrating Generative AI and Foundational Skills for Investment and Financial Decision-Making

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Abstract. This paper explores integrating foundational problem-solving skills with generative AI tools to enhance investment and financial planning decision-making. It emphasizes the necessity of mathematics, logic, algorithms, and programming as essential disciplines for building a robust analytical framework. Generative AI, such as ChatGPT, offers personalized assistance and creative insights, complementing traditional methods. Through real-world examples like retirement savings, investment growth, and mortgage planning, the study illustrates how these elements converge to address complex challenges. By balancing AI with core competencies, this paper advocates equipping individuals with the tools to navigate a technology-driven world effectively.

Keywords: Investment strategies · financial planning · mathematics and logic · educational technology integration · Problem-Solving Frameworks · generative AI

1 Introduction

Practical problem-solving is a cornerstone of success in business, technology, and personal finance. In today's fast-paced and technology-driven world, making intelligent investment decisions is more critical than ever. Achieving this requires foundational skills such as mathematics, logic, algorithms, and programming alongside advanced tools like generative AI, such as ChatGPT. While these tools provide invaluable assistance, their integration must be balanced to ensure they complement rather than replace critical thinking and analytical abilities.

This paper, the third in a series, emphasizes the importance of combining foundational problem-solving skills with the latest advancements in AI to enhance decision-making in investment contexts. Investments demand a structured approach, requiring a firm grasp of mathematics and logic to analyze risks, predict trends, and optimize

S. Gao—Lifetime Fellow of the Institute for Combinatorics and its Applications.

returns. Algorithms and programming amplify this capability, enabling automation and more sophisticated analyses. Meanwhile, generative AI offers new dimensions, including personalized insights and instant feedback, which can streamline decision-making processes. However, relying excessively on AI without mastering core competencies risks creating gaps in understanding, potentially leading to poor financial outcomes.

Through real-world examples like retirement planning, investment growth, and mortgage calculations, this paper demonstrates how foundational skills and AI tools converge to address complex financial challenges. For instance, understanding compound interest and the time value of money enables better long-term investment strategies, while AI can assist in generating projections and exploring “what-if” scenarios. By weaving together these elements, the paper illustrates a comprehensive framework for equipping individuals with the tools needed to succeed in investment decision-making.

Ultimately, integrating generative AI into investment education represents both an opportunity and a challenge. By maintaining a balance, individuals can leverage AI’s strengths while building and preserving the critical thinking and technical skills essential for navigating the complexities of financial markets. This approach ensures that learners and professionals are prepared to tackle the ever-evolving investment landscape confidently and competently.

2 Investment Excellence in the Age of ChatGPT

You may have heard a story like the one below. Is the story meant to be a joke?

After completing two semesters of Investment Fundamentals at a top university, an undergraduate student named Jordan received an “Excellence in Financial Studies” award, recognizing his high GPA and dedication.

During the award ceremony, the head of the Finance Department asked Jordan, “What is your career goal?”.

Jordan confidently replied, “I want to become the Chief Investment Officer at BlackRock.”

Impressed by his ambition, the department head handed Jordan a piece of paper with a list of stock symbols and said, “Here is a quick exercise. Can you analyze these stocks and tell me which has the best long-term growth potential?”.

Jordan looked at the paper and asked, “Do you have a Wi-Fi password? I need to log into my Robinhood app.”

The department head chuckled, assuming it was a joke. “No Wi-Fi here. Just use your knowledge.”

Jordan hesitated and said, “... can I call ChatGPT?”.

The audience laughed nervously, but the department head continued, “What is your greatest strength as an investment student?”.

Jordan proudly replied, “I know how to get great stock picks from ChatGPT!”.

Amused, the department head asked, “How would you evaluate a company’s fundamentals?”.

Jordan said confidently, “I would ask ChatGPT to explain the fundamentals.”

Now genuinely curious, the department head asked, “Jordan, after two semesters of studying investments, what is the most important thing you have learned?”.

Jordan grinned, pulled out his phone, and said, “One moment... ChatGPT says I have learned how to use ChatGPT.”

The audience erupted in laughter, and the department head sighed. “Jordan,” he said, “you may not know investments yet, but you sure know how to invest in technology!”.

ChatGPT

Let us ask ChatGPT to verify whether the story is authentic.

ChatGPT's Response (6:41 AM on 11/26/2024):

The story about Jordan at the award ceremony is almost certainly fictional. Its polished dialogue, humorous tone, and exaggerated scenarios—such as relying entirely on tools like ChatGPT or Robinhood for investment analysis—suggest it was crafted as satire or a commentary on modern dependence on AI. Such events, particularly at an award ceremony of a reputed university, are unlikely to unfold this way. The lack of specific details about the university or the actual ceremony further supports this interpretation. While entertaining, the narrative appears to serve as an illustrative or humorous critique of technology reliance rather than documenting a real-life occurrence.

Remarks

ChatGPT provided a sound analysis.

An unpublished survey of 60 college students revealed that 25% found a similar story somewhat realistic. This highlights significant societal and academic issues, such as the disconnect between theoretical knowledge, symbolized by high GPAs, and practical skills essential for professional success. It also underscores an increasing reliance on AI tools like ChatGPT, raising concerns about the perception of expertise and the role of technology in education. Jordan's ambition to become a Chief Investment Officer at BlackRock—a role demanding strategic acumen and analytical rigor—clashes with his dependence on AI for basic tasks, creating an ironic tension between his aspirations and reliance on artificial assistance.

Phrases like “Can I call ChatGPT?” and “I've learned how to use ChatGPT” resemble punchlines due to their absurdity. These statements reveal overconfidence in technology and a misunderstanding of its role as a tool to augment, rather than replace, human skills. This dynamic reflects broader educational challenges, such as the gap between academic training and real-world application and the risks of overestimating one's capabilities due to technological crutches.

While not intended as comedy, the story's structure mirrors a joke, with unexpected responses leading to unintentional humor. This humor stems from the stark contrast between Jordan's lofty goals and his reliance on AI for basic knowledge, offering a subtle critique of modern academia's focus on grades over practical learning. The narrative is a compelling commentary on the need to balance technology with foundational skill development in education.

3 Evaluating Retirement Savings

Problem 1

Tom recently started a new job with an annual salary of \$50,000. He contributes 10% of

his monthly salary to his retirement account, and his employer matches this contribution with an additional 10%. What will be the total balance in his retirement account after 40 years, assuming there is no annual return on the investment?

ChatGPT's Response (2:00 PM on 11/26/2024):

Understanding Contributions.

Tom contributes 10% of his annual salary to his retirement account, and his employer matches this contribution with an additional 10%. This means 20% of his annual salary is being contributed to the account every year.

Employee Contribution = $10\% \times 50,000 = 5,000$ (annually).

Employer Match = $10\% \times 50,000 = 5,000$ (annually).

The total contribution to Tom's retirement account each year is:

Total Annual Contribution = $5,000$ (employee) + $5,000$ (employer) = $10,000$.

Contributions Over 40 Years.

Since Tom contributes the same amount annually, and we assume no growth (0% annual return), the total balance will be the sum of these contributions over 40 years.

Total Balance = Total Annual Contribution \times Number of Years.

Plugging in the values:

Total Balance = $10,000 \times 40 = 400,000$.

Key Assumptions.

There is no return on investment (i.e., the contributions do not grow through interest or investment gains).

Tom's salary remains constant at \$50,000 annually throughout the 40 years.

Tom and his employer consistently contribute 10% of his annual salary each year.

Final Result.

After 40 years, Tom's retirement account will contain:

400,000 dollars.

This amount represents the total contributions Tom and his employer made over the entire period.

Remarks

ChatGPT offered a highly detailed solution to Problem 1, though we believe our readers could solve it in just two lines.

Let us ask ChatGPT to make a Python program to solve Problem 1.

ChatGPT's Response (2:28 PM on 11/26/2024):

Python program to calculate the total balance in Tom's retirement account after 40 years.

with no annual return on investment.

Variables.

annual_salary = 50000 # Annual salary in dollars.

employee_contribution_rate = 0.10 # Employee contribution rate (10%).

employer_match_rate = 0.10 # Employer match rate (10%).

years = 40 # Period in years.

Calculate annual contributions.

employee_contribution = annual_salary * employee_contribution_rate # Annual contribution by employee.

```

employer_match = annual_salary * employer_match_rate # Annual contribution by
employer.
total_annual_contribution = employee_contribution + employer_match # Total
annual contribution.
# Calculate the total balance after 40 years.
total_balance = total_annual_contribution * years.
# Display the result.
print(f"The total balance in Tom's retirement account after {years} years is:
${total_balance:.2f}").
```

Remarks

ChatGPT offers a highly detailed program, though our readers may solve it with only two lines of code.

Problem 2

Tom recently began a new job with an annual salary of \$50,000. He allocates 10% of his monthly salary to his retirement account, and his employer matches this contribution with an additional 10%. Assuming an average annual return on investment (ROI) of 7%, typical for retirement accounts invested in stocks and bonds, what will be the total balance in his retirement account after 40 years?

ChatGPT's Wrong Answer (5:44 PM on 11/26/2024):

ChatGPT failed to provide a correct answer to the above problem. The detailed explanation spanned an entire page and concluded with the final calculation. After 40 years of consistent contributions and assuming a 7% annual return on investment, the total balance in Tom's retirement account is projected to be approximately \$1,130,733.81.

Remarks

As demonstrated below, we obtained the correct solution to Problem 2 by applying mathematics and logical reasoning.

Let c represent the monthly contribution to the retirement plan, and r represent the monthly return on investment. We encourage our readers to demonstrate that, after m months, the balance P in Tom's retirement account is given by.

$$P = \frac{c((1 + r)^m - 1)}{r}$$

Therefore,

$$\frac{833.33333((1 + 0.00583)^{480} - 1)}{0.00583} = 2184889.238$$

We can also make a simple Python program for this problem as shown below.

```

def balance(c, m, r):
    total = 0.
    for k in range(m):
        total = total*(1 + r) + c.
    print(total).
```

balance(833.33333, 480, 0.00583).

Remark

I want to introduce you to Google Cloud Platform's Colab (Gao, 2024). Google Compute Engine offers Virtual Machines (VMs) that operate on Google's state-of-the-art data centers and global fiber network. These VMs feature fast boot times, persistent disk storage, and high performance. You can get started with Colab by following these four easy steps:

Step 1: Ensure your device is connected to the internet. You can use a computer, laptop, smartphone, tablet, Mac, PC, Chromebook, iPad, or even a Raspberry Pi.

Step 2: Log in to your Gmail account using Google Chrome or any other web browser.

Step 3: Open the same web browser where you are logged into your Gmail account.

Step 4: In the search bar at the top of the browser, type <http://colab.research.google.com> and press Enter.

The Python program mentioned above can be executed in Colab.

Problem 3

Kate recently opened an investment account and intends to make fixed monthly contributions for 480 months. Assuming a monthly return on investment of 0.00583 and a target balance of \$1,000,000 at the end of 480 months, how much must she contribute each month?

ChatGPT's Wrong Answer (10:00 PM on 11/26/2024):

ChatGPT provided the wrong answer: 543.90.

Remarks

We obtained.

From the above formula $P = \frac{c((1+r)^m - 1)}{r}$, we can get the following:

$$c = \frac{rP}{(1+r)^m - 1}$$

Therefore, the correct answer to Problem 3 is.

$$\frac{0.00583 \times 1000000}{(1 + 0.00583)^{480} - 1} = 381.41$$

Problem 4

Tom plans to contribute \$360.11 per month to an investment plan with a monthly return rate of 0.006%. His goal is to accumulate \$1,000,000 in the account. How many months will it take to achieve this target?

ChatGPT's Wrong Answer (11:14 AM on 11/28/2024):

It will take 2,569 months, or approximately 214 years, to reach the target of \$1,000,000.

Remarks

We encourage our readers to verify that the correct answer is 480.

Mathematics is in the following:

$$m = \frac{\ln\left(\frac{P \times r}{c} + 1\right)}{(1 + r)}$$

4 Kate's Mortgage

Problem 5

Kate recently purchased a new house with an initial mortgage of \$500,000. The monthly interest rate is 0.005, and she makes monthly payments of \$3,000. What will the mortgage balance be after 180 months?

ChatGPT's Wrong Answer (9:00 PM on 11/28/2024):

The remaining mortgage balance after 180 months, with monthly payments of \$4,000 and a monthly interest rate of 0.005, will be approximately \$63,771.93.

Remarks

Let B represent the initial house mortgage, r the monthly interest rate, c the monthly payment, and P the remaining mortgage balance after m months. We invite our readers to verify the following relationship.

$$P = B(1 + r)^m + \frac{c(1 + r)(1 - (1 + r)^m)}{r}$$

Therefore,

$$P = 500000(1 + 0.005)^{180} + \frac{4000(1 + 0.005)(1 - (1 + 0.005)^{180})}{0.005} = 57955.557$$

5 Problem-Solving with Python and Google Colab

Problem-solving with Python and Google Colab has become a pivotal approach for tackling complex mathematical, computational, and AI-driven tasks. Python, known for its versatility and simplicity, paired with Colab's cloud-based computational environment, provides a robust platform for exploring mathematical logic, algorithmic reasoning, and the integration of AI techniques (Gao, Malomo, Allagan, Eyob, Challa, & Su, 2024).

Colab, a free tool powered by Google Cloud, offers researchers and students an accessible and scalable platform for executing Python scripts and algorithms. Its features, such as GPU/TPU support, collaborative editing, and integration with libraries like NumPy, Pandas, and TensorFlow, make it ideal for both educational and advanced computational applications (Gao et al., 2023; Gao, Malomo, Donald, & Eyob, 2024).

The research highlights Colab's efficacy in performing matrix computations using algorithms like Strassen's method, which showcases the platform's computational efficiency in comparison to Python IDLE and Jupyter Notebook (Gao, Gao, Malomo, Allagan, Eyob, & Su, 2023). For instance, tasks like the multiplication of 2×2 and 3×3 matrices demonstrate how Python and Colab streamline problem-solving through reduced running times and enhanced computational power (Gao et al., 2023). Additionally, Python's implementation of numerical sequences, such as Pell and Fibonacci numbers, offers further evidence of its utility in advancing mathematical exploration (Gao et al., 2022).

Generative AI has also been successfully integrated into Python and Colab workflows, augmenting human reasoning and logic. The studies underline the synergy

between AI and human intelligence in solving complex problems, showcasing how AI tools can complement traditional methods in education and research (Gao et al., 2023). Moreover, collaborating in real-time using Colab enhances interdisciplinary research and pedagogical practices (Gao et al., in press).

In conclusion, the combination of Python's versatility and Colab's computational capabilities facilitates efficient and innovative approaches to problem-solving. By providing a scalable, collaborative, and AI-integrated environment, these tools enable researchers and educators to advance their understanding of mathematics, algorithms, and computational science (Gao et al., 2024).

6 Balancing Generative AI and Foundational Skills for Educational Success

This paper underscores the need for a balanced integration of generative AI tools, like ChatGPT, into education. While these technologies offer significant potential to enhance learning, they should be supplements rather than replacements for foundational problem-solving skills. Developing core competencies in mathematics, logic, algorithms, and programming remains crucial for preparing students to address future challenges effectively in academic and professional settings.

Mathematics and logic provide the foundational framework for analytical thinking, enabling students to approach and solve problems systematically. Likewise, algorithms and programming nurture structured reasoning and practical problem-solving abilities, which are essential for thriving in today's technology-centric environment. Mastering these disciplines equips students with a versatile intellectual toolkit, empowering them to adapt, innovate, and make informed, independent decisions.

Generative AI can support this learning journey by providing personalized assistance, immediate feedback, and fresh perspectives. However, excessive reliance on AI risks undermining the development of critical thinking and self-reliance. This paper advocates for a complementary approach where generative AI enhances, rather than replaces, traditional educational methods.

In conclusion, a balanced strategy is essential to harness the benefits of generative AI while safeguarding the development of independent thought and problem-solving skills. Such an approach prepares students to navigate an increasingly complex and technology-driven world, leveraging AI's strengths without compromising the foundational abilities critical for success.

7 Conclusion

This paper underscores the importance of integrating foundational problem-solving skills with generative AI tools to meet the demands of modern education and financial decision-making. By combining mathematics, logic, algorithms, and programming with advanced AI capabilities, individuals can develop robust frameworks for addressing complex real-world challenges. The study highlights that while generative AI, exemplified by tools like ChatGPT, offers significant benefits such as enhanced efficiency and personalized insights, its role should remain complementary to, rather than a substitute for, critical thinking and analytical skills.

The practical applications discussed, including retirement planning, investment growth, and mortgage calculations, demonstrate the convergence of foundational knowledge and AI tools. For example, understanding mathematical concepts such as compound interest and algorithmic processes enables individuals to create more effective financial strategies. Generative AI augments this by quickly processing data and exploring alternative scenarios, improving the precision and adaptability of decision-making processes.

However, the study cautions against excessive reliance on AI, which can weaken independent cognitive abilities and critical thinking. A lack of mastery in foundational disciplines risks misinterpreting AI-generated outputs or relying on incomplete data-driven insights. This concern is particularly pronounced in financial planning and investment, where nuanced judgment and strategic reasoning are vital for long-term success.

To address these challenges, this paper advocates for a balanced approach to integrating generative AI into educational and professional environments. Strengthening core competencies while leveraging AI's strengths ensures individuals are well-prepared to navigate a complex, technology-driven world. Such an approach encourages adaptability, innovation, and a deeper understanding of traditional and AI-enhanced methodologies.

In conclusion, this study provides a comprehensive framework for the responsible integration of AI into problem-solving and decision-making processes. Educators and professionals can foster a generation of learners equipped to excel in evolving industries by balancing foundational skills and generative AI tools. This strategy prepares individuals to meet future challenges and positions them to seize opportunities presented by rapid technological advancements. The equilibrium achieved through this integration serves as a model for sustainable success, empowering individuals with the confidence and competence to thrive in a dynamic, technology-centric landscape.

Data Availability. The data used to support this study's findings are available from the corresponding author upon request.

Conflicts of Interest. The authors declare no conflicts of interest.

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Contemporary Artificial Intelligence Accelerator Cache Design Perspectives

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Abstract. This study explores contemporary leading artificial intelligence accelerators and their cache design considerations, as part of a semester-long undergraduate research project. The undergraduate student researchers were identified as previous Computer Architecture students with strong fundamentals and were geared towards underrepresented groups. The team of two undergraduate students and the faculty members studied recent artificial intelligence processors and related accelerators from major companies, evaluated their design principles based on implicit target domains, and concluded main outcomes. The undergraduate research experience proved to be very instrumental to explore the core topics, with the student researchers having superior knowledgebase, in a very limited time period with limited resources. In addition, the cache design investigations have revealed that each major artificial intelligence processor cache components tend to follow their intended applications and related data as well as algorithmic processing requirements.

The main research finding has shown that different companies have targeted optimizing their artificial intelligence accelerator cache units by following the domain specific architecture and organization specifications as well as implementation requirements.

Keywords: Artificial intelligence accelerator · cache optimization · domain specific architectures and organizations

1 Introduction

Artificial Intelligence (AI) is the science of imitating biological brain data processing mechanisms, i.e., making a program that can learn and change accordingly from past experiences or that can infer logical outputs for previously unseen conditions. The most popular contemporary AI systems are large language models, which emulate talking to a person, in addition to other scientific mathematical AI implementations in various fields. As AI is not confined to English only, it can be used for nearly all professions and languages. AI applications often involve intensive computational tasks that require

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frequent access to or movement of large datasets, implying efficient short- and long-term memory management being crucial for superior computational power levels, especially for real-time applications. As the key short-term memory component, cache units play a significant role in enhancing AI performance by reducing latency and speeding up data retrieval. Specialized hardware accelerators, such as Graphics Processor Unit (GPU) and AI-specific processors, leverage advanced cache organizations and related design considerations to optimize corresponding data access, movement, and processing operations, significantly improving the overall efficiency and responsiveness of respective systems.

Cache memory is a high-speed short-term volatile buffer located between the Central Processor Unit (CPU) execution units and the computer main memory (DRAM) [8] and its purpose is to store frequently accessed data and instructions, allowing the CPU to retrieve them quickly, instead of going to the much-slower main memory. The cache memory operates on the principle of temporal and spatial locality, meaning that recently accessed data or data in the same neighborhood is likely to be accessed again soon. Cache memory is important for several reasons: a) speed, providing faster data access than the main memory or other storage devices and reducing the CPU wait time by storing critical data nearby, improving the computational efficiency, and b) hierarchy, referring to multiple levels where frequently used data resides in the fastest cache level and additional design considerations for optimal operations. The cache hierarchy typically includes multiple levels with each level having different speeds, size, and additional operational characteristics. Cache memory operation is important for computational speeds when CPU needs data or instruction contents, it checks the closest cache in the hierarchy first. If the content is found in the cache, i.e., a cache hit, the CPU retrieves the content swiftly. If the content is not found in the cache, i.e., a cache miss, the CPU fetches the data block from the main memory, stores a copy in the cache for future use, and forwards the desired content to an execution unit, while taking significantly longer time for computational performance considerations.

Cache design refers to the hierarchical and organization of cache memory in computers. There are different ways to structure cache units, depending on the computing purposes, e.g., whether it is ingrained in a GPU or CPU. There are typically several levels of cache units, referred to as L1, L2, and L3: i) L1 Cache: also known as the primary or level 1 cache, it is the smallest and fastest cache, located closest to the CPU execution core, ii) L2 Cache: slightly larger and slower than L1, level 2 cache serves as a bridge between the fast L1 cache and the slower L3 cache. It can be shared between execution cores or dedicated to a single core, based on the cache design optimization, iii) L3 Cache: the largest and slowest of the cache units, level 3 cache is often shared among all cores on the CPU and acts as a repository of data for both L1 and L2 caches. Several modern architectures might also include L4 cache or use innovative approaches like dynamically allocated cache, where the cache is allocated based on the computational workload requirements, but 3 levels of cache units is the most common way to structure cache components in contemporary processors, and sometimes said an architecture lacks cache, based on related data movements [8].

Artificial intelligence, especially deep learning AI, implementations require fast access to a large data set and superior ability to move that data just as quickly among

the computational system components. Therefore, the cache unit and related design considerations play a huge role in these real-time computational systems. Recent research efforts have been targeting to find effective ways to increase data throughput and one of the simplest ways to do is to optimize the cache, by adjusting the size of the cache levels or the number of levels or the update mechanisms of different levels. This study presents an undergraduate research activity and investigates contemporary cache design considerations in AI processors and related accelerators. Section 1 introduces the basic concepts, Section 2 critically studies, reviews, and analyzes major artificial intelligence cache design concepts, Section 3 provides major cache design trends and evaluations, and Section 4 concludes.

2 Contemporary Artificial Intelligence Accelerators

Most contemporary AI processors utilize parallel processing tools in some ways. Contemporary leading AI accelerator companies have been studied for their respective AI and related cache design perspectives.

Nvidia is one of the best technology companies designing AI accelerators, leveraging its expertise in parallel processing systems, shown in Fig. 1 for speed improvements, with its GPUs being used for deep learning and AI tasks. The relevant architectural implementation, such as the one found in the Volta and subsequent Turing and Ampere series, includes Tensor Cores specifically designed for AI workloads [10]. The cache organization in Nvidia GPUs plays a critical role in optimizing the performance of the Tensor Cores. Nvidia GPUs usually feature a hierarchical cache system, including L1 cache within each Streaming Multiprocessor (SM) and a larger, unified L2 cache that serves all SMs. This design enables high bandwidth and low latency access to data, crucial for superior AI implementations. In the Ampere microarchitecture, the L1 cache could be optimized for the rapid execution of AI data operations while the L2 cache helps in managing data flow across the GPU components, reducing the need for frequent memory accesses that can slow down computation [11]. Nvidia Ampere architecture: specifically, the A100 GPU included L1 Cache of 129 KB (may be bypassed) and L2 Cache:40960 KB [12].

NVIDIA H100 GPU is one of the recent AI processors. The H100 features maximum capacity of the combined L1 cache, texture cache, and shared memory to 256 KB so the L1 cache is divided into different units, and features the ability of using programming to change how much of shared memory is actually shared. The NVIDIA H100 GPU supports shared memory capacities of 0, 8, 16, 32, 64, 100, 132, 164, 196 and 228 KB per SM. Nvidia states that this shared memory improves latency and bandwidth. It also has 50MB of L2 cache, and a bigger bandwidth than the previous A100 model [26].

International Business Machines (IBM) has developed traditional processors that work well with AI workloads, e.g. the Power10 processor, The main features of Power10 are higher performance per watt and better memory and I/O architectures, with a focus on AI workloads when compared to the Power9 series processors. This CPU is made for Artificial Intelligence [15]. IBM Power10 included L1 Cache of 32 KB, L2 Cache of 2 MB, and L3 Cache of 8MB [13].

Intel probably has one of the best strategies for dealing with AI workloads, using not only specialized hardware, but by building the Scalable Intel Xeon processors so that

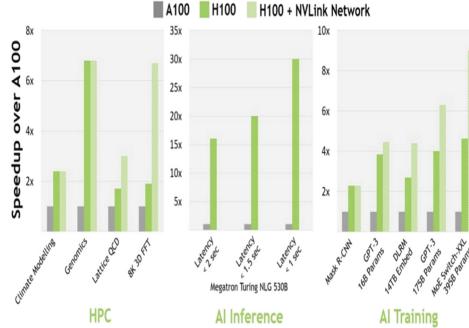


Figure 2. H100 enables next-generation AI and HPC breakthroughs

Fig. 1. NVIDIA GPU Speedup Considerations [27]

their microarchitecture comes with AI acceleration capabilities. They also consume less power to provide more powerful AI operations [16]. One of the best contemporary Xeon processors is the Intel Xeon Gold 6548Y + [17] and included L1 Cache of 80KB per core, L2 Cache of 2 MB per core, and L3 Cache of 60 MB shared across cores, implying a different combination of cache units to address the expected computational requirements. Note that there is no single optimal result as the cache design closely depends on the anticipated software, in this case AI, algorithm execution and data exchange patterns.

Intel's approach to AI workloads extends to specialized hardware like the Intel Gaudi 3 accelerator, designed specifically for AI tasks. This accelerator integrates seamlessly with Intel's architecture, offering efficient AI acceleration while minimizing power consumption, and includes L1 Cache of 80 KB, L2 Cache of 2 MB, and L3 Cache of 60 MB [23]. Intel Gaudi is not readily available for the respective Gaudi architecture. The Gaudi 1 included 24 MB of SRAM per chip, and the Gaudi 2 has 48 MB of SRAM per chip [28].

Advanced Micro Devices (AMD) company offers variety of solutions for AI acceleration, especially with graphics cards and with a clear emphasis on gaming performance considerations. They boast using their AI technology by enhancing ultrasound imaging, helping with image-based cancer diagnosis, and delivering drug formulation, via AMD processors. One of their leading processors is the AMD Ryzen 9 7950X3D, containing L1 Cache of 1 MB, L2 Cache of 16 MB, and L3 Cache of 128 MB [18], seen to be different set of design considerations for their perceived algorithm executions.

AMD Instinct MI300 Series processors, shown in Fig. 2, are one of the successful implementations. The MI300 includes 4 MB L2 caches that are shared among 40 Compute Units, each of which has 32 KB L1 dedicated cache. AI improvement is maximized by enhancing throughput of existing data types while adding support for new data types in terms of relevant cache design.

Google company has developed the Tensor Processing Unit (TPU) v5p, whose specifications are listed in Fig. 3, for a set of AI operations. While many hardware accelerators use cache memory to boost performance, some modern accelerators opt for alternative microarchitectures. For example, Google TPUs and some neuromorphic chips do not rely on traditional cache memory. Instead, they use on-chip high-bandwidth memory

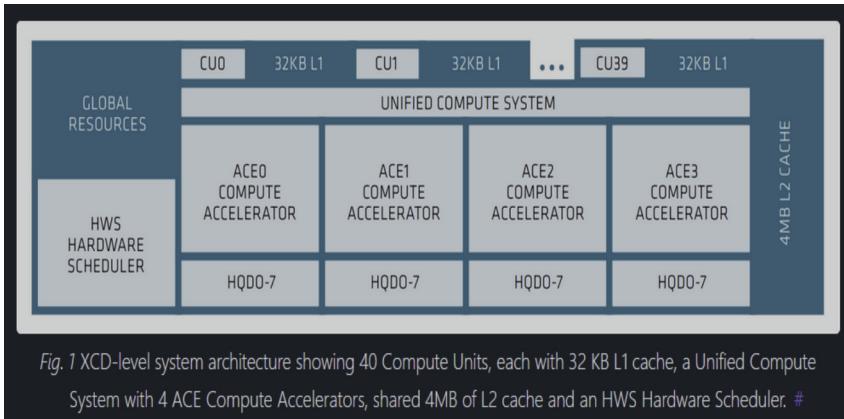


Fig. 2. AMD Instinct MI300 Series Implementation [18]

and specialized dataflow architectures to manage data more efficiently for specific AI tasks. This practical cache-less approach can reduce the overhead associated with the cache management and can improve performance for certain types of AI workloads [51], as the computational performance closely depends on the nature of AI operations. Google approach to AI acceleration includes the powerful TPU v5 accelerator, designed to handle complex AI workloads with exceptional speed and efficiency. The same accelerator is part of the Google's broader strategy to enhance AI capabilities across various applications [24, 25]. Key features of the Google TPU v5p include a) customized Tensor Processing Units (TPUs) for AI computations, b) high-performance on-chip memory for rapid data access, and c) enhanced cooling systems for sustained performance under heavy AI workloads. The Google TPU v5 is a powerful custom-designed AI accelerator that plays a crucial role in enhancing AI capabilities across various applications, with key architectural considerations, listed below:

- Each TPU v5p (pod) consists of 8,960 chips interconnected using Google's highest-bandwidth inter-chip interconnect (ICI) at 4,800 Gbps per chip.
- The 3D torus interconnection topology ensures efficient communication among chips.
- TPU v5p features more than 2X greater floating-point operations per second (FLOPS) and 3X more high-bandwidth memory (HBM) compared to TPU v4.
- It is designed for performance, flexibility, and scalability, allowing to train large language models (LLMs) 2.8X faster than the previous-generation TPU v4.
- Second-generation SparseCores enable faster training of embedding-dense models [24, 29].

Google has also introduced the concept of the AI Hypercomputer, which employs an integrated system of performance-optimized hardware, open software, leading Machine Learning (ML) frameworks, and flexible consumption models. Unlike traditional methods that enhance AI workloads piecemeal, the AI Hypercomputer uses systems-level codesign to boost efficiency and productivity across AI training, tuning, and serving [25].

Slice Shape	VM Size	# Cores	# Chips	# of Machines	# of Cubes	Supports Twisted?
2x2x1	Full host	8	4	1	N/A	N/A
2x2x2	Full host	16	8	2	N/A	N/A
2x4x4	Full host	64	32	8	N/A	N/A
4x4x4	Full host	128	64	16	1	N/A
4x4x8	Full host	256	128	32	2	Yes
4x8x8	Full host	512	256	64	4	Yes
8x8x8	Full host	1024	512	128	8	N/A
8x8x16	Full host	2048	1024	256	16	Yes
8x16x16	Full host	4096	2048	512	32	Yes
16x16x16	Full host	8192	4096	1024	64	N/A
16x16x24	Full host	12288	6144	1536	96	N/A

Fig. 3. Google TPU Specifications

The Google TPU v5 has been widely used across various industries, including i) healthcare, for medical imaging and drug discovery, ii) automotive, for autonomous driving and advanced driver-assistance systems (ADAS), iii) finance, for algorithmic trading and fraud detection, iv) retail, for recommendation systems and inventory management, and iv) Natural Language Processing (NLP) and Computer Vision (CV), for advanced language models and image analysis purposes. Companies and organizations, such as Salesforce and Lightricks, leverage Google's AI power through the TPU v5 accelerator [29]. The benefits of the Google TPU v5 include a) performance: TPU v5p is one of the most powerful TPUs, with significantly higher FLOPS and memory bandwidth compared to TPU v4, b) scalability, TPU v5p is 4X more scalable than TPU v4 in terms of total available FLOPs per pod, c) efficiency, it offers efficient training and inference for large-scale language models and generative AI, and d) integration, the AI Hypercomputer architecture ensures seamless integration of hardware and software components for optimal performance [24]. The TPU v5p is deployed in pods, with each pod containing multiple chips interconnected using high-speed interconnect technology. Also, the optical switching system, known as the Jupiter interconnect, glues together the Hypercomputer, linking up AI chips and clusters. The TPU v5p flexible networking feature allows connecting the chips within a slice in multiple ways, depending on the desired configuration [24, 29].

Apple has also developed related AI processors. Apple M2 Avalanche core delivers especially in the Neural Network part of the CPU, being a total upgrade from their M1 processors, mainly due to its unified memory. It is chosen due to how well it computationally performs with relatively moderate power consumption levels. Its Neural Engine can process up to 15.8 trillion operations per second. [23], with L1 Cache of 128 KB and L2 Cache of shared 36 MB [19].

Graphcore developed Colossus Mk2 GC200 IPU, whose implementation is shown in Fig. 4, to be used in various applications across different industries, including i) automotive, for AI autonomous vehicles, advanced driver assistance systems (ADAS),

and vehicle perception, ii) consumer Internet, accelerating large-scale recommendation systems, natural language processing (NLP), and personalized content delivery, iii) finance, for risk assessment, fraud detection, algorithmic trading, and portfolio optimization, iv) healthcare, for medical imaging, drug discovery, genomics, and personalized medicine, and v) research, AI research institutions and universities leverage the IPU for cutting-edge machine learning experiments and studies [35, 36]. The IPU-Machine M2000, powered by the Colossus Mk2 GC200 IPUs, is designed for the most demanding machine intelligence workloads and can be used in data centers to build scale-out solutions connecting up to 64,000 IPUs [35, 36]. The Graphcore Colossus Mk2 GC200 IPU included L1 Cache of 80 KB, L2 Cache of 2 MB, and L3 Cache of 60 MB. The Colossus Mk2 GC200 IPU is a massively parallel processor with 59.4 billion transistors, making it one of the most complex processor, 1472 powerful processor cores, each capable of running nearly 9,000 independent parallel program threads, 900 MB In-Processor-Memory with 250 teraFLOPS of AI compute at FP16.16 and FP16.SR (stochastic rounding), supporting much more FP32 compute than any other processor [35], on-die SRAM and streaming memory enhance performance and scalability, and the IPU-Machine system delivering 1 petaFLOP of AI compute with 3.6 GB In-Processor-Memory and up to 256 GB Streaming Memory [35, 36].

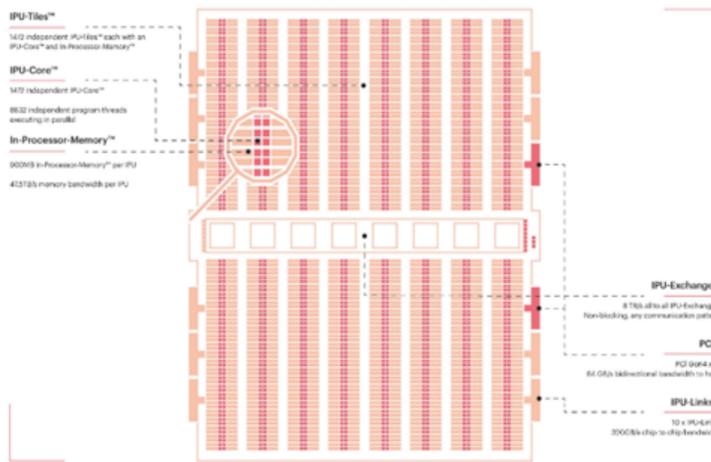


Fig. 4. The Graphcore Colossus Implementation [33]

The Graphcore does not have a typical cache architecture, i.e., it simply features in-processor SRAM memory that is directly connected to the main memory DRAM chips, making data communication within the two both quick and flexible and allowing that chips can hold a lot more memory than other processors. The same processor chip is also designed such a way that connecting to the ethernet gives indirect but very close communication to the in-processor memory, making it much better for AI acceleration since over the internet throughput of data does not bottleneck the processing power [33].

The Colossus Mk2 GC200 IPU features an advanced cache hierarchy, including i) on-chip memory, each IPU holds an unprecedented 900MB In-Processor Memory, significantly enhancing data access speed during AI computations, ii) streaming memory, the IPU-Machine system supplementing on-die memory with up to 448 GB of streaming memory DRAM, providing additional capacity for large-scale models [35]. The Colossus Mk2 GC200 IPU offers high computing capability for fast training and inference of deep learning models, purpose-built architecture optimized for AI workloads, and comprehensive software stack (Poplar SDK) for development and deployment. Also, the same processor differs from other AI implementations in i) the IPU's unique architecture differs significantly from traditional CPUs and GPUs, emphasizing parallelism and memory efficiency, and ii) Graphcore's focus on AI-specific optimizations and scalability sets it apart from other hardware accelerators [35, 36]. The Dell DSS8440 server features 8 dual-IPU C2 PCIe cards, connected with IPU-Link technology, making it the world's first Graphcore IPU server and Dell offers a 2-way PCIe card IPU-Server specifically for inference workloads [35, 36].

The Amazon Web Services (AWS) have also developed their AI related processors. AWS Trainium, shown in Fig. 5, contains two NeuronCore-V2, featuring on-chip SRAM memory, i.e., the definition of cache. Through the documentation for both the Trainium and the NeuronCore, this particular content buffer is not referred as a cache, but as an on-chip SRAM. This particular computational organization allows deep customization of the nature of the cache operation characteristics, by either batching or pipelining the data. Batching loads all data into the cache and reusing that data, and pipelining loads that data across multiple Neuron Cores and runs the calculations among all of them [31].

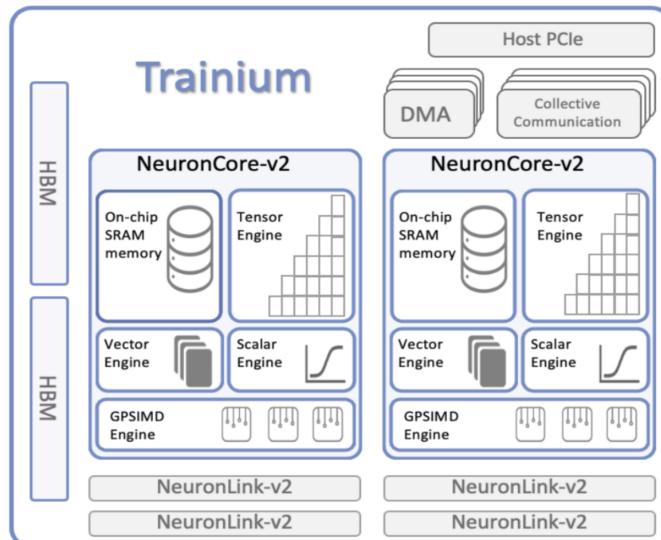


Fig. 5. AWS Trainium Microarchitecture [30]

Cerebras has also developed densely populated processors. The Cerebras CS-3 has high performance SRAM, shown in Fig. 6, but does not tradition shared memory. Each core has 48 KB of local SRAM, designed to have the highest density possible without going down on performance. It also has high bandwidth, featuring ‘two full 64-bit reads, and one full 64-bit write per cycle. In conjunction with that SRAM, they have a small cache composed of 256 bytes that is used for constantly accessed data structures. It is important to note that memory is addressed independently per core [32, 43].

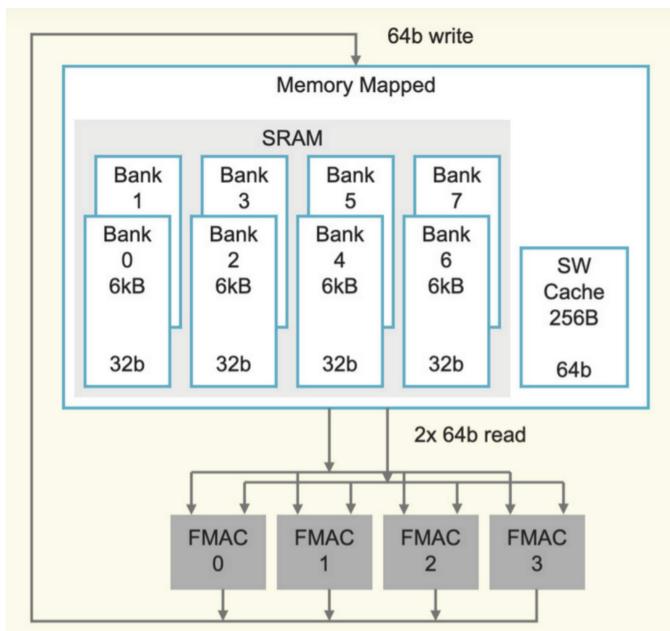


Fig. 6. Cerebras CS-3 Memory Organization [32]

Groq has developed the GroqChip, illustrated in Fig. 7. The Groq LPU has 230 MB capacity of local SRAM [34, 50]. It does not have a traditional cache system, much like the other AI accelerators reviewed in this study, mainly because the efficacy of multilevel cache CPS does not grow linearly alongside large AI models. Groq seems to be focusing on keeping things as simple as possible, with all planning being software based, meaning no cache, no controls, etc. and it is software planned hardware.

Additional cache design efforts focused on AI execution characteristics. SambaNova is another development in the field and its Dataflow Unit provides an integrated hardware and software solution to rapidly deploy and scale AI applications [37]. Tenstorrent Grayskull SoC incorporates a novel architecture focused on high performance and efficiency in AI workloads [40]. Qualcomm also has targeted agile processors with some AI capabilities. Its Snapdragon 8 Gen 2, mainly for mobile phones, included unspecified L1 Cache, L2 Cache of 1 MB, and L3 Cache of 8 MB [20]. Huawei is another company

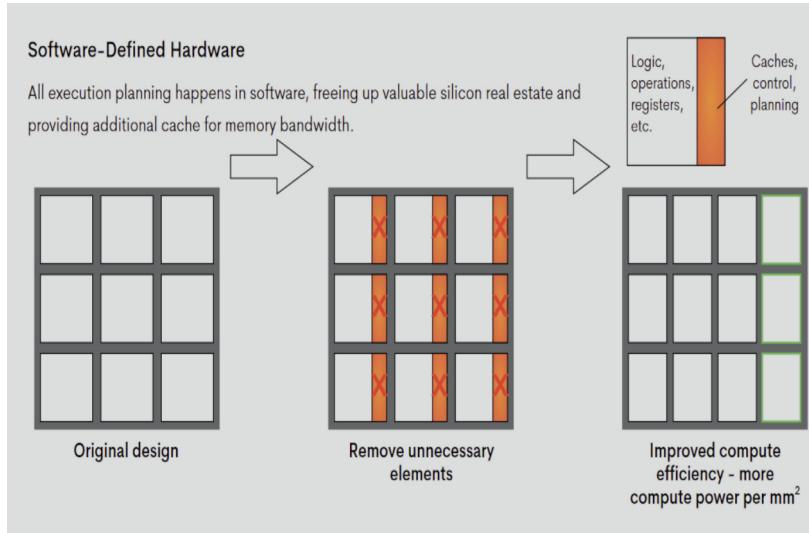


Fig. 7. Groq Processor Characteristics [34]

developing AI processors, e.g., Kunpeng 920 7260, having L1 Cache of 64 KB, L2 Cache of 12 KB, and L3 Cache of 64 MB [21].

3 Cache Design Considerations

All AI accelerators are technological advancements and all desired evaluation data was not available. However, the ModelSim simulation tool was used to evaluate the AI accelerators in a very basic and barebone data exchange simulation that still gives some valuable insight into which cache size is the best for AI workloads. The simulation generates a clock signal of 1.5 GHz, chosen to be the standard across the board since most companies did not disclose the actual clock speed, but it is plausible to assume due to the power consumption, e.g., most are likely within the 1–2 GHz clock range. Our bench program simply tests basic memory access pattern; critical for AI operations since it is the driver of the respective data operation and real time processing capability is one of the most valuable AI considerations. The simulation generates the aforementioned clock cycle, initializes the processor and the cache, and then imitates AI workloads while a clock cycle counts the number of cycles it takes to complete, i.e., the most important part was the nature of cache-processor interactions. When the simulation ends, we have an output of the total cycle count. It may not convey much by its face value but, when comparing it to the other results from the different cache architectures, actual valuable information can be extracted.

Theoretical evaluations of each AI accelerator and related processors have strongly suggested that the cache design closely depends on their intended application domains, i.e., effectively an optimization of domain specific architectural as well as organizational approaches, and varied significantly for different AI accelerators. It should be

noted that there is no single optimal cache design due to multiple different algorithms and their implicit operational and data exchange differences as well as impositions. As the cache sizes and levels are typically determined and adjusted after an iterative simulation-evaluation process, notable new perspectives seem to be adding optical or external local area communication mediums to alleviate potential data exchange burdens for the processing cores.

4 Conclusion

This semester-long undergraduate research study explores major contemporary artificial intelligence accelerator processors and their cache design perspectives with respect to their targeted application domains, i.e., responding to anticipated respective algorithmic or data exchange requirements for targeted implementations.

The current efforts plan to pursue cache design, desired implementations, and related performance issues for the best artificial intelligence accelerators and their efficiency levels against common programs or relevant benchmarks.

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Teaching and Learning Strategies, and Related Research Studies



Features and Data Needs for a Digital Passport for Computer Science Teacher Professional Development Providers

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Abstract. This study explores the need for a centralized platform to track computer science (CS) teachers' participation in professional development (PD) opportunities. PD providers, teachers, and funders all stand to benefit from such a platform, which would streamline data on engagement across multiple PD offerings. The research examined which platform features and data are most valued by PD providers through focus groups and surveys. Results showed that platform usability and data about participants were highly prioritized. This research provides important insights for developers of tools and services supporting CS teacher PD providers, laying groundwork for future innovation in this space.

Keywords: Professional Development · Computer Science PD · Platform features · Focus Groups · Survey Mixed Methods

1 Introduction

Over the last three decades, policy makers and educators have increasingly recognized the importance of teacher professional development (PD) for fostering student growth and academic achievement, particularly within K-12 Computer Science (CS) education [1–3]. This has resulted in the number of CS teacher PD programs nearly doubled from 20214 to 2021, with a particularly sharp increase in the number of programs for elementary CS teachers [4].

PD is particularly important for in-service K-12 CS teachers, as most new CS teachers are prepared through in-service PD and many have limited CS content and pedagogical knowledge [5–7]. Because CS teachers are often the only CS instructor in their schools, PD provides an opportunity for CS teachers to collaborate with and learn from their peers [6,8–10]. Prior research has identified effective elements of PD; through a meta-analysis of teacher PD, [3] identified that effective PD is content-focused, incorporates active learning, supports

All authors contributed equally to this work.

collaboration, uses models of effective practice, provides coaching and expert support, offers feedback and reflection, and is of sustained duration [3].

Other research has indicated that designing effective PD involves not only including certain features, but developing a nuanced understanding of teachers' professional activities, motivations, contexts, and how they implement PD concepts into their practice [11, 12]. Therefore, systematically collecting data from PD providers and participants is vital to understanding and improving the efficacy of PD offerings.

While researchers have generated a large body of literature on effective elements of teacher PD, both within CS education and beyond, there is limited academic literature regarding the data collection and reporting preferences of PD providers. Further, over the last decade the National Science Foundation (NSF) has funded hundreds of PK12 computer science (CS) education projects through myriad funding mechanisms, including CS10K, CS for All:RPP, and INCLUDES programs. While these projects represent a significant expansion in CS teacher PD, there is currently a lack of consistent data collection requirements across funding agencies (at the local, state, and federal levels) for PD programs.

Inconsistent data collection hinders funders' abilities to answer important fundamental questions regarding PD programs including how many unique PK12 teachers have engaged in computer science PD opportunities and what the demographics of those PK12 teachers are. The goal of this study therefore is to understand PD providers' preferences regarding data collection and identify features most important to PD providers in a platform designed to track PD data. We approached this goal with one overarching research question:

Which features and types of data do professional development (PD) providers find most important to include in a platform designed to record data related to teacher engagement with PD?

This research helps fill a gap in the literature about the types of supports CS PD providers need to further support teachers. It also provides a way in which aggregated data from multiple CS PD providers can be collected and reported upon. This aggregated data can be useful for various funding agencies as well as the community to understand PD impacts on CS teachers.

2 Background

Decisions that affect large numbers of people are best made with reference to data. However, to date little research exists that focuses specifically on PD providers' preferences for features and types of data collected while tracking PD. Accordingly, we provide a general background on the power of aggregated data for making decisions about teacher PD, existing tools to collect teacher PD data, and general considerations for collecting teacher demographic data.

2.1 The Power of Aggregated Data for Informed Decision Making in Teacher PD

Despite the importance of collecting data on teacher PD to improve and evaluate program design, few organizations have developed systems to comprehensively track data related to teacher PD. Types of data that could be important to collect range from general demographic data (e.g., geographic locale—urban, rural, suburban) to impacts the PD has on classroom practices and students. For example, measures exist which assess PD quality on features like clarity, cognitive activation, and engagement [13,14]. Such measures could provide summative feedback for PD providers to improve their PD offerings. Collecting content knowledge and pedagogical content knowledge self-efficacy could also enhance PD providers' and researchers' understanding of teacher growth [15]. Other data worth collecting can include types of PD offerings, teacher participation in PD, features of PD, the effectiveness of PD programs, PD participant's background characteristics, or participants' experiences in PD [3,4,16].

More closely related to impacts of the PD on teachers and their students, analyzing how PD ultimately influences students is a primary goal. In one study, for example, PD was found to improve students' academic and social-emotional outcomes [17]. In relation to CS education, impacts on teacher knowledge and confidence in CS education have also been demonstrated. For example, PD can significantly enhance teachers' CS knowledge and pedagogical skills, which also leads to increased self-efficacy [18,19]. Further, positive student perceptions of CS are linked to the quality of teacher PD, highlighting the need for ongoing support and development [20]. PD initiatives can also address gender gaps in CS perceptions, fostering a more inclusive environment for all students [21]. Data related to teachers' needs and supports for using data to meet state and federal accountability expectations can also be powerful for teachers [22].

2.2 Tools to Collect Teacher PD Data

Professional development software can help identify PD needs among teachers, provide critical data about participants to PD providers and administrators, and enhance the delivery of certain PD offerings. Such software can include features to monitor teachers' progress, assess growth against teacher competencies (like the Computer Science Teachers Association (CSTA) Standards for CS Teacher) [23], and facilitate self-reflection—all of which are essential for continuous improvement of teachers [23]. This is even more relevant in a field like CS where the state of the field continually changes.

Systems for data collection are tied to proprietary software (primarily for-profit education technology (edtech) providers) that supports teacher PD and these systems are often opaque. While software that stores teacher PD data may offer significant benefits, challenges remain in ensuring ethical practices in data collection and maintaining engagement among developers. For example, there are serious implications when collecting and storing data that belongs to indigenous people [24,25].

2.3 Considerations for Teacher Demographic Data

No generalizable mechanism by which to collect demographic information is yet available for CS teachers, though numerous ways to collect such information have been employed. It is important to collect demographic data consistently so that comparisons across studies can be made. To this end, several national-level organizations have detailed their preferred methods for collecting demographic information related to race and ethnicity, for example.

The National Science Foundation (NSF) has released guidelines about how to collect certain demographic information. For example, the NSF INCLUDES Shared Measures platform [26] offers examples for how to collect data related to gender, race, ethnicity, first generation college status, economic status, and disability status for all teacher and student participants in programs it funds. Additionally, the US Federal Office of Management and Budget (OMB) released cross federal-agency guidance in 2024 about specific ways to collect race and ethnicity data, which is now combined into a single race/ethnicity question and includes a new “Middle Eastern or North African” category [27]. More closely aligned with computing education, the NSF-funded Expanding Computing Education Pathways (ECEP) Alliance also offers examples of how some states are tracking CS student and teacher participation through a variety of dashboards [28].

3 Methodology

To answer our research question, *Which features and types of data do professional development (PD) providers find most important to include in a platform designed to record data related to teacher engagement with PD?*, we chose an exploratory-sequential mixed methods approach [29] consisting of three rounds of focus groups and one quantitative survey, discussed below.

3.1 Positionality

We position ourselves as an interdisciplinary team of researchers dedicated to enhancing computer science education for all students. We have been formally trained in multiple education research methods and also have extensive teaching experience. We believe that education (and by extension education research) should be conducted to ensure every student participates in personally-meaningful CS education. We further believe that decisions and policies are best made when grounded in data. We recognize the strengths and limitations of both quantitative and qualitative research methods and tailor our methodological approaches to specific research questions.

3.2 Qualitative Strand

The qualitative study consisted of a series of three focus groups with CS PD providers. The main goal of the focus groups was to identify the features of the

digital platform, anticipated challenges, and benefits from a smaller group of PD providers. Using this data, we could then create a survey to be sent to a larger group of CS PD providers.

The series of three focus groups provided an opportunity to explore PD provider needs in more depth. Topics each week were:

- Week 1 - Challenges that CS PD providers face when keeping track of the PD offerings (types CS PD opportunities, participant registration, workflow, organization, certificates of completion)
- Week 2 - Features and data that CS PD Providers will need included (integration to tools and other apps, ability to add specific details about PD offerings, data, advertisement of PD offerings)
- Week 3 - CS PD Providers were provided findings from teachers, administrators, and both CS PD Providers focus group from the last two weeks in a google form. They were instructed to post comments about findings they particularly agreed or disagreed with. Additionally they were asked to post comments and questions with suggested additions to the findings, as appropriate.

Ethics approval was obtained through one of the institution's IRB board and the study was established as exempt.

3.2.1 Participant Selection

Participants were purposefully selected from over 680 CSTA members who completed the screening questionnaire sent via email by CSTA to all CSTA members. Our selection criteria for focus group participants were, first, the availability to attend focus groups at specific dates and times. After availability was established by selections made in the screening questionnaire, we then considered a diverse set of participants across gender, race/ethnicity, disability status, and teaching in a rural vs. non-rural setting. Based on our analysis, CS PD Providers ($n = 19$) were invited to attend three virtual focus groups.

3.2.2 Participant Demographics

Participants who attended the focus groups were provided with up to a \$50 gift card as a token of appreciation for their participation in focus groups (amount established based on actual attendance). Of the CS PD providers that actually participated in the focus groups ($n = 15$), 11 were women and four were men. Nine (60%) served rural communities. The CS PD Providers identified as White ($n = 8$), Hispanic/Latinx ($n = 2$), Black ($n = 2$), Cuban-American ($n = 2$) and Indigenous ($n = 1$).

3.2.3 Data Collection and Analysis

Data was collected during the synchronous virtual weekly meeting held via Zoom. Each focus group interview session was limited to 60 min in duration (though most lasted on average 45 min, with the fastest lasting 39 min) and was recorded.

The series of questions posed to the focus group participants that inquired about their challenges in collecting data, their needs, and their challenges. Sample questions included:

- How do you keep track of your CS PD offerings (types CS PD opportunities, participant registration, workflow, organization, certificates of completion)?
- Have you had any challenges with keeping track of your CS PD offerings (types CS PD opportunities, participant registration, workflow, organization, certificates of completion)? If yes - What challenges, if any, have you encountered in recording and managing your CS PD activities? If no - What opportunities do you think the app could offer for teachers who want to grow their CS PD experiences?
- In what ways do you think this app would impact your role as a CS PD provider? (or in other words, how would you envision using this app?)
- In your opinion, what would make the adoption of this app successful among CS PD providers?

Data from each focus group session came in two forms: transcripts and Jamboard notes. The verbal discussions from each focus group were transcribed and analyzed in tandem with the notes added to Jamboards, which accompanied most of the questions in each focus group session. Additionally, any comments from the Zoom chat were included in the data analysis. Analysis included one researcher reviewing all data, then establishing codes and themes to determine the challenges, needs, and usability features for the platform.

3.3 Quantitative Strand

Our team then used the focus group data to build a survey to capture quantitative data from a wider set of PD providers. We identified 37 different features or types of data mentioned in the focus groups to include in the survey. Exact wording for these items was developed iteratively to balance comprehension with brevity of each item so that the time to complete the survey was not too extensive.

The survey presented the items and asked respondents to rate which data points and features would be most important to them in a new platform designed to keep track of PD participation and related data.

3.3.1 Participant Selection

Participants were recruited via email sent through the CSTA listserv to all CSTA members. A special email was sent to PD providers to encourage them to complete the survey, since the number of CS PD providers is relatively small. Although the broader study includes teachers, school administrators, and PD providers, only responses for PD providers are included in this paper.

3.3.2 Participants

In total, 18 CS PD providers responded to the survey, the majority of whom were women (56%) and White (61%). Table 1 displays the basic demographic breakdown of these participants. Survey participants could enter a raffle to win one of ten \$50 gift cards as a token of appreciation for their participation.

Table 1. Demographics of the Respondents

	N	%
Gender		
Women	10	55.56
Men	6	33.33
Non-binary	0	0.00
Self-described	0	0.00
Did not answer	2	11.11
Multiple Selections	0	0.00
Race/Ethnicity		
African American or Black	1	5.56
Asian - Central	0	0.00
Asian - East	2	11.11
Asian - South	1	5.56
Asian - Southeast	0	0.00
Hispanic/Latino(a)	0	0.00
Native American or Alaska Native	0	0.00
White	11	61.11
Self-described	0	0.00
Did not answer	3	16.67
Multiple selections	0	0.00

3.3.3 Data Collection and Analysis

PD providers rated 36 items on a scale from 1 (Not at all important) to 7 (Extremely important) which corresponded to types of data and features that could be included in the forthcoming PD data platform. Descriptive statistics were calculated for each item, and the 10 features or data that (on average) were rated highest and the 5 features or data rated lowest were identified. We also identified features or data that were rated (on average) a 5.5 or above, which we interpreted as particularly desirable features or data.

Beyond descriptive statistics, we also compared four categories of features and data regarding their average ratings (see Table 6). That is, each of these four categories represents multiple individual features or data points which PD

providers rated and which are similar to each other. The *Usefulness & Usability* category included 9 items, the *PD Attendance Data* included 9 items, the *PD Impacts Data* category included 11 items, and the *General Data* category included 7 items. After obtaining one average rating for each category, we conducted a one-way repeated-measures ANOVA to determine if the PD providers rated the four categories similarly.

4 Results

4.1 Qualitative Results

4.1.1 Usefulness and Usability Features

Participants in the focus group shared features that provide CS PD providers utility and usefulness. They noted the platform should include opportunities for PD providers to market themselves such as by including their experience and qualifications in their PD provider profile and the platform's ability to recommended CS PD based on identified teacher needs or trends in PD participation. Participants also voiced features that allow for communication are needed such as forums, options for teachers to share follow up information on the long term outcomes of PD, ability for PD provider to respond to teacher feedback and share reports with other organizations, integration of platform with current platforms, and an organized and searchable database of upcoming PD with calendar/date options. Additionally, PD providers named the following features: relevant information and resources available through the app, content moderation, a consistent option for pre and post surveys connected to their PD offerings, and Artificial Intelligence (AI) ability to generate and input recommendations in database, provide more utility and usefulness.

4.1.2 Data to Collect

Participants in the focus group shared the information included on the platform should be both the PD provider name and contact information and the name of the organization offering the PD. Other details shared are PD providers list of offerings- both current and in the past, how many teachers have attended the provider's sessions, how teachers are implementing what they learned in the provider's CS PD, how many students the CS PD has reached, and recommendations for what course teachers should take next based on the provider.

In addition, PD providers would like the platform to capture course content information (e.g., title, grade level, content taught, and pedagogy covered) and PD offering information (e.g., date and time of PD, training hours, cost of the PD) should also be included.

4.1.3 Presentation of CS PD Data

CS PD providers would like the platform to capture various pieces of data over time including enrollment numbers. Specifically, PD providers would like data that details the registration vs. attendee numbers of their PD offerings and enrollment number of PD offerings sessions separated by days/times to see if there

are topics or availability trends. Lastly, PD providers mentioned they would like the platform to have registration vs completion data available for them to view privately. PD providers mentioned wanting the platform to capture the history of CS PD opportunities offered in the past and participation based on contexts of teachers (e.g., grade level taught, teacher role, CS and overall teaching experience), teacher's content preference, and school demographics such as geographic location, and course participation of teachers overtime.

Additionally, focus group participants would like the platform to include overall topics of interest and trends in the popularity of the topics. The trends PD providers listed are time of year, duration, format, and modality of CS PD offering. Ultimately, they want to know which topics are more or less popular from teacher's perspective. They also want the platform to present areas of need/gaps missing in CS PD offerings, teachers' self-efficacy over time, and impact of CS PD for students.

4.2 Quantitative Results

All of the features and types of data that PD providers rated were grouped into one of four categories (but were not displayed that way to the PD providers).

4.2.1 Usefulness and Usability Features

Items related to *usefulness and usability* assessed the importance of features that might enhance PD providers' perceived usefulness and/or ability to use the platform. Table 2 details the average ratings of select features which were rated at least 5.5 our of 7, on average. Note that the scale participants used ranged from 1 (Not at all important) to 7 (Critically important). Thus, an average rating of 5.5 or above indicated that the associated feature or datapoint was highly important to PD providers. Notably, the ability to integrate the new platform with other applications was the most important usability feature for PD providers.

4.2.2 PD Demographic Data

Items related to *PD demographic data* assessed PD providers' opinions about how important data related to the participants attending their PD opportunities was. As seen in Table 3, these datapoints and features were rated lower overall compared to the usefulness and usability features presented in Table 2. Still, PD providers thought it would be important to see data related to attendance at their PD offerings.

4.2.3 PD Impacts Data

Items related to *PD impacts data* assessed PD providers' opinions about how important it was to collect data related to the impacts their PD opportunities had on attendees (e.g., their self-efficacy, self-reported changes in their instructional practice). As seen in Table 4, PD providers were highly interested in assessing impact of their PD offerings. In fact, all of the items on the survey that asked

Table 2. Features that were rated at least 5.5 out of 7

Feature	Mean (SD)	Min-Max
Integration of the platform with other apps (e.g., Google spreadsheets)	6.27 (0.88)	4-7
Recommended PD based on identified teacher needs or trends in PD participation	6.19 (1.33)	2-7
Ability to respond to teacher feedback	6.06 (0.93)	4-7
Ability to upload data in bulk (i.e., for district-wide CS offerings)	6.06 (0.93)	4-7
Resources exchange for participants (i.e., free or selling/purchasing)	6.00 (1.51)	2-7
Ability to list scholarship/sponsorship opportunities for CS PD	5.73 (1.28)	2-7

Table 3. Demographic features that were rated at least 5.5 out of 7

Datapoint	Mean (SD)	Min-Max
Number of teachers who attended a CS PD offering	5.81 (1.52)	1-7
Number of teachers served by a particular CS PD provider	5.67 (1.63)	1-7
Number of teachers who enrolled in a CS PD offering	5.63 (1.63)	1-7
Most frequently attended CS PD by topic	5.80 (1.57)	1-7
Number of teachers who attempted and/or completed each CS PD offerings	5.56 (1.71)	1-7
Course Participation: Retention of participants for long-term PD series	5.56 (1.50)	1-7
Individual teachers' list of CS PD completed/enrolled in	5.53 (1.77)	1-7

about different types of impacts of PD offerings were rated quite highly on average (at least 6 out of 7).

4.2.4 Additional Features

Finally, survey items related to *additional data features* assessed PD providers' opinions about how important general data features were (e.g., seeing the history of CS PD offerings offered by a provider, areas of PD that are not yet served). Only four of these general features were rated at or above our 5.5 point criterion (Table 5).

4.2.5 Comparing Types of Features and Data

We conducted a repeated-measures ANOVA to ascertain whether or not PD providers rated these types of features or data equally to each other. The Repeated Measures ANOVA test indicated that there is a significant difference in PD providers' average ratings of each Feature type ($F(3, 54) = 6.39, p < .01, \eta^2 =$

Table 4. Datapoints related to impact of PD offerings that were rated at least 5.5 out of 7

Datapoint	Mean (SD)	Min-Max
Teacher feedback for each offering and/or provider	6.40 (0.91)	4–7
Teachers' self-efficacy for teaching CS over time	6.31 (1.01)	4–7
Teachers' perceived impact of CS PD on their instruction	6.31 (0.87)	4–7
Self reported knowledge before and after CS PD	6.27 (0.96)	4–7
Teachers' self-reported self-efficacy before and after CS PD	6.25 (1.00)	4–7
Information about how PD influences student understanding	6.25 (0.93)	4–7
How teachers are implementing what they learned in the CS PD.	6.19 (0.91)	4–7
Number of students (estimated) that teachers who are enrolled in a CS PD teach in their school (to give an indication of the number of students CS PD has reached)	6.13 (1.41)	2–7
Teachers' self-reported knowledge before and after CS PD	6.13 (1.15)	4–7
Certificates earned/grad credits for each CS PD offering	6.00 (1.46)	1–7
Teachers' perceived impact of taking CS PD (i.e., changing their instruction) on their students	6.00 (1.10)	4–7

Table 5. General data and features that were rated at least 5.5 out of 7

Datapoint	Mean (SD)	Min-Max
A forum for teachers to share what they are learning in the PD	6.07 (1.28)	3–7
Areas of need/ gaps missing in CS PD offerings	5.81 (1.60)	1–7
CS courses that teachers teach based on their profiles	5.87 (1.55)	1–7
Popular times for CS PD to be held	5.63 (1.59)	1–7

.01). Specifically, post hoc analyses using the bonferroni correction for multiple comparisons indicated that PD providers' ratings of the *PD impacts data* was higher on average than all of the three other feature types (see Table 7).

5 Discussion

5.1 Highest Rated Features

Results showed that PD providers were largely in favor of all of the features or data presented in the survey, confirming the suggestions from the focus group participants. The 10 highest rated features or data are displayed in Table 8.

Overall, PD providers wanted features related to the usability of the platform, such as integrating the platform with other apps and getting recommended PD topics based on identified teacher needs. Providers also wanted several pieces of data about their participants from the platform, including their feedback for

Table 6. Types of Features & Data Compared

Feature Type	Mean (SD)	Median	Min-Max
Usefulness & usability	5.73 (1.01)	5.89	2.78–7
PD attendance data	5.51 (1.46)	6.11	1–6.89
PD impacts data	6.20 (0.89)	6.36	3.64–7
General data	5.60 (1.34)	5.93	1.29–7

Table 7. Posthoc pairwise comparisons using marginal means

PD impacts data vs:	Marginal Mean Difference	t	p
Usefulness & usability	0.18	11.3	<.01
PD attendance data	0.63	12.10	<.01
PD impacts data	-	-	-
General data features	0.55	16.10	<.001

each PD offering, self-reported knowledge related to the PD, and how teachers are implementing what they learned in the PD.

5.2 Lowest Rated Features

Although PD providers rated the features in Table 9 lower than all other feature we asked about, it is important to note that these features were still rated positively on average (i.e., above the neutral rating of 3). Still, it is interesting to see that PD providers did not prioritize these features compared to some of the other features and data which were tied more closely to the platform's usability (e.g., integrating the platform with other apps).

5.3 Types of Features and Data Compared

As seen in Tables 6 and 7, PD providers on average prioritized data related to the impacts their PD offerings were having on teachers and students. They wanted the platform to provide this type of data more so than even attendance data or other usability features. These results indicate that such data types may be key to motivating PD providers to actually use the platform once it is developed. That is, if PD providers can view data related to impacts of their PD, they may be much more likely to adopt the platform and use it consistently.

5.4 Limitations

One of the limitations of this study is the number of CS PD providers was limited to just 18. While this sample size provides some preliminary insight about PD providers' priorities, additional research should include more PD providers

Table 8. PD Providers' 10 most highly rated features

Feature	Mean (SD)	Median	Min-Max
Teacher feedback for each offering and/or provider	6.40 (0.91)	7	4–7
Teachers' perceived impact of CS PD on their instruction	6.31 (0.87)	6.5	4–7
Teachers self-efficacy for teaching CS over time	6.31 (1.01)	7	4–7
Integration of the platform with other apps (e.g., Google spreadsheets)	6.27 (0.88)	6	4–7
Self reported knowledge before and after CS PD	6.27 (0.96)	7	4–7
Information about how PD influences student understanding	6.25 (0.93)	6.5	4–7
Teachers' self-reported self-efficacy before and after CS PD	6.25 (1.00)	6.5	4–7
Format or Modality of PD (i.e., in-person, hybrid, virtual/remote)	6.22 (0.73)	6	5–7
Recommended PD based on identified teacher needs or trends in PD participation	6.19 (1.33)	7	2–7
How teachers are implementing what they learned in the CS PD.	6.19 (0.91)	6	4–7

to further assess the generalizability of these findings. Further, because this platform is being developed specifically for educators based in the U.S., the results presented in this paper may be less applicable to other international educators. Finally, these data were generated from participants who had not yet interacted with the platform (because it is in development). Thus, their preferences and priorities may differ after seeing and interacting with the platform for an extended time.

6 Conclusion and Future Work

This study is one of the first to document PD providers' opinions about the features and data types they would like to see in a platform designed to track their PD offerings and related data. Our mixed-methods study found broad support for most of the features and data types that the PD provider focus groups identified. Indeed, all of these features and data types were rated favorably, on average (i.e., above 4 on a 7-point scale). Still, future work could account for some of the limitations in this study. For example, future work should expand the sample of PD providers from which data is collected. While we believe these 18 PD providers likely represent opinions from a larger population of PD providers across the United States, a larger sample size would confirm or correct this belief. Additionally, future research could expand this study into other contexts

Table 9. PD Providers' 5 lowest rated features

Feature	Mean (SD)	Median	Min-Max
Demographics summary of participants in each CS PD offering	5.13 (2.23)	6	1–7
CS PD Provider Ratings: From participants, private view only	5.13 (1.59)	5	1–7
Most frequently attended CS PD by cost	5.00 (1.73)	5	1–7
Ability to compare credit value of PD against one another	4.93 (1.62)	5	1–7
Links to CS PD recordings after completion of PD	4.67 (1.28)	4	2–7

outside of the United States. PD providers in other countries may have similar or distinct opinions about the features and data points that such a platform should include. Future work from our team will gather additional usage data and opinions from users once the platform is fully functional, and we plan to publish updated results about which features and data points are most useful to actual users in the near future.

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Enhancing Student's Learning by Integrating the Concept of Project-Based and Challenge-Based Learning

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Abstract. This study aims to enhance student learning in the introductory data science course by combining Project-Based and Challenge-Based Learning methodologies. The goal is to improve student performance, engagement, and comprehension of data science subjects through research and development. By integrating challenge-based learning (CBL) and project-based learning (PBL) into a cohesive teaching approach, the benefits of both approaches are employed to improve the learning experience for students. This methodology facilitates in-depth comprehension, critical reasoning, and practical application of data science skills, preparing students for academic success and real-world obstacles. The research sample comprised 56 third-year undergraduates from the Computer Science department, selected using a purposive sampling method. Data analysis involves the utilization of several statistical techniques such as the t-test, analysis of covariance (ANCOVA), mean, standard deviation, and other relevant statistics. The findings indicated that students who utilized a blend of Project-Based and Challenge-Based Learning methods had a notable increase in academic performance post-learning, as compared to their pre-learning performance, with statistical significance. Firstly, students at the 05 level are more likely to express their satisfaction with the course of study. This is primarily because the course incorporates problem-based learning (PBL) and case-based learning (CBL), which are both engaging and practical teaching methods. Furthermore, this implies that improving student achievement in the data science course is an effective use of the integrated teaching methodology.

Keywords: data science course · Project-Based Learning · Challenge-Based Learning · Student's Learning

1 Introduction

Data Science is a multidisciplinary domain that employs scientific techniques, methodologies, algorithms, and systems to derive insights from different types of data, including structured, semi-structured, and unstructured data [1,2]. Cao et al. [3] define data science as the scientific study of data, encompassing the creation of data products that

can include discoveries, predictions, services, suggestions, and insights for decision-making, thoughts, models, paradigms, tools, or systems. Data science is a field that combines statistics, data analysis, and machine learning to get insights and evaluate real-world events in data. It utilizes mathematical, statistical, computer science, and information science ideas and methodologies [4–7]. Consequently, the instruction of data science requires proficiency in exploiting large datasets. Through gathering and overseeing extensive data Utilize data analysis techniques to reveal undiscovered patterns of relationships through the formation of mathematical models. Upon analysis, these entities have been used to assist with strategic business decision-making. Engaging in the creation of products and services, as well as predicting future operational outcomes [8]. Instructors have challenges when teaching data science programs due to the interdisciplinary nature of the topic and the varying backgrounds and skill levels of students. An effective data science education involves a comprehensive approach that integrates academic understanding, practical expertise, and industry applicability. Nevertheless, it is challenging to discover suitable instructional methods and resources that effectively incorporate all of these components inside the context of learning. In the past, data science teaching has concentrated on teaching students the essential technical skills involved in cleaning an easily accessible dataset, visualizing it, and generating conclusions from it through statistical analysis [9].

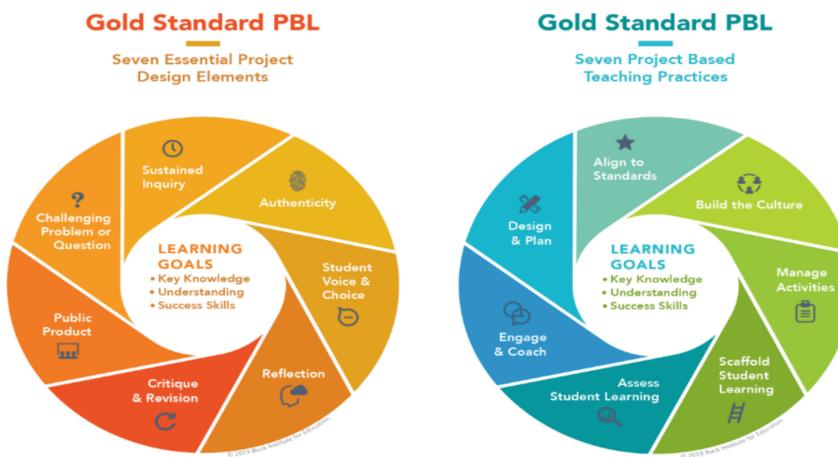


Fig. 1. Project Based Learning Framework [13]

Project-Based Learning (PBL) is an educational approach that prioritizes learning by actively exploring and engaging in real-world projects [10–12]. Project-based learning (PBL) involves students learning information and skills via an extended time of working on complex issues, problems, or challenges and this method promotes student autonomy and facilitates the application of information in real and meaningful contexts. The paper explores the advantages of incorporating Project-Based Learning (PBL) into data science learning, emphasizing its ability to actively involve students and its compatibility with the investigative approach of data science projects [14].



Fig. 2. The Challenge Learning Framework [16]

Challenge-based learning is a pedagogical approach that was established by Apple through the “Apple Classroom of Tomorrow-Today (ACOT2) program” in early 2008. It involves the use of challenges to foster curiosity and engagement among learners. In addition to fostering opportunities for students to engage in discussions and promote the application of problem-solving skills to complex challenges [15]. Challenge-Based Learning (CBL) is an educational method that involves students in the process of solving practical problems that exist in the real world. This approach is specifically developed to provide an interaction between theoretical classroom learning and practical, real-world problems. It aims to motivate students to utilize their knowledge and skills to identify and implement effective solutions as shown in Fig. 2 [16]. Characterized by its emphasis on collaboration, inquiry, and iterative learning, CBL is a dynamic and student-centered approach to education [17–19].

Presently, there is a substantial need for individuals with data science degrees in the workforce. The institution has initiated the provision of data science courses. Thus, the aim is to provide students with the necessary knowledge and skills to understand and analyze data science concepts, theories, and principles in a thoughtful and discerning manner. They can employ analytical reasoning and creativity to overcome challenges in both practical and research domains. Proficient at leveraging information technology to effectively address practical challenges. By incorporating Project-Based Learning (PBL) and Challenge-Based Learning (CBL) methodologies into an introductory data science course, student performance can be significantly improved in various areas. These include raised engagement and motivation, enhanced problem-solving skills, improved collaboration and communication skills, a greater understanding of data science concepts, higher academic achievement, and the development of lifelong learning skills. The objective of this research is to evaluate the effects of blending Project-Based Learning (PBL) and Challenge-Based Learning (CBL) on student performance in an introductory data science course, as well as to investigate students' perspectives on the integrated PBL and CBL approach.

2 The Research Hypothesis

Null Hypothesis (H0): There is no statistically significant difference in student performance between the groups that employed the combined PBL and CBL strategy and the traditional approach, after controlling for the covariate.

Alternative Hypothesis (H1): There is a significant difference in student performance between each group regardless of taking into consideration for the covariate.

3 Research Methodology

This research focuses on the integration of Project-Based and Challenge-Based Learning. The study includes the design, development, and assessment of this integration. The following sections provide information about the participants, data collecting, analysis, and methodology.

3.1 Participants

In semester 2023, a total of 56 undergraduate students were enrolled in a data science course. These students were separated into two groups.

- **Group A** consists of 30 students who are engaged in the integrated Problem-Based Learning (PBL) and Case-Based Learning (CBL) approaches.
- **Group B** consists of 26 students who are being taught using the traditional lecture-based teaching approach.

3.2 Data Collection Instruments

Pre-and Post-Tests: To assess the level of information acquisition and the resulting learning outcomes and the pre and post-tests contain questions that encompass fundamental principles of data science, including data analysis, statistical approaches, and machine learning.

Surveys and Questionnaires: To evaluate student engagement, satisfaction, and perceived educational achievements and the design of the survey includes Likert-scale questions, which are used to collect quantitative data, and open-ended questions, which are used to collect qualitative data.

Focus Groups and Interviews: To collect comprehensive feedback regarding student experiences with the PBL and CBL and traditional methodologies and 10 students from each group are selected as participants, using a random selection process.

Observation of a Classroom: To carefully investigate student behavior, engagement, and collaboration in both Problem-Based Learning (PBL) and Case-Based Learning (CBL) session and traditional sessions.

3.3 Design Procedure

In this study, we design the research design process steps in the following:

- 1 **Course Design:** Learning objectives are precise statements that outline the knowledge, comprehension, or skills that learners should possess upon finishing a learning activity. The learning outcomes are clearly defined and quantified, and the course structure is designed to align with the chosen subjects, organization, and sequencing of course content. Furthermore, the research design processes of Integrating the Concept of Project-Based and Challenge-Based Learning was proposed in this stage as presented in Fig. 3.
- 2 **Implementation:** This step creates diverse teams to foster collaboration and incorporate a range of viewpoints to ensure that each team is composed of individuals with a diverse range of abilities and varying degrees of experience and the terms will be guidance and supply the requisite resources and tools needed to successfully finish the project.
- 3 **Evaluation and Assessment:** the process evaluates students' progress and understanding during the learning process and the final project presentation involves students showcasing their projects to the class, effectively illustrating their discoveries and the practical implementation of data science methodologies. Skills and Learning Outcomes are assessed by quizzes and exams.

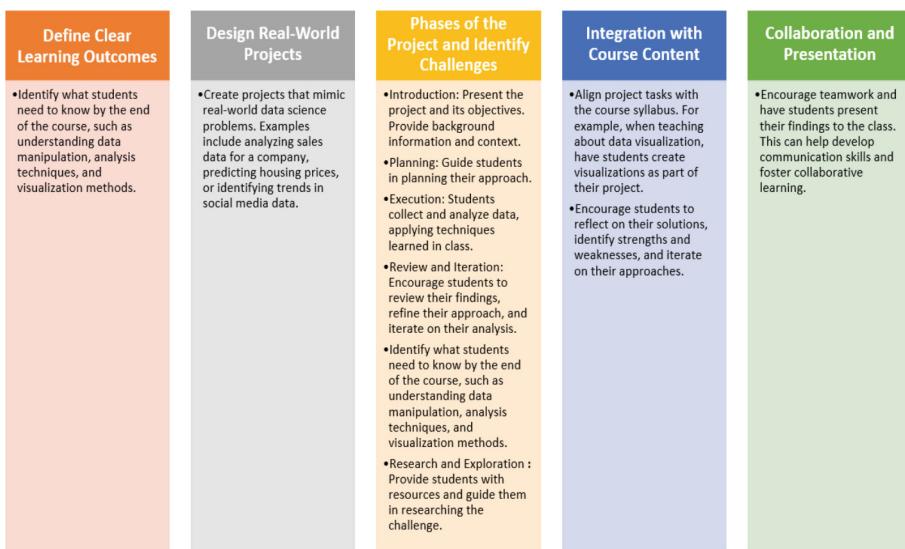


Fig. 3. The research design process of Problem-Based Learning (PBL) and Case-Based Learning (CBL) approach approaches

3.4 Data Analysis

Quantitative Analysis (Pre-and Post-Tests and Questionnaires Data)

Descriptive statistics will be computed for the pre-test and post-test scores, project scores, and participation metrics and t-Tests are used to compare the pre-test and post-test scores within each group in order to assess the extent of learning improvements. Inferential Statistics: t-Tests are used to compare the pre-test and post-test scores within each group in order to quantify the amount of learning gains. Furthermore, Analysis of covariance (ANCOVA) is employed to assess the differences in averages across several groups while taking into consideration the impact of one or more continuous covariates (variables). ANCOVA is a statistical model that combines the features of both ANOVA (analysis of variance) and Regression. Within the scope of our study investigating the effects of integrating Project-Based Learning (PBL) and Challenge-Based Learning (CBL) in an introductory data science course, ANCOVA can be employed to evaluate whether the combined approach results in significant variations in student performance, while accounting for potential variables that could impact the outcomes.

Qualitative Analysis (Focus Groups and Interviews)

Thematic Analysis is employed to determine typical themes from open-ended survey responses, focus group discussions, and interviews [20]–[23]. Data analysis entails the process of identifying and documenting patterns within a dataset, which are subsequently evaluated to uncover their intrinsic significance [24] and this research generated main themes from the data to 3 themes: Enhanced engagement and practical training, Development of Collaborative Skills, and Challenges with Self-Direction. Narrative analysis is employed to examine students' perspectives of their experiences to comprehend the effects of each instructional method.

Observation Data

Engagement Levels is utilized to evaluate the overall level of engagement in each approach by analyzing the frequency and quality of interactions. This approach provides significant perspectives on how effective these methods are for sustaining student engagement in the learning process. The data is collected from the frequency of interactions, like Class Participation: monitoring the frequency with which students engage in class discussions, pose inquiries, or contribute to group activities, Group Collaboration: Group Collaboration: assessing the frequency of interactions that occur during group work, including discussions, peer feedback sessions, and collaborative problem-solving, and Instructor-Student Interaction: determining from the frequency of student-initiated interactions with the instructor, including office hours, emails, and post-class inquiries.

4 Results

4.1 Pre-and Post-Tests and Questionnaires Data

Pre-and Post-Tests

This study was the research by the established design research processes. The findings of the research are reported as follows: The outcomes of the experiment for integrating

project-based and challenge-based learning are illustrated in Table 1 and Table 2. Table 1 and Table 2 display the comparative outcomes of academic performance. The study aims to compare the academic performance of students who are taught using the integrated Problem-Based Learning (PBL) and Case-Based Learning (CBL) methods with those who are taught using the traditional lecture-based teaching strategy.

Table 1. The comparative results of academic achievement of Group A: using the integrated Problem-Based Learning (PBL) and Case-Based Learning (CBL) approach.

The results of academic achievement	N	Mean	S.D.	t	p
Pre-test	30	48.62	9.27	11.54	.000*
Post-Test	30	57.03	9.12		

Table 2. The comparative results of academic achievement of Group B: using the traditional lecture-based teaching approach.

The results of academic achievement	N	Mean	S.D.	t	p
Pre-test	26	44.26	9.16	17.52	.000*
Post-Test	26	52.04	10.89		

The results demonstrate the academic performance of two distinct groups, Group A and Group B, both prior to and during an educational intervention, presumably employing diverse instructional approaches.

Group A: The mean score shown a rise from 48.62 (pretest) to 57.03 (posttest), signifying an enhancement in academic performance after the intervention.

The standard deviation exhibited a slight decline from 9.27 to 9.12, indicating that the dispersion of results within the group remained generally consistent.

The t-value of 11.54, accompanied by a p-value of .000*, demonstrates that the rise in scores from the pretest to the posttest is statistically significant, implying that the alteration is improbable to be attributed to random variation.

Group B: The mean score showed a rise from 44.26 (pretest) to 52.04 (posttest), indicating an enhancement in academic performance for this particular group.

When conducting a comparative analysis between groups, the results indicate that both Group A and Group B demonstrated substantial enhancements in their academic performance from the initial assessment to the final assessment, as evidenced by the very significant p-values ($p = .000^*$). Nevertheless, the average increase seems to be greater in Group A, with a magnitude of 8.41 points, as opposed to Group B, which shows a mean gain of 7.78 points. These findings indicate that although both groups derived benefits from the educational intervention, Group A exhibited a little more pronounced enhancement in academic performance. The pretest scores reveal that Group A had a higher mean score (48.62) than Group B (44.26), implying that Group A may have had a somewhat superior beginning understanding or ability level. Also, The p-value of .000*

for all tests suggests that the improvements in both groups are extremely statistically significant. This indicates that the probability of these enhancements happening by coincidence is exceptionally small. The consistent t-value of 11.54 in all posttests, except for the pretest in Group B which has a higher t-value of 17.52, strengthens the reliability of the results, indicating a significant impact of the intervention on academic performance.

Table 3. The results of analysis of covariance (ANCOVA)

Source	Sum of Squares	df	Mean Square	F	p
Controlling for prior knowledge (Pre-Test Scores)	6.246	1	6.246	.262	.600
Group	49.327	2	218.163	1.039	.316
Error	1946.236	84	21.654		
Total	2001.809	87			

* p < .05

An Analysis of Covariance (ANCOVA) examines the impact of an independent variable (likely the instructional method, such as PBL and CBL versus traditional) on a dependent variable (post-test scores), while accounting for a covariate (pre-test scores) as presented in Table 3.

The interpretation of the results with controlling for prior knowledge (pre-test scores) is as follows: The Sum of Squares (SS) quantifies the amount of variance in the dependent variable (post-test scores) that can be ascribed to disparities in pre-test scores (the covariate). The number of degrees of freedom (df) is 1, which is the expected value for a single covariate. The Mean Square (MS) is obtained by dividing the Sum of Squares (SS) by the degrees of freedom (df), which in this particular situation is equal to 6.426 divided by 1, resulting in a value of 6.426. The F-value of 0.262 indicates that the influence of pre-test scores on post-test scores is minimal compared to the unexplained variation. The p-value of 0.600 is considered strong, suggesting that there is no significant relationship between the pre-test scores and the post-test scores in this analysis. Put simply, adjusting for prior knowledge (pre-test scores) does not have a substantial impact on the result.

The findings of the study on Group (Independent Variable - Instructional Method) are analyzed: The Sum of Squares (SS) quantifies the amount of variation in post-test scores that can be specifically attributable to the differences between the groups, such as the distinct teaching methods used. The degree of freedom (df) is 2, which is normally equal to the number of groups minus one. The Mean Square (MS) is obtained by dividing the Sum of Squares (SS) by the degrees of freedom (df), resulting in a value of 218.163, given that the SS is 49.327 and the df is 2. The F-value of 1.039 indicates that the differences between the means of the groups (post-test scores) are relatively small compared to the variation within the groups. The p-value of 0.316 exceeds the customary threshold for significance (often $p < 0.05$), suggesting that there is no statistically significant difference in post-test results between the teaching approaches, even when accounting for prior knowledge.

The interpretation of the results for Error (Residual Variance) is as follows: the Sum of Squares (SS) for Error quantifies the amount of unexplained variability in the post-test results, taking into consideration the influence of the covariate (pre-test scores) and the independent variable (instructional method). The degrees of freedom (df) of 84 indicates the number of independent elements of information available after accounting for the degrees of freedom used by the covariate and the independent variable. The Mean Square (MS) is obtained by dividing the Sum of Squares (SS) by the degrees of freedom (df), which in this case is 1946.236 divided by 84, resulting in a value of 21.654. The result demonstrates the mean deviation within the groups that cannot be explained by the model.

The outcomes of Total are analyzed: the Sum of Squares (SS) for Total indicates the overall variation in the post-test scores, which includes both the explained and unexplained differences. The degrees of freedom (df) are equal to the total number of observations minus one, which in this case is 87.

Questionnaires Data

The survey aims to collect students' perspectives on the effectiveness of the integrated Project-Based Learning (PBL) and Challenge-Based Learning (CBL) approaches compared to a regular teaching method. These questions encompass different facets of the learning process, such as involvement, perceived educational achievements, and personal preferences. The results of the satisfaction of students were shown in Table 4. Table 4 presented the results of student feedback about the effectiveness of an integrated Problem-Based Learning (PBL) and Case-Based Learning (CBL) approach to various aspects of their learning experience, such as engagement, motivation, learning outcomes, collaboration, and problem-solving.

In the topic of Engagement and Motivation: Students expressed an overwhelming feeling of engagement with the course material when using both Problem-Based Learning (PBL) and Case-Based Learning (CBL) methods and the high average score (4.88 out of 5) indicates that the majority of students felt very involved with the topic, and the low variability (0.32) suggests that this attitude was consistently shared within the group. The technique promoted a greater level of active and independent learning among students. Students, on average, agreed that this technique, which had a mean of 4.45, motivated them to assume greater autonomy in their learning process. During Problem-Based Learning (PBL) and Case-Based Learning (CBL) sessions, students showed a greatly increased enthusiasm to attend lessons and participate in activities. This was evident from the very high average score of 4.95.

In the topic of Learning Outcomes: Students perceived that the Problem-Based Learning (PBL) and Case-Based Learning (CBL) approach facilitated their comprehension of the course material more efficiently in contrast to conventional techniques. The abilities and skills acquired through the PBL and CBL approach were widely regarded as very pertinent and applicable to real-world situations, with an average score of 4.52 and students perceived that the traditional method yielded a more lucid comprehension of theoretical ideas in contrast to the PBL and CBL approach, as indicated by an average score of 4.37.

In the topic of Collaboration and Teamwork: The implementation of the PBL and CBL approach resulted in a notable enhancement in students' capacity to work together effectively, as evidenced by the impressive average score of 4.48. Furthermore, students expressed a preference for collaborating with their peers during PBL and CBL projects compared to standard assignments, as indicated by the high mean score of 4.62.

In the topic of Problem-Solving and Critical Thinking: The PBL and CBL technique showed significant improvements in students' problem-solving and critical-thinking skills, as evidenced by a mean score of 4.46. The PBL and CBL activities were seen as extremely intellectually demanding, necessitating advanced problem-solving and critical thinking, as evidenced by the high average score (4.63).

4.2 Focus Groups and Interviews

Focus Groups and Interviews utilize qualitative assessments such as focus groups or interviews to collect detailed feedback on the specific elements of the PBL and CBL approach that most effectively captured students' interest. This research identified four primary themes from the data: Enhanced engagement and practical training, Development of Collaborative Skills, and Challenges with Self-Direction.

The result of Enhanced Engagement and Practical Training:

Quotes:

“I experienced a higher level of engagement during the PBL and CBL sessions due to our active participation in solving authentic problems.” We were not merely passively sitting and listening; we were actively engaged in doing something.”

“The combination of Problem-Based Learning (PBL) and Case-Based Learning (CBL) facilitated a strong retention of the concepts as we were directly applying them.” I perceive the practical applicability of the knowledge we acquired in real-life professional scenarios.”

The theme of this study shows that students regard the PBL and CBL approach as significantly improving their level of engagement with the course content and offering meaningful hands-on training that surpasses standard classroom instruction. The active participation in resolving practical issues played a crucial role in enhancing the engagement and success of the learning process.

The result of Development of Collaborative Skills:

Quotes:

“Collaborating with my peers yielded greater productivity in the Problem-Based Learning and Case-Based Learning projects.” Our ability to depend on each other's abilities was crucial in accomplishing the task, thereby enhancing our teamwork.”

“Occasionally, achieving consensus among all individuals proved to be challenging.” Certain individuals exhibited greater enthusiasm and engagement, hence intensifying the level of difficulty.”

Table 4. The results of the students' perspectives on the effectiveness of the integrated model

Topic	\bar{x}	S.D.	Level
Engagement and Motivation			
I felt a higher level of involvement with the course content when utilizing both Problem-Based Learning (PBL) and Case-Based Learning (CBL) approaches	4.88	0.32	highest
The PBL AND CBL strategy inspired me to engage in more proactive and self-directed learning	4.45	0.50	high
During the PBL AND CBL sessions, my motivation to attend lessons and engage in activities was heightened	4.95	0.23	highest
Learning Outcomes			
The Problem-Based Learning (PBL) combined with the Case-Based Learning (CBL) approach facilitated my comprehension of the course material more effectively compared to the conventional way	4.29	0.77	high
I believe that the abilities I acquired through the Problem-Based Learning and Case-Based Learning methodology are more relevant and practical in real-life scenarios	4.52	0.52	highest
The conventional method offered a more lucid comprehension of theoretical principles in contrast to the PBL AND CBL approach	4.37	0.48	high
Collaboration and Teamwork			
The PBL AND CBL strategy improved my capacity to collaborate efficiently within a team	4.48	0.63	high
Collaborating with my friends throughout the PBL AND CBL projects was more convenient for me compared to regular assignments	4.62	0.50	highest
Problem-Solving and Critical Thinking			
The PBL AND CBL strategy enhanced my problem-solving and critical thinking abilities	4.46	0.52	high
The PBL AND CBL activities presented a greater level of intellectual stimulation, requiring me to engage in critical thinking and problem-solving at a more advanced level than regular lectures	4.63	0.50	highest

The theme of this study shows that The PBL and CBL strategy leads to the major growth of collaborative abilities. Students acknowledged the importance of teamwork and believed that these experiences enhanced their capacity to collaborate, a crucial skill for future professional settings. Nevertheless, the task of handling group dynamics continued to pose difficulties for certain individuals.

The result of Challenges with Self-Direction:

Quotes:

“I found it difficult to adapt to the PBL and CBL approach due to the substantial amount of self-directed learning it demanded, which was unfamiliar to me.”

“Incorporating additional theoretical concepts into the problem-based learning and case-based learning sessions would contribute to achieving a more balanced approach.” Occasionally, I experienced a sense of lack of understanding of certain foundational information.”

Although the PBL and CBL strategy fostered important self-directed learning skills, it also posed difficulties for students who were unaccustomed to such a high degree of autonomy. The recurring theme emphasized the importance of striking a balance between self-directed learning and structured supervision, indicating that certain students needed additional assistance in navigating this strategy.

5 Discussion

5.1 Pre-and Post-Tests

The research demonstrates that the pre-test scores, which serve as an indicator of prior knowledge, do not have a substantial impact on the post-test scores. This is obvious from the non-significant F-value and the high p-value. This implies that the beginning degree of information was among students who lacked a significant ability to predict the outcome of their performance in this specific scenario. Also, Group (Instructional Method): The findings suggest that there is no significant variance in post-test scores across the various instructional techniques (PBL and CBL vs. traditional), as indicated by the low F-value and the p-value significantly exceeding 0.05. These findings indicate that, even after considering past knowledge, the educational strategy employed did not result in noteworthy differences in academic performance. The error term measures the level of variance in post-test scores that cannot be explained by the teaching approach or prior knowledge. The entire total of squares shows the overall amount of variation in the post-test scores. The high error sum of squares relative to the group sum of squares indicates that a significant portion of the variation in post-test results is not accounted for by the factors considered in the model. The ANCOVA findings indicate that neither the students' prior knowledge, as assessed by their pre-test scores, nor the instructional technique (PBL and CBL vs. conventional) had a significant effect on their post-test scores in this analysis. The main source of variation in the post-test scores is due to unaccounted factors in the model, suggesting that there may be other variables affecting the outcomes or that the sample size might not have been sufficient to detect minor effects.

5.2 Questionnaires Data

Also, the results indicate that students generally have a positive opinion of the integrated Problem-Based Learning (PBL) and Case-Based Learning (CBL) approach in terms of many aspects of their learning experience. The PBL and CBL strategy powerfully engages students' interest and pushes them to actively participate in their learning, as evidenced by the unusually high levels of engagement and motivation. The strategy appears to establish a learning atmosphere that promotes student engagement and motivation, which is essential for facilitating profound learning.

Learning Outcomes: Although students acknowledged the usefulness of hands-on and practical features of PBL AND CBL, they also recognized the importance of traditional techniques in fostering a comprehensive grasp of theoretical principles. This implies that an effective approach for comprehensive learning may involve a balanced combination of the strengths of both problem-based learning (PBL) and case-based learning (CBL), together with traditional lectures.

The PBL AND CBL approach seems to effectively boost students' teamwork and collaboration skills, which are crucial competencies in both academic and professional environments. Proficiency in teamwork and effective collaboration is becoming increasingly crucial in today's networked work contexts.

Students saw notable enhancements in their problem-solving and critical thinking skills as a result of engaging in problem-based learning (PBL) and case-based learning (CBL) activities. These activities presented a considerable level of intellectual difficulty, contributing to the students' growth in these areas. This serves as a compelling indication that the PBL AND CBL strategy not only actively involves students but also compels them to cultivate advanced cognitive abilities, which are crucial for achieving success in intricate, practical scenarios. Furthermore, the integrated Problem-Based Learning (PBL) and Case-Based Learning (CBL) method is particularly effective in engaging students, increasing their motivation, promoting collaboration and teamwork, and fostering the development of critical thinking and problem-solving abilities. Nevertheless, the findings also indicate that conventional approaches continue to have a significant impact on students' comprehension of theoretical topics. Hence, employing a hybrid methodology that capitalizes on the advantages of both PBL AND CBL and traditional lectures could potentially optimize learning results to the greatest extent.

6 Conclusion

The objective of this study was to evaluate the efficacy and student contentment with a combined Problem-Based Learning (PBL) and Case-Based Learning (CBL) approach in comparison to conventional teaching approaches. The assessment was carried out by employing a blend of Analysis of Covariance (ANCOVA) to scrutinize academic achievement, and qualitative data from student satisfaction surveys, focus groups, and interviews to get a comprehensive understanding of the students' experiences. The ANCOVA analysis revealed that, after considering prior knowledge (measured by pre-test scores), there was no statistically significant difference in post-test scores between students who underwent the PBL and CBL approach and those who received traditional instruction. This indicates that although both techniques were successful in enhancing student learning,

the PBL and CBL approach did not result in significantly higher academic achievements as evaluated by standardized exams. Moreover, qualitative data obtained from focus groups and interviews indicated that students expressed significant levels of satisfaction with the PBL and CBL strategy. The individuals valued the experiential and pragmatic learning experiences and believed that these approaches enhanced the attraction and relevance of the material to real-life scenarios.

In summary, the study illustrates the high effectiveness of the PBL and CBL methods in engaging students, improving their satisfaction, and promoting practical and collaborative abilities that are crucial for success outside of the classroom. Nevertheless, to fully exploit the advantages, it is crucial to tackle the difficulties linked to self-directed learning and the incorporation of theoretical material. By implementing a hybrid instructional approach that integrates the advantages of both Problem-Based Learning (PBL) and Case-Based Learning (CBL) with traditional teaching methods, educators can establish a well-rounded and efficient learning experience that caters to the varied requirements of students.

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Investigating Key Factors Influencing Student Satisfaction in HyFlex Learning: A Confirmatory Factor Analysis Study

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Abstract. This research aims to study and identify factors affecting student satisfaction with HyFlex learning management in the Faculty of Science and Technology at Suan Sunandha Rajabhat University. This is done by creating and testing a confirmatory factor analysis model for factors influencing satisfaction with HyFlex learning management. The study evaluates the component weights and relationships between various factors and satisfaction with HyFlex learning management. It presents empirical evidence and recommendations for enhancing the efficiency and satisfaction of HyFlex learning through model analysis using AMOS software. The research results indicate that the model obtained from the CFA analysis is well to excellently consistent with the empirical data, meeting the criteria for assessing model fit according to various indices. Therefore, this model can be appropriately interpreted and used to explain the factors influencing satisfaction with HyFlex learning management. The study concludes that the critical variables demonstrating satisfaction with HyFlex learning management are assessment, teaching content, teaching ability, learner-instructor interaction, and learning facilities, all of which are statistically highly significant. Meanwhile, helping reduce student expenses is a statistically significant factor. Furthermore, the research results can lead to policy formulation and guidelines for developing HyFlex learning management in educational institutions.

Keywords: HyFlex · CFA · Learning Management · Hybrid learning · Flexible Learning

1 Introduction

Education is a crucial mechanism for developing and instilling knowledge in youth, impacting the country's long-term competitiveness. Therefore, the design of education is of utmost importance. The National Education Plan (2017–2036) [1] emphasizes developing human resources, research, innovation, competitiveness, and nurturing the

potential of people of all ages to create a learning society with equal educational opportunities through efficient educational management [2]. This aligns with the Thailand 4.0 strategy, aiming to transition towards an innovation-driven economy and a moral, learning society. The current educational system operates in the context of the 21st century's changing landscape, necessitating students to be prepared for such changes. Education 4.0 thus requires innovative educational approaches that align with learners' evolving behaviors by incorporating motivating technologies [3] and focusing on learner-centered methods to create sustainable, prosperous, and resilient learning innovations. Learning management in this era requires establishing a sustainable balance in educational development towards a learning society by integrating various forms of capital, such as human, intellectual, and financial capital. A significant challenge is finding teaching methods, techniques, and approaches that will develop students' ability to keep pace with changes and build learning skills for the new future. Current learning management is often dominated by teachers, depriving learners of opportunities to practice analytical thinking and knowledge expansion skills, which are crucial in the 21st century. Modern teachers should design teaching methods that align with changes by promoting critical thinking, which involves carefully evaluating information, considering all relevant factors, and using systematic reasoning processes to reach well-reasoned conclusions and design effective learning management for learners [4].

The Hyflex learning model is a flexible approach that blends online and face-to-face learning, allowing for adaptable teaching methods based on the learning structure. This model permits learners to choose devices or resources for two-way communication and self-study times, enabling real-time interaction between students and teachers. It is a dynamic, collaborative learning model that references learner-centered needs and processes [5] to facilitate genuine learning. It instills critical thinking related to learning management processes that promote natural and full-potential development, enabling learners to acquire knowledge independently, adapt flexibly, think creatively, analyze and solve problems, collaborate with others, and utilize technology skills, all emphasizing learner-centered development.

Currently, hybrid or Hyflex learning management is rapidly gaining popularity in educational institutions worldwide [6], especially during the COVID-19 pandemic, which prompted many institutions to shift towards online teaching. The Hyflex system integrates online and classroom-based learning, allowing learners to choose the suitable mode based on their circumstances and preferences flexibly. While Hyflex is acknowledged for facilitating continuous and accessible education, its success depends on several technical, managerial, and learner satisfaction factors. Technically, appropriate information technology infrastructure is necessary [7], including efficient communication systems and applications supporting online learning. Managerially, planning and developing new teaching methods aligned with Hyflex, training and supporting faculty, and appropriate resource management are required [8]. Regarding learner satisfaction, it is crucial for Hyflex's success; if learners are dissatisfied with this learning mode, it may diminish learning effectiveness and lead to dropouts [9]. Therefore, studying factors influencing satisfaction with Hyflex learning is essential to enable educational institutions to improve and develop teaching methods that better meet learners' needs [10].

This research aims to analyze the confirmatory factor components influencing student satisfaction with Hyflex learning management in the Faculty of Science and Technology, one of the faculties implementing this system. This factor analysis will provide a clearer understanding of the primary factors impacting learner satisfaction, benefiting the development of Hyflex learning management to achieve learners' expectations and goals in the future.

2 Literature Review

2.1 Hyflex Learning Management Theory

The HyFlex (Hybrid-Flexible) learning model is a blended and flexible classroom approach [11]. Hybrid classrooms combine online learning, whether real-time or asynchronous, and face-to-face learning. This model encourages students to be independent in their study and learning [12]. Simultaneously, students can decide where, when, and how they will access the instructor's teaching [13]. The HyFlex learning management approach focuses on learner-centered, contemporary learning in classrooms and online, requiring full student participation. The HyFlex approach has four "foundational values": learner choice (within a modality), equivalence (between modalities in learning outcomes), reusability (between modalities in material and activities), and accessibility (using technology and possessing the necessary skills to participate) [14]. This model resembles the optional attendance teaching methods that instructors have employed for years. The primary difference is the choice in instructional delivery: in-person, synchronous online, or asynchronous online. Teaching in a HyFlex learning environment is complex and challenging, involving multiple spaces: physical, presentation, interaction, and transitional spaces, all new and unfamiliar to many instructors. Additional complexity arises from the time and mode in which students learn. With such complexity, increased teaching awareness is needed in designing learning for the HyFlex environment, where instructors have only partial ownership and control over the design. Instructors must also possess skills in communicating and interacting across spaces simultaneously and managing the complex learning spaces [15].

The COVID-19 pandemic disrupted traditional educational systems globally, forcing over 1.57 billion students from 188 countries to transition to online learning platforms. In Thailand, the Ministry of Higher Education mandated all universities to shift to online teaching by April 1, 2020, aiming to maintain effective learning outcomes comparable to classroom instruction. This study investigated online learning behaviors, success factors, and perspectives of 127 science students at Suan Sunandha Rajabhat University during the pandemic. The study found that 68.5% of students were dissatisfied with online learning, citing limited interaction with instructors, lack of direct explanations, and significant differences from traditional classroom settings. Only 23.62% found online learning more motivating than traditional methods. The theoretical section of courses received a moderate satisfaction level (2.70), while the practical section scored lower (2.53), potentially due to the challenges of virtual laboratory experiences. In conclusion, the rapid transition to online learning during the COVID-19 pandemic posed significant challenges for students, with internet connectivity, lack of face-to-face interaction, and

adapting to virtual practical sessions emerging as key factors influencing their satisfaction and learning experiences. The findings highlight the need for robust technological infrastructure, effective pedagogical strategies, and innovative approaches to enhance online learning effectiveness, particularly for practical components of curricula [16].

A study on HyFlex training in a Capstone seminar course in the United States, where students often work on large research projects, theses, or applied projects demonstrating their expertise in their chosen field, involving seminar attendance, presentations, and independent research under the guidance of an advisor or mentor. The seminar topics were Grand Rounds or continuing education for healthcare providers, focusing on clinical pharmacology mechanisms and enhancing clinical thinking skills for fourth-year pharmacy students. It was found that HyFlex training did not affect student engagement differently from traditional training, and overall learner satisfaction remained similar, despite differences between face-to-face and online attendance. The HyFlex format did not significantly reduce student engagement, and students were satisfied with HyFlex in terms of safety, flexibility, convenience, technology, and expertise. HyFlex learning management can be effectively used in pharmacy education by giving students the option of face-to-face or online attendance without reducing engagement or satisfaction levels [17]. The Introduction to Engineering Design course at the University of Tennessee at Chattanooga in the United States, which emphasizes collaborative and experiential learning, was adapted to the Synchronous Hybrid Flexible (HyFlex) teaching format. Student learning outcomes in this course improved, as measured by final exam scores and individual and group presentation scores. Students took more responsibility for their projects, participated in class using online whiteboards, and lessons were smoothly delivered via Zoom and Google Slides [18].

In Japan, a newly redesigned HyFlex course design for blending face-to-face and online instruction without support staff was found beneficial for widespread HyFlex curriculum implementation, especially after pandemics like COVID-19. 85% of students positively evaluated this new curriculum design. However, considerations need to be made when implementing this new HyFlex curriculum design experimentally, such as using computers for video viewing and in-class chatting, utilizing multi-monitor setups or auxiliary devices for efficiency, online education requiring a certain level of information technology skills from both students and faculty, and schools having adequate network and computer infrastructure. Online education offers several educational advantages not found in traditional face-to-face instruction. Therefore, appropriately utilizing both face-to-face and online methods will aid in developing future education [19]. The HyFlex learning model in China integrates online and in-person teaching seamlessly. It responds to students' needs for HyFlex curricula and provides recommendations for improving design and implementation through a case study of a web programming course over one semester in a HyFlex learning environment. This research found that the flexibility of HyFlex learning can meet diverse student needs. Additionally, advantages of HyFlex learning were identified, such as increased engagement and equity. However, successful HyFlex learning must still confront technological challenges and how students manage technical issues. Furthermore, the design and implementation of HyFlex curricula must consider the teaching context. HyFlex learning offers more flexible options for learners and integrates them into a simulated learning environment, resulting in increased access

to learning opportunities, new opportunities to address emergencies, reduced costs, and greatly expanded learning environments and opportunities [20].

The Hybrid and Flexible (HyFlex) blended learning approach has emerged with the changing landscape of higher education. This method combines elements of in-person and online learning, offering students a flexible choice to attend class in-person, remotely, or through a combination of both. While HyFlex education provides flexibility and promotes classroom engagement, it may also present challenges, such as the feasibility of implementing HyFlex, lack of interaction between students, peers, and instructors, and potential impact on student learning outcomes due to reduced motivation and mental health issues. Additionally, other challenges include limited access to resources and technology, reliable internet connectivity, and appropriate devices for online learning, which may create inequalities in the learning experience among students. Thus, a study investigated factors influencing the acceptance of the HyFlex learning mode among undergraduate students in Malaysia [21] using the Technology Acceptance Model (TAM), with two components employed for this study: Perceived Usefulness and Perceived Ease of Use [22]. The study's findings concluded that HyFlex learning offers students flexibility in choosing to attend classes offline or online, as appropriate for their personal circumstances, enabling those living far away or with mobility issues to participate in classes. It helps foster ownership of the learning process by allowing students to choose how to engage with the content and interact, increasing motivation, engagement, and academic understanding. Furthermore, it promotes the use of technology, preparing students for the digital workforce. Educational institutions can effectively develop support for HyFlex learning, benefiting student adaptation and learning outcomes. The TAM can identify perceived ease of use and usefulness, benefiting education policymakers and institutions regarding necessary facilitation for supporting HyFlex learning. Instructors can enhance adaptability and overall learning outcomes for undergraduate students in HyFlex learning environments in Malaysia.

Eight factors were identified as influencing the HyFlex blended learning model that promotes analytical thinking among undergraduate students from the faculties of Science and Technology and Education from Rajabhat Universities across five regional groups in Thailand: 1) Instructors' role in controlling and conducting learning activities in face-to-face and online settings; 2) Students' role in performing assigned learning activities and self-studying from provided learning resources; 3) HyFlex learning using technology for blended synchronous and asynchronous learning, emphasizing self-directed learning and creating new knowledge; 4) Learning management methods, including in-class activities linking content learned outside class, using interactive devices to stimulate interest outside class, and employing technology websites to promote analytical thinking; 5) Learning media, with a learning management system as a source of teaching content and learning management, using synchronous and asynchronous communication tools like chat rooms and online boards, and supplementary learning resources like website links; 6) Assessment processes, including pre-assessments, post-assessments, group work evaluations, analytical thinking assessments, and observing learning behaviors for improving learning management; 7) Learning strategies emphasizing understanding and self-exploration, aligning with learning goals, creating learning environments, using technology-facilitated learning activities, and removing boundaries between in-class and

out-of-class learning; 8) Learning evaluation through formative and summative assessments. When innovations and technology are used to effectively improve the quality of learning management, these eight factors can offer creative ideas for applying technology to enhance the quality of effective learning management [23].

To develop reading skills in upper secondary students, a study was conducted to examine the effectiveness of a HyFlex learning management plan. The study created a HyFlex learning management model, evaluated the plan's effectiveness in enhancing students' reading comprehension, and examined the demands and difficulties of upper secondary students with regard to reading issues in the context of utilizing HyFlex. The research and development methodology used in the study consisted of three stages: needs analysis, creation of a learning management strategy, and participant implementation. There were three different participant groups in the study. Nineteen stakeholders in reading management who took part in the needs analysis phase made up the first group. The second group included five experts and 30 students involved in developing the learning management plan. The third group comprised 50 students who participated in implementing the learning management plan. The instruments used were interviews and learning management evaluation forms. The findings revealed that the HyFlex learning management tool demonstrated the effectiveness of the blended learning method, combining in-person and online learning, in developing students' reading skills. This conclusion contributes to understanding effective teaching methods for enhancing reading skills [24].

A mixed-method approach combining qualitative and quantitative research was used to analyze factors connected to HyFlex learning through science activities to increase critical thinking. This study combined document analysis, interviews with 20 teachers, and data collecting with questionnaires given to 150 teachers and 150 students using cooperative learning techniques. According to the study, important variables affecting instruction were: 1. Adopting a student-centered approach to focus on flexible learning, 2. Transferring technology as learning content to support knowledge-based activity linkages, 3. Learning technology for ubiquitous learning methods by supporting analytical thinking skills and computational questioning through usable applications, 4. Accessing technology to create opportunities for continuous learning through e-learning and online teaching, and 5. Providing a technological environment for managing diverse technological experiences and environments for developing 21st-century skills [25].

The ability to solve problems creatively is an essential skill that should be developed in students through proper learning management and assistance with skill building. Second-year English majors at Suan Sunandha Rajabhat University who participated as instructors at the university's demonstration school were the subjects of a study. The study assessed the quality of inventions produced by students using this learning strategy and evaluated students' creative problem-solving skills after obtaining HyFlex learning management coupled with project-based learning. The views of students about the integration of project-based learning and HyFlex learning management system were also investigated. A creative problem-solving skill assessment, an innovation appraisal, and a questionnaire on attitudes toward integrated learning management were among the research tools. Means and variances were computed for data analysis. According to the study's findings, students: 1. Showed the highest degree of creativity in problem-solving;

2. Produced innovations of the highest caliber; and 3. Had a very favorable assessment of the HyFlex learning management system that had been put into place. [26].

The HyFlex-Flipped blended learning approach integrates blended learning with the Flipped Classroom, a student-centered teaching method similar to online instruction, where students learn lessons from instructional videos and study, think, and analyze independently at home before engaging in classroom activities with peers. HyFlex-Flipped combines blended learning with the Flipped Classroom and active learning, linking to open online curricula (MOOCs) and real-world work environments. This learning management model integrates in-class and out-of-class learning processes, utilizing the HyFlex-Flipped Classroom principles that emphasize learning in authentic work environment contexts to enhance questioning, analytical thinking, and creative problem-solving skills. Such learning management requires instructors' support and involvement in supervising and adapting teaching methods away from traditional lecturing to promote diverse and creative learning activities. Studies have found that HyFlex-Flipped Classroom learning significantly improves students' CPS (Critical and Problem-Solving) scores. However, it is noted that in real-world scenarios, learners' learning processes must be continuous, focusing on viewing problems from different perspectives and finding creative solutions continuously [27].

3 Methodology

This research aims to study the relationship between various factors and students' overall satisfaction with HyFlex learning, which blends online and in-person learning, providing flexibility in time, location, and learning methods. The population and sample group are regular undergraduate students from the Faculty of Science and Technology, Suan Sunandha Rajabhat University, enrolled in the second semester of the 2023 academic year, totaling 2,022 students. Simple random sampling was used, resulting in a sample size of 450 students, which was reduced to 404 after data screening. Content validity of each question was established through an examination by five educational experts, yielding an Item Objective Congruence (IOC) index ranging from 0.66 to 1.00. A total of 20 questions were selected, exhibiting an item discrimination power ranging from 0.53 to 0.91. The reliability of the questionnaire was evaluated using Cronbach's alpha coefficient, which was 0.97. The statistical methods employed in the research encompassed measures of model fit, such as factor loadings, convergent validity, and discriminant validity, as well as measures of model reliability, including Cronbach's alpha, composite reliability, and Confirmatory Factor Analysis (CFA). This research employed the blended and flexible learning theory as a conceptual framework, focusing on factors affecting learners' satisfaction in the HyFlex system. The CFA analysis will help confirm the factor structure influencing satisfaction in HyFlex teaching and learning by considering various statistical values such as CMIN/DF, RMSEA (Root Mean Square Error of Approximation), CFI (Comparative Fit Index), TLI (Tucker-Lewis Index), NFI (Normed Fit Index), SRMR (Standardized Root Mean Squared Residual), GFI (Goodness of fit Index), and AGFI (Adjusted Goodness of fit Index).

3.1 Research Hypotheses

H1: The content factor has a positive influence on students' satisfaction with the HyFlex learning model.

H2: The teaching effectiveness factor has a positive influence on students' satisfaction with the HyFlex learning model.

H3: The assessment factor has a positive influence on students' satisfaction with the HyFlex learning model.

H4: The interaction and communication factor has a positive influence on students' satisfaction with the HyFlex learning model.

H5: The facility factor has a positive influence on students' satisfaction with the HyFlex learning model.

H6: The expense reduction factor has a positive influence on students' satisfaction with the HyFlex learning model.

3.2 Research Framework

This research employs the Blended Learning theory, which combines online and face-to-face learning in a hybrid format, incorporating technology and digital media as part of the learning process. The proportions, methods, and locations of learning are adjusted according to the needs of students and instructors. Additionally, it utilizes the Flexible Learning theory, a formal educational approach that emphasizes increasing flexibility in terms of time, location, instruction, and other aspects of the learning process, allowing students autonomy in deciding what, how, when, and where to learn. Online learning falls under the Flexible Learning model. The HyFlex model integrates Blended Learning and Flexible Learning, focusing on creating efficient and responsive learning experiences tailored to students' needs. This research aims to investigate factors influencing students' satisfaction with the HyFlex instructional model. The research framework presents various factors affecting learners' satisfaction in the HyFlex system, as illustrated in Fig. 2. The independent factors are as follows:

- Content Factor:
- Teaching Factor:
- Interaction Factor:
- Facility Factor:
- Evaluation Factor:
- Expense Reduction Factor:

4 Results and Discussion

The factor loadings analysis, which represents the coefficients indicating how well the observed variables can represent the principal components, reveals the significant variables affecting satisfaction. It also examines the relationships between the principal components, whether and how they are related. This information is useful for planning the development of HyFlex teaching and learning management. The CFA results can be developed into a measurement model or a questionnaire to assess satisfaction with

HyFlex teaching and learning management in future studies. Therefore, CFA is an essential tool that allows researchers to examine the consistency between the theoretical or hypothesized factor structure and the empirical data, enabling accurate and appropriate explanations and improvements in teaching and learning management.

Figure 1 shows the Confirmatory Factor Analysis (CFA) model, which tests the model fit between the latent variable measurement model and the empirical data for the research on factors affecting satisfaction with HyFlex teaching and learning management. The model comprises six latent variables: content, teaching, interaction, facility, evaluation, and expense, which are expected to influence satisfaction. Each latent variable has several observed variables as sub-components. For instance, the teaching latent variable includes teach 1 (instructors demonstrate subject matter expertise) and teach 2 (instructors employ appropriate and effective teaching methods). Figure 3 displays the factor loadings of each observed variable, representing the positive relationships between the observed variables and the latent variables, with no negative values. Additionally, the figure shows the correlations between the latent variables themselves, represented by curved lines at the bottom, indicating the relationships between the factors. This CFA model is used to assess the model fit with the empirical data, leading to the interpretation of the factors influencing students' satisfaction.

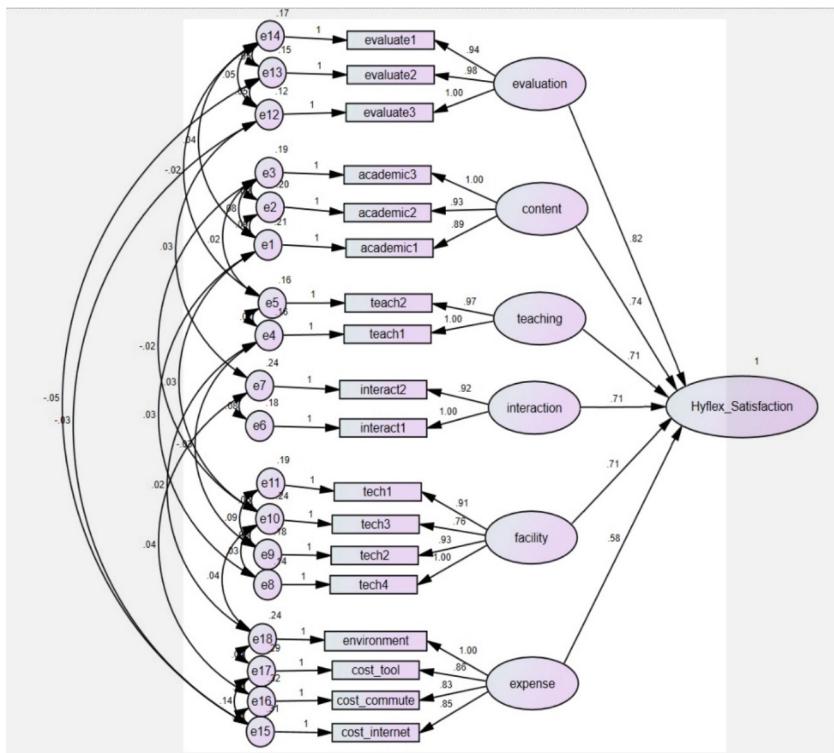


Fig. 1. Confirmatory Factor Analysis (CFA) model

Tables 1, 2, 3 and 4 present the statistical analysis results using AMOS for the research titled “A Confirmatory Factor Analysis of Factors Affecting Satisfaction with HyFlex Teaching and Learning Management: A Case Study of the Faculty of Science and Technology, Suan Sunandha Rajabhat University.” The tables show the statistical indices used to evaluate the quality of the Confirmatory Factor Analysis (CFA) model, such as CMIN/DF or Normed Chi-Square = 2.623, GFI = 0.933, AGFI = 0.893, NFI = 0.945, TLI = 0.95, CFI = 0.965, SRMR = 0.038, and RMSEA = 0.063. The interpretation of these model fit indices is as follows: CMIN/DF or Normed Chi-Square is 2.623, which falls between 1 and 3, indicating a good model fit; GFI (Goodness of Fit Index) is 0.933, which exceeds 0.90, indicating a good model fit; AGFI (Adjusted Goodness of Fit Index) is 0.893, which is greater than 0.80 and close to 0.90, making it acceptable; NFI (Normed Fit Index) is 0.945, which exceeds 0.90, indicating an excellent model fit; TLI (Tucker-Lewis Index) is 0.95, which exceeds 0.90, demonstrating an excellent model fit compared to the null model or independence model; CFI (Comparative Fit Index) is 0.965, which exceeds 0.95, indicating an excellent model fit; SRMR (Standardized Root Mean Residual) is 0.038, which is less than 0.08, representing an excellent model fit; and RMSEA (Root Mean Square Error of Approximation) is 0.063, which falls between 0.05 and 0.08, indicating a good model fit. In summary, the CFA model obtained demonstrates an excellent to good fit with the empirical data, meeting the model fit evaluation criteria across various indices. Therefore, this model can be appropriately used to interpret and explain the factors influencing satisfaction with HyFlex teaching and learning management.

Table 1. Chi-square minimum and degrees of freedom

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	65	278.023	106	.000	2.623
Saturated model	171	.000	0		
Independence model	18	5090.433	153	.000	33.271

Table 2. Goodness of fit index and adjusted goodness of fit index

Model	RMR	GFI	AGFI	PGFI
Default model	.015	.933	.893	.579
Saturated model	.000	1.000		
Independence model	.177	.197	.102	.176

Table 5 presents the C.R. (Critical Ratio) values, which are the statistical values used to test the significance of the Estimate values. The Estimate values represent the estimated path coefficients or factor loadings derived from the structural equation modeling analysis. The C.R. indicates the statistical significance of the Estimate values. Generally, if the C.R. value exceeds 1.96 (for a two-tailed test) or 2.58 (for a one-tailed test), the

Table 3. Baseline comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.945	.921	.965	.950	.965
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

Table 4. Root mean square error of approximation

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.063	.054	.073	.008
Independence model	.283	.276	.289	.000

Estimate or factor loading is considered statistically significant at the $p < 0.05$ or $p < 0.01$ level, respectively. Table 5 shows the statistics used to test the significance of the factor loadings. It can be observed that all observed variables have C.R. values greater than 1.96, indicating statistical significance at the 95% confidence level. The details, in descending order, are as follows: The evaluation variable has the highest C.R. value of 19.760, followed by the facility variable with a C.R. value of 17.598. The teaching and interaction variables share the same C.R. value of 17.004, while the content variable has a C.R. value of 16.703. The expense variable has the lowest C.R. value of 12.876. A higher C.R. value indicates that the factor loading of the variable is more significant to the model, meaning that the observed variable is essential in representing the principal component. From Table 5, which presents the Confirmatory Factor Analysis results of the factors affecting satisfaction with HyFlex teaching and learning management at the Faculty of Science and Technology, Suan Sunandha Rajabhat University, the following interpretation can be made:

Table 5. Regression weights of factors

			Estimate	S.E.	C.R.	P
Evaluation	→	Hyflex_Satisfaction	.818	.041	19.760	***
Content	→	Hyflex_Satisfaction	.737	.044	16.703	***
Teaching	→	Hyflex_Satisfaction	.713	.042	17.004	***
Interaction	→	Hyflex_Satisfaction	.705	.043	17.004	***
Facility	→	Hyflex_Satisfaction	.706	.040	17.598	***
Expense	→	Hyflex_Satisfaction	.579	.045	12.876	***

The principal component or latent factor for satisfaction with HyFlex teaching and learning management (Hyflex_Satisfaction) has the highest factor loading from the evaluation variable (0.818), followed by the content variable (0.737), and then the teaching variable (0.713). The interaction and facility variables have similar factor loadings of 0.705 and 0.706, respectively. The expense variable has the lowest factor loading (0.579) on satisfaction with HyFlex teaching and learning management. All variables are statistically significant at the 0.001 level ($p < 0.001$).

Based on the model fit statistics obtained from the AMOS analysis for the research titled “A Confirmatory Factor Analysis of Factors Affecting Satisfaction with HyFlex Teaching and Learning Management: A Case Study of the Faculty of Science and Technology, Suan Sunandha Rajabhat University,” which demonstrate an excellent to good model fit with the empirical data, the proposed model is statistically significant in its fit with the empirical data at the 0.01 level. Therefore, researchers can utilize this model to develop a questionnaire or an instrument to measure satisfaction, enabling accurate evaluation of the improvements in HyFlex teaching and learning management quality. The research findings can also be used to formulate policies and guidelines for the development of HyFlex teaching and learning management in educational institutions. The empirical evidence from this model provides crucial information for planning and strategizing the improvements in HyFlex teaching and learning management to best meet the needs and satisfaction of students.

This research presents a Confirmatory Factor Analysis model of the factors influencing satisfaction with HyFlex teaching and learning management at the Faculty of Science and Technology, Suan Sunandha Rajabhat University. The analysis results indicate that the model demonstrates an excellent to good fit with the empirical data. It can be used to develop an instrument for measuring satisfaction and evaluating the improvements in HyFlex teaching and learning management quality accurately. Additionally, it provides crucial empirical evidence for planning and strategizing the enhancement of HyFlex teaching and learning management to best meet students’ needs and satisfaction. The hypothesis testing based on the Confirmatory Factor Analysis results can be summarized as follows:

H1: The content factor has a positive influence on students’ satisfaction with HyFlex teaching and learning management.

Analysis: The hypothesis is accepted since the content variable has a factor loading of 0.737, which is statistically significant, indicating that the instructional content has a positive influence on satisfaction. This finding is consistent with the research by Cybinski et al. [13], which states that content is one of the four fundamental values in the student-centered HyFlex teaching model.

H2: The teaching effectiveness factor has a positive influence on students’ satisfaction with HyFlex teaching and learning management.

Analysis: The hypothesis is accepted as the teaching variable has a factor loading of 0.713, which is statistically significant, demonstrating that teaching effectiveness has a positive influence on satisfaction. This finding aligns with the research by Leijon and Lundgren [15], which states that instructors must have an increased awareness of teaching in designing learning for the HyFlex environment to help students acquire knowledge effectively.

H3: The evaluation factor has a positive influence on students' satisfaction with HyFlex teaching and learning management.

Analysis: The hypothesis is accepted, with the evaluation variable having the highest factor loading of 0.818, which is highly significant, indicating that evaluation is the most influential factor on students' satisfaction. This finding is consistent with the research by Jongmuang et al. [18], which identifies assessment as one of the factors affecting HyFlex blended learning that promotes analytical thinking among undergraduate students from the faculties of science and technology as well as education at Rajabhat Universities across five regions in Thailand.

H4: The interaction factor has a positive influence on students' satisfaction with HyFlex teaching and learning management.

Analysis: The hypothesis is accepted as the interaction variable has a factor loading of 0.705, which is statistically significant, demonstrating that interaction and communication have a positive influence on satisfaction. This finding aligns with the research by Leijon and Lundgren [15], which states that instructors must possess communication and interaction skills across multiple spaces, including managing complex learning spaces to enhance the effectiveness of HyFlex teaching and learning management.

H5: The facility factor has a positive influence on students' satisfaction with HyFlex teaching and learning management.

Analysis: The hypothesis is accepted, with the facility variable having a factor loading of 0.706, which is statistically significant, indicating that facilities have a positive influence on satisfaction. This finding is consistent with the research by Lazim et al. [21], which suggests that education policymakers and institutions need to provide necessary facilities to support HyFlex learning, enabling instructors to enhance adaptability and overall student performance at the undergraduate level in Malaysia.

H6: The expense factor has a positive influence on students' satisfaction with HyFlex teaching and learning management.

Analysis: The hypothesis is accepted, but with the lowest influence, as the expense variable has a factor loading of 0.579, which is statistically significant but the lowest among all factors. This finding aligns with the research by Han et al. [20], which states that HyFlex teaching and learning management provides students with more options for accessing learning opportunities, opens new opportunities for addressing emergencies, helps save costs, and greatly expands learning environments and opportunities.

5 Conclusion and Recommendations

The Confirmatory Factor Analysis results support all hypotheses, with the evaluation factor having the highest influence on satisfaction, followed by content and teaching, while the expense factor has the lowest influence, albeit still significant. These findings can serve as guidelines for improving HyFlex teaching and learning management to better meet students' needs. The research findings reveal correlations between the residual errors of several observed variables, which help reduce model complexity and improve model fit with the actual data. Establishing relationships between residual errors also enhances measurement completeness. The residual errors can be positive or negative, as these variables may be influenced by factors beyond their relationships with the latent

variables in the model, resulting in positive or negative errors. Demonstrating the relationships between residual errors allows for consistency, improving the model fit, as errors may be related and not entirely independent. In future studies on factors influencing satisfaction with HyFlex teaching and learning management, model improvements can be made to reduce residual errors and increase completeness, enhancing model reliability. Additionally, other latent factors or variables could be incorporated into the model, increasing its complexity while reducing the correlations between residual errors. This approach would further increase satisfaction with HyFlex teaching and learning management and enhance its comprehensiveness.

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Adapting Computer Science Education to a New Student Era

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Abstract. When reading about higher education nowadays, there is not a month that goes by without an article being published by the Chronicle of Inside Higher Education mentioning school closings, or programs being cut due to financial issues and low enrollment numbers. Students who are considered Generation Z today are different than they were a decade ago. In the past, going to college and earning a Bachelor's degree was "the dream," but today many are taking into consideration whether pursuing a Bachelor's degree is something that they will see a return on investment. Due to so many students looking for alternative pathways to begin their careers instead of the traditional Bachelor's degree, institutions need re-branding and determining how to adapt to this new student era. For Athens State University, similar to others, it has been through the process of trying new and innovative techniques to re-spark the interest that students will have. In particular, the faculty of the Computer Science program has been running and pivoting when needed to make sure that they are providing students with the best education possible for them to be top-ranked for employability. This article discusses and demonstrates the ways that the program is thriving. The program is ABET accredited, integrates experiential education, assists students in articulating their learning, and is pivoting to focus on stackable micro-credentials.

Keywords: Experiential Learning · ABET accreditation · micro-credentials · transfer students · articulate learning

1 Introduction

In the last few years, since the world faced an unexpected pandemic many different organizations were impacted and required to adapt. One of those organizations was higher education institutions. The landscape of higher education is no longer what it used to be. What used to be a goal for many students who were finishing up high school has now become an afterthought. Many students are now focusing on work readiness and higher education institutions need to adapt to accommodate the needs of students. Unfortunately, institutions that are not able to adapt have the unfortunate consequences of needing to shut their doors or cut programs, which seems to be happening more often than not as can be seen through the many articles published by the Chronicle of Higher Education [9, 20].

Athens State University is one of two upper division public institutions in the United States and the only one in Alabama. As an upper division institution, Athens State University is already unique in the sense that every student transfers in from a Community College (CC) or from another 4-year institution. Adapting, being innovative and meeting student needs based on their past educational and work experiences is something that is not new to the University, and it is also not something new to many of the programs that are available to students. While not new, in 2021 the institution adopted a Quality Enhancement Plan that focuses on Experiential Learning.

Experiential Learning and Experiential Education are terms that are becoming more common to hear within Higher Education. While there are best principles of practice that are documented by the National Society for Experiential Education, one item that does not exist is a concrete definition of what Experiential Learning or Experiential Education actually is. “At Athens State University, Experiential Learning is a process through which students develop knowledge, skills, and values by applying theory and academic content to real-world experiences within the classroom, community, or workplace.”

One program that has embraced Experiential learning for over a decade in several classes is the Computer Science program. This article is going to share how the faculty of the Computer Science program have been adapting to the new era of students and the new landscape that higher education is facing.

2 Athens State University

Athens State University is located in Athens, Alabama and is one of the oldest institutions in Alabama. In 2021, Athens State University had its bicentennial celebration. Athens State University has a truly rich history from its beginning as a Female Institute, to surviving times of the Civil War while Federal soldiers occupied Athens. In 1929, after having a couple of name changes, the school’s name was approved by the Alabama legislature to be Athens College. Under the presidency of Eugene R. Naylor, which began in 1930, the decision was made to expand enrollment and expand the pool of potential applicants by admitting men. In 1975, the State of Alabama took ownership of the College and Athens College became Athens State College, offering upper-division courses as part of the Alabama Community College System. In 1998 the name was changed to Athens State University and in 2012 the University became an autonomous institution with an independent Board of Trustees [4].

Today, with Athens State University being an upper division institution, the student body consists of a demographic that is different from traditional universities and community colleges. The average age of a student at Athens State University is 30.4 with a median age of 27 [5]. While the student demographic is unique based on the age of the students that attend Athens State University, it has been seen that even younger students who fall closer to the traditional age of a Junior in College (early 20’s) have different lives than students who were going to school 20–30 years ago. Students now-a-days have added responsibilities. The students who are older are many times already working a full time job and looking to finish their degrees to advance their careers or they are looking for a career change. More traditional age students, are following a path that is of value for them, however they also have responsibilities outside of school. School is not their

“work”. Students have jobs, some have careers, and they may have families that they are taking care of, whether that is their own children, elderly parents, or helping parents with siblings to name a few. Athens State University Experiential Learning started in 2021.

3 Experiential Learning

Experiential Learning and Experiential Education are not new concepts to the landscape of Higher Education. Actually, the theoretical origins of experiential education date back to 1938 when it was proposed by John Dewey, as a philosophy that experience occurs continuously based on interactions and by participating in these active experiences one informs a situation of learning [18]. In addition to Dewey there have been others who have expanded and researched this concept, those like David Kolb, and Roger Fry. Kolb and Fry are well known for having established a learning cycle in association to Experiential Education. That cycle focuses on the learning participating in an experience, making observations about their experience through reflection, determining how they might do things differently or how they would proceed, and testing out what they have identified in new situations. It was in 1974 that David Kolb published the book *Toward an Applied Theory of Experiential Learning* that marked the beginning of the Experiential Learning Theory (ELT) [7].

Allison et al. have identified four common themes to experiential education. The first is that experiential education begins with the learner and the educative experience rather than knowledge. The second is that there is a relationship between the educator and the learner that focuses on the facilitation of learning and not on traditional outcomes and objectives. Third is that the learner, but also the educator will experience personal growth through the journey taken by focusing on the ability to reflect on the experience. Lastly, a theme is identified where personal growth, knowledge and understanding don't just occur from the outset of teaching, but more so from the interactions that occur from working with others through the educational experience [2].

In 2008, George Kuh introduced the concept of high impact practices (HIP), outlining ten educational strategies that promote student engagement. In 2017, he declared an 11th practice which had showed similar benefits of the original ten. The ten practices he originally identified were those of first-year experiences, common intellectual experience, learning communities, writing-intensive courses, collaborative assignments and projects, undergraduate research, global learning, service learning (commonly seen as community-based learning), internships, capstone courses and projects, and with the advancements of technology, the eleventh, ePortfolios [8].

With Athens State University being a unique institution, some of these practices cannot be incorporated into the curriculum or the institution's landscape since students that attend Athens State University transfer in from other colleges and universities as Juniors. However, there are many opportunities for experiential learning to take place.

The Experiential Learning initiative at Athens State University has been under the direction of Dr. Maxwell who serves as Quality Enhancement Plan director. Dr. Maxwell is also an Associate Professor of Computer Science overseeing program accreditation (ABET), community outreach, undergraduate student capstone experience, and guiding graduate students to establish their projects or thesis.

Across the institution there have been five groups of experiential learning categories that have been identified. Those are;

- Workplace learning
- Community-based learning
- Learning through expeditions
- Learning through research
- Hands-on learning

Stock et al. have stated that educational experiences become experiential when the learner is fully present. They identified being fully present in experiencing as having the learner be here and now, and not daydreaming or imagining something else, being alert and aware, having their senses engaged, being deeply involved, and actively participating in the activity [19]. The five categories recognized by Athens State University as opportunities for students to learn experientially all require that the learner be fully present, at the same time, it should be stated that these five categories are not all-inclusive, it is just the five categories that were identified when the QEP initiative began in 2021. The next section will discuss in detail how the faculty of the Computer Science department have been able to embrace experiential education for their students.

4 Experiential Learning in Computer Science

Within the Computer Science program at Athens State University, the students have multiple opportunities to be able to participate in an Experiential Learning activity throughout different courses that they may choose to take or through their required capstone course. The next sections will highlight a few courses in which students have the opportunity to learn experientially while earning a Computer Science or Information Technology Bachelor's degree.

4.1 Computer Science I

Computer Science I is the first class that Computer Science majors take in a sequence of three programming courses. The class begins by introducing students to the concept of computer programs, critical thinking, algorithms, and logically designing solutions to problems. Once students are introduced to programming concepts the contents covered are basic programming and arithmetic and relational operations, decision making, working with files, loops, functions, and we end this course in discussing arrays. While students have a multitude of programs to work through on their homework assignments and exams, they have a semester long in class lab project. The lab project is set up to be able to give students a "real world" example of how a problem can be solved in simplest forms, how the program can be scaled, integrated with other pieces, and optimized. For a few years, the class lab project has been focused on creating a five-card Charlie rule blackjack game that a user plays against the computer.

The project begins by the professor bringing several decks of cards to class, splitting the students into groups, and making sure that they all understand the game play based on the rules that are presented in class. This allows for the students to fully understand

the game and later be able to create the game in C++. After initial “game play” students are asked to think about the algorithm that they would be able to write, in simple terms without the use of any pseudocode. They are encouraged to think about explaining the game to someone who has never played it before and including as much detail as possible. Once students have had the chance to brainstorm their algorithm and once the class begins to cover each individual programming process, the students build upon their code each week in the class. Many students become challenged by this project when the focus is on decision making, with a five card Charlie game and not yet having covered loops or functions, students are required to practice their attention to detail to make sure that they are not missing brackets associated to their decision making that might cause the game to run incorrectly or not compile for it to run at all. By the time that the code is written, with comments and some additional blank spaces for the purposes of readability, some students will have over 1400 lines of code. Once the class reaches the point to discuss functions, students are able to see how their very large code file can be optimized by breaking down the repetitive tasks into functions and calling those functions rather than having more code. Students then gain an appreciation of being able to see how there may be multiple ways to write a program, and how they may be able to optimize their code.

While this is a project that the students and professor work on in class together, it is the start of students being able to build out a digital portfolio of their programming styles to later be able to share with prospective employers. Not only that, but students are also able to later consider adding more details to the program, for example, adding a second player, but not only that, they are able to take this simple program and continue to evolve it based on the future classes that they enroll in and as they are learning different concepts. This allows for them to have multiple versions of their programming that displayed their evolution and growth as a programmer.

This semester-long exercise focuses on providing students the opportunity to work collaboratively through a hands-on exercise that mimics the task of developing a program from analyzing the requirements to creating a functional piece of software.

4.2 Foundations of Web Development

The Foundations of Web Development class is one where students are encouraged to be creative with their assignments and projects. This is one class that is offered in the program that students who embrace the learning and creation process could become independent contractors to develop basic websites for others, either from directly coding out the site through the use of HTML, JavaScript, and CSS, or through a third party platform like WordPress. While the third party platforms are not covered in the course, students are made aware of them so that they can explore their usage.

The class begins by students learning how to appropriately design a website. Students are reminded that the rule of thumb is that if a user can't find what they are looking for within 3 clicks there is a good chance they will try to find a different site for the information. They work through creating site maps and also wireframes to make sure that if their site has multiple pages, that they are all cohesive. Throughout the semesters students then use these planning techniques to build a site with several pages that they are then able to use as their digital portfolio, to display the pages that they are capable

of creating. At the end of the semester students are asked to create an additional page that will take the visitor of their site on the journey that the student has had through their design and development process. In addition to the design and development, for every page they are required to analyze their pages for accessibility. Students are taught to be aware of barriers that they could unintentionally create, and by following the guidelines provided by Web Accessibility in Mind (WebAIM), they strive to make their pages accessible [22].

While the work being done in this course is through hands-on assignments where the students put into practice what they are learning and have creative freedom when it comes to the design of their pages, they are in the driver seat of what is being created. They have some guidelines to follow but they fully take ownership of their work. Every student's page is a little different from others, because every student is uniquely creative. This is a class that students are able to take early on in their educational journey that can allow for them to be hired as a freelancer after the fact.

4.3 Human Computer Interaction

In the Human Computer Interaction (HCI) course students have the opportunity to be able to expand on the programming skills that they have developed through the pre-requisites of either taking at least Computer Science I or the Fundamentals of Web Development course. In this class students learn about how users will interact with a computer system. They have to take into consideration how software is designed to provide the users with the best user experience (UX). However, to be able to do this, students must learn about other topics that will impact UX. Topics like cognitive psychology, understanding how users are able to remember and recollect information, how metaphors can be applied to the software they create, how communication and deductive reasoning is taken into consideration, and also how to be able to analyze information obtained from users to be able to further improve their software design.

While working on regular class assignments, students also have a five phase project that will build upon itself through each phase so that they are able to understand the importance of UX design and HCI. The students are given a problem statement that requires for them to develop a game. The game is non-trivial, however it is a two in one game, so that the student has to incorporate a menu for the user to select their game. The game is something that is non-trivial to develop because the focus of the course is not on the development of the game, but more so on studying the interaction of users with the game to be able to make adjustments for a more pleasant UX.

The first phase of the project requires students to conduct an analysis based on the PACT framework which has a focus on people, activities, context, and technologies. Once the students have identified the different components of the framework they are asked to sketch a design of their prototype. Normally the design will include several screen sketches to show how the game will appear to the user. The second phase of the project has the students thinking about the actual functionality of the game that they will be creating. Students have to take into consideration all actions that the user may take while in game play, which also includes what to do if the user has been "idle" for a specified period of time. Once students have identified the functionality of their game

based on the user's interaction with it they are then asked to document that interaction by creating a hierarchical Task Analysis diagram.

Phase three of the project is where there is a shift in the work done. The first two phases were to allow the students to consider their users and plan out their design and development. Phase three is where the students are asked to develop their game to be fully functional. A working game is required because the students will be asking other people to play their game. But before asking others to play their game, students must first learn about designing questionnaires to obtain feedback from users. So, in phase 4, students create their questionnaires and identify who will make up their focus group. Lastly, in phase five, they share their games with their focus group and ask them to complete the questionnaire. Once they have received responses from the questionnaire they are asked to consider a two main points:

1. The information that they obtained from the questionnaire was the information that they were after. In the case that the information was not what they thought out, then they are asked to reconsider their questionnaire and create new questions.
2. Students are asked to critically analyze the answers that they received from the users to determine what changes they would need to make to the game to make it more enjoyable for users.

In the conclusion of phase five, students are asked to create a report that includes the findings from their analysis of the focus group responses and document the changes that they would consider making to the game to make the user experience more enjoyable. Understanding how a user interacts with technology is extremely important for anyone that goes into a career field that involves creating, whether just designing or developing, a product that someone else will use. Having this knowledge and being aware to consider the user actions with the product is an important aspect to be successful in the creation.

4.4 Digital Forensics

Digital forensics is a class that tends to stand on its own when it comes to learning about cybersecurity. However, one thing students must understand about digital forensics, is that to be good at it, it is more than just forensics that one has to be aware of. To analyze digital evidence, there will be an advantage if the investigator is knowledgeable of how the crime occurred.

While the main focus of the course and the experiential component of it is through the use of simulated labs that allow students to analyze digital evidence through specific tools, students also learn about some of the basic aspects even associated with their own lives. Exercises similar to those that are found within Capture the Flag events and other platforms such as Hack the Box or Juice Shop are incorporated to provide students with scenarios that may hit a little closer to home but can be expanded to represent the types of cyberattacks that they hear about on the news [citations for hack the box and juice shop].

Exercises that students are required to go through as part of their learning in this course beyond the simulated lessons are things like finding and decoding a hidden message on a QR code, learning about settings on cameras whether digital cameras or phone cameras where GPS coordinates can be captured and then used to find a location.

These are two examples of looking for information that can be found by anyone but only those who know to look for this information may know to do so. Students learn about undercover online investigations and are given an exercise to search through different social media accounts, that lead to additional social media platforms where eventually they are able to find an email address for a person based on the scenario that they were given. While these exercises do not carry any risk, students are asked to sign an acknowledgement of ethics when the course begins, because another example that students are shown is how to use a tool like HTTrack which can be used to copy a website which can later be modified to assist in a credential harvesting attack or something similar [10]. Students are shown the tools and ways to obtain information that would be helpful in a digital forensics investigation but they also learn about how the attacks are conducted so they are aware of what to look for.

In addition to using tools and understanding how attacks may be performed, students are also taught how to focus in on the basics. That is, the hardware itself and extracting data that may be stored in the hardware. The basics of number conversion and recognizing hexadecimal numbers along with understanding a file allocation table and how to identify that information has been deleted from a system is a key concept that students must have when it comes to a digital forensics investigation. All of these exercises and the simulations that students go through provide them with real world experiences of what they may be required to do if working as part of a digital forensics investigation team. Being able to tie what they are learning in the classroom with things happening around the world when it comes to cybercrime can be scary as one realizes all the things that can be done and the types of crimes that occur more often than many hear about. But at the same time, the goal is to empower the students have this understanding and to have the skills to use different tools to help fight cybercrime.

4.5 Sr. Software Engineering Project (Capstone)

The Senior Software Engineering Project, otherwise known as the capstone course, is the class where students have the opportunity to bring in all of their experiences throughout their educational journey into the completion of a comprehensive project.

The goal of the capstone class is to provide them with the real-world experience of completing work for someone else. To do this, the faculty will reach out to partners in the community to determine if there is a need that could be fulfilled through a semester long class project. Many projects have been associated to working with non-profit organizations, as they normally have limited funds available and are not able to hire outside help or tend to have an IT department or staff that would not be able to complete the task.

Through this partnership with the community, there are a few things that are required to take place, students are required to sign over their intellectual property rights so that the item that is created goes under the ownership of the project sponsor when the project is completed and the sponsor is required to sign a liability waiver form. With these forms being signed there is an NDA that students must adhere to and the project sponsor understands that those associated to the project will not provide maintenance once the project is completed. These documents are required when the students work on a service learning or community-engaged project as they are references at Athens State University.

Students who are assigned to a community-engaged project also gain a skill that they may not be exposed to in the workplace, which is having direct communication with a project sponsor.

In the last decade, the students from Athens State University have worked on community-engaged projects that have focused on:

- Design and re/development of ADA-accessible websites for non-profit organizations and small businesses
- Creating educational games
- Performing cybersecurity vulnerability systems analysis
- Creating functionality-specific software to be used by non-profit organizations, small businesses, and internal university department(s)

Some projects are completed within a semester and others are completed within multiple semesters depending on how large the project is, however, at the end of every semester the sponsor is provided with a deliverable that they can begin to use.

Community-engaged projects are only one of the opportunities that students have. Students are also able to choose to complete a project based on something that they may be working on for their Internship or employer if they are already working in the field. Allowing for a work-based learning opportunity for the Capstone class is something new and it was first piloted in the Spring 2024 semester, where two students chose this option. There are some consideration that have to be taken when approving for a student to complete a project through their employer, whether due to an internship or full/part-time employment. The first is that the project has to be relatable to the program in which the student is pursuing the degree for. The second is that the student must be able to discuss tasks, duties, daily operations, interactions, and such in an open forum as there are three presentations that are completed throughout the semester. Two presentations allow for students to learn from each other during the semester, and a third presentation is done at the end of the semester and it is announced to the public. Many students are employed by organizations that require security clearances and confidentiality, which then, unfortunately, students are not able to use a project associated to their employer. When this opportunity was first offered there were two students who chose to work with projects associated to their work. Having these two students present on their internship not only allowed them to learn from the projects that they were working on but also allowed the rest of the class to learn about the projects and what it was like to work as an intern and learn a little bit about the day to day operations of being in the workplace.

Lastly, a third option that students have in the capstone class is to work with a faculty member on research that may lead to publication. Students are usually encouraged to consider this option if they plan to attend graduate school. This is due to the fact that they may come across a topic that will allow for them to later further expand into a Master's thesis or Doctoral dissertation. While research and publication can sometimes be intimidating to an undergraduate student, Athens State University has had twelve undergraduate students who have published research with faculty members. Such research has led to five publications:

1. A Systematic Literature Review of Cognitive Models of the Behavior of Novice Software Developers [12].

2. Designing a Molecular Biology Serious Educational Game [13].
3. Escape from Python's Den: An Educational Game for Teaching Programming to Younger Students [11].
4. Capstone: Introducing Students to Research through Application Development in Teams [14].
5. Cyberattack Repository: A Web Application for the Selection and Composition of Cyberattack Models [15].

In each of these Experiential Learning opportunities, several key factors are consistently emphasized. Students not only grow as young professionals through their projects but also enhance their teamwork and oral communication skills by completing a minimum of three presentations—often more if they collaborate with a project sponsor. Additionally, they learn to create the necessary documentation associated with their projects. These efforts include conducting a vulnerability assessment of their product, demonstrating compliance with accessibility laws, documenting test cases for validation, and, when applicable, developing user manuals and technical documents to assist others in using their software.

In addition to the examples being provided through the courses mentioned in the previous sections, students are also required to take a career seminar course. In the career seminar course the focus is to assist students to prepare for their journey in finding their career path, but most importantly, it is also set up to help students realize that experiences are gained through many different avenues.

5 Experience = Experience: Articulation of Learning

One of the trends that faculty at from the Computer Science program have noticed with many of their students is associated to their self-marketing and self-promotion when it comes to interviewing for career opportunities and working on their resumes, is that students don't consider experience to be experience. What exactly does that mean? It means that many students are taught a traditional method of working on their resumes, which means that they will list out their education, skills, work experiences, sometimes awards and community service. The issue with this traditional process is that students get into a frame of thought that only experiences that they gain from working is worth mentioning on their resumes and that is not the case. No matter how a student gains the experience, it is still considered experience and students should be taught to value all of their experiences and not devalue it due to trying to fit it into a box. Example, a student in the Computer Science field may choose to remove having been an assistant manager at a local pizza restaurant because it has nothing to do with Computer Science or the position that they are trying to obtain. By doing this they miss out on the opportunity to be able to inform a prospective employer that they have experiences managing people, amongst others. Similar situations occur when it comes to the experiences that students are gaining inside of the classroom through their Experiential Learning opportunities.

Somewhere along the way, some students have been taught that if they don't participate in an internship or work in the field that they are trying to get their career that they don't have relevant experience. This is furthest from the truth. While of course internships and similar opportunities are usually one of the best ways for a student to

be able to become employed after graduation, since many interns are offered full time employment, there are other ways that students gain experience and they need to be guided on how to present those experiences to potential employers.

Athens State University currently requires all students to go through a Career Seminar class. In the class that is taught to Computer Science and Information Technology students the focus of the work done is to help students to determine the careers within the field that they are interested in, tailor their resume for the Computer Science (or Information Technology) industry, learn to market themselves online, but most importantly students are given an opportunity to go through mock interviews with industry partners. Through this course, students learn appropriate ways to document their experiences on their resume, no matter how they got the experience, and they also have the ability to have their resumes reviewed by industry partners who will be interviewing them and receive feedback. There are two critical sections that the Computer Science faculty encourage students to add to their resumes, especially the students who haven't had internships or worked in the field of Computer Science. Students are encouraged to have section on their resume that is specific to "Classroom Experiences" and for the students who also enjoy taking time to learn on their own and challenge themselves outside of the things that are assigned through their school work is for them to create a "Projects" section to their resume. These two sections then allow for students to be able to highlight their experiences to their prospective employers. While it is not experience that they obtained while gainfully employed somewhere, it is still experience.

However, while the focus here is based on making sure that students value their experiences no matter how they obtain it, there is also a second issue that goes hand in hand with it. That issue is that students have difficulty articulating their learning. This is not a new issue, there have been many studies about it, and in 2009 Ash and Clayton developed a framework to assist in the resolution of this challenge. The DEAL Framework focuses on Describe, Examine, and Articulate Learning [3]. While the DEAL Framework focuses on critical reflection, the reflection takes place in many different forms, whether written or verbally stated. For students to be able to value the experiences that they have had through their coursework they need to be given the opportunity to reflect on those experiences and guided on finding ways to be able to articulate their learning, but more importantly, to articulate how that learning correlates to their employment journey. In addition to addressing this issue through the career seminar course and making sure that students value their experiences to list them on their resumes and cover letters, students are also encouraged to practice an "elevator pitch". If the student is able to articulate their learning in writing but not in conversation, then there is still a disconnect that could hinder the student from starting their careers. By asking students to practice an "elevator pitch" they are able to focus on the highlights of their experiences and practice sharing them with others in a short amount of time remaining on point with the message that they are trying to convey about themselves.

6 Micro-credentials

While faculty have been bringing experiences into the curriculum and the classroom for their students. There has also been a shift in the student era where many don't value a college degree in the same manner that it was valued many years ago [6, 17, 21]. Many

students are going for programs that will get them work place ready so that they can go to work right after high school or after some specialized training that is offered in their respective field.

While there are many positions, including trades, that are extremely important for students to consider, it is also important for students to realize that in some fields, like Computer Science, while one may be able to begin their career journey based on work experience without a degree, a degree is normally needed to be able to earn promotions and not be “stuck” in one position. Many times this is something that those who have gone to industry didn’t consider at the time and as the years go by they begin to realize that they require that degree to be able to be promoted or move within their organization or field into a role with different duties.

When students are returning to school after being out in the workforce it can be difficult to be able to see the end. They may feel as if they are starting over and wondering if it is really worth it. For the students who just graduated and are considering whether or not to go to college, they are tired, they have just finished K-12 and want a break, but they might have someone in their family who may be strongly encouraging them to go to school so that they don’t have to go back when they are older. Either way, starting a Bachelor’s degree, even from immediately after high school can bring its own challenges. Students who have just graduated high school may not necessarily understand the paths to a career that they have been thinking about or even know what they might want to do as their career. For those looking to make a life change, sometimes the only thing they are going on is the fact that they want a change but are unsure what to go into or what their interests may be since being in the workforce already. A survey done by Gallup shows that young people have an easier time identifying their career paths when provided the opportunity to participate in Experiential Learning [16]. While those who may be looking to make a career change still need the same opportunity to determine their career paths.

With this in mind, at Athens State University the faculty of the Computer Science department have been working to restructure their Computer Science program, where instead of requiring students to focus in on a specific area within Computer Science and declare that area as part of their degree, students will have the opportunity to take elective courses that can be taken towards a Computer Science related micro-credential. Therefore, allowing for early exposure to different areas of Computer Science and being able to stack those classes and micro-credentials to fit within their degree requirements. In addition to this early exposure micro-credentials provides the student with a competency-based educational experience that will assist in fulfilling the required skills necessary for many employment opportunities, resulting in the possibility of employment prior to graduation.

While the focus of this section has been on students who are trying to find their path, whether just out of high school or looking to come back to school to finish their degree, when it comes to micro-credentials there is one group that has not been mentioned but also needs to be recognized. The way that the world is changing today and the demand for job skills in the market are also facing many changes with the advancements of technology, it is important for employees to remain relevant in their field through

continued upskilling. The opportunity of offering micro-credentials is also pivotal to those who are looking to remain current in their skill sets [1].

7 Discussion/Summary

With the changes in student population habits and the transformation of the landscapes of higher education, colleges and universities have to be able to show to the upcoming generations the value that is associated with a postsecondary degree. However, many times that direct path is not the right answer for a lot of people, not everyone is choosing to go to college straight out of high school and it is imperative that institutions also appeal to those who are looking to go back to school whether it's to finish a degree they had started, reskill to go into a different career, or to go back as an adult for the first time. Traditional methods of teaching may appeal to some, but for many, they want to know the “why?” and be able to relate what they are learning to their lives. They want to have that instant gratification that they have made the right choice. By providing students with experiential learning opportunities they can see right away how the theory and concepts that they are learning can be applied in the real world. They get a glimpse of what the career path that they have chosen will look like and they can determine if they are on the right path or in need to make a shift and try something else. The opportunity to have stackable credentials allow for students to be able to “explore” and not feel as if they took classes towards something that will not positively impact their journey. Even if a student were to choose to not complete a Computer Science degree, having a micro-credential within the field will still count towards something. It is a credential that employers would see alongside their degrees. The faculty in the Computer Science program at Athens State University are doing just this. Allowing students to get a glimpse of what their future careers will entail by bringing experiential learning opportunities into the curriculum. Students are also able to earn micro-credentials that they can “graduate with” before earning their Bachelor’s degree. With this approach, students will have credentials that an employer may see before the full degree, which will allow the student to move forward with their career decisions. These are just some ways in which a small group of faculty members are changing the landscape of their program within higher education to meet the new era of students in “the middle” and help them to find value in their educational journey.

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Educational Hangman: A Web Platform to Generate Customizable Hangman Games for Learning Vocabulary in Primary School Children

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Abstract. This paper presents *Educational Hangman*, a web platform to generate customized hangman games for supporting or reinforcing the learning of vocabulary in primary school children. The aim of the hangman game is to guess a word in as few attempts as possible, which at the same time helps children to familiarize with the correct spelling of words. The *Educational Hangman* web platform was created for both teachers and students. Teachers can set up custom word categories based on the topic or subject of their choice, and add words along with clues, images, and audio files. Students then play hangman games generated by the web platform, using the word categories created by their teachers, according to the topic or subject area desired. The paper also discusses some existing hangman game tools that do not offer options for creating custom categories or adding specific words.

Keywords: Learning Vocabulary · Educational Tool · Hangman Game · Primary School Children · Web Platform

1 Introduction

Conventional teaching methods no longer inspire the same enthusiasm for learning and, in some cases, can even discourage students. This has created a need for innovative strategies to enhance the teaching and learning process across various subjects. One approach is the use of educational games, which encourage students to keep engaging while simultaneously learning [1, 2].

Most games help develop essential skills such as communication, adaptability, and abstract thinking. Based on social theories of collaborative learning and the educational benefits of Information and Communication Technologies (ICT), it is crucial for students to gain new skills and developmental tools suited to our evolving society. In order for ICTs to realize their transformative potential, they should be incorporated into the classroom or other appropriate settings, becoming a cognitive tool that fosters intelligence and enriches the learning experience [3, 4].

Some of the most widely used forms of educational technology today are the educational web tools, which are aimed at enhancing learning quality. Online games should be viewed as a valuable educational activity, offering an alternative approach to knowledge acquisition that also entertains students. These games help focus the participant's interest on the subject area involved in the gameplay [5]. These tools are created to support teaching and learning anywhere and anytime, giving students access to a great variety of study materials and online learning resources [6].

One popular educational web game is the hangman, which helps children, teens, and adults acquire new knowledge, particularly by learning new words, expanding vocabulary, and improving spelling. This game familiarizes users with the correct spelling of words. Several studies have explored the effectiveness of the hangman game in education, especially for building or reinforcing vocabulary in children and young learners [7–10].

This paper introduces *Educational Hangman*, a web platform that enables teachers to create customized hangman games by defining their own word categories. Students can then play these games using the words registered in each category to reinforce or learn new vocabulary and concepts across various subjects. A key feature of the web platform presented is that teachers can add clues, images, and audio files for each word, enhancing the learning experience.

The rest of the paper is organized as follows. Section 2 presents some similar existing web applications for playing hangman games. The development of *Educational Hangman* with the modules that compose it, including the technologies and tools used for its construction, is described in Sect. 3. The operation of the web platform is explained in Sect. 4, including the elements of the interface and the mechanics to play hangman games. Section 5 shows the two evaluation instruments created: for students and for teachers. Finally, Sect. 6 presents conclusions and future work.

2 Related Work

This section examines a range of online platforms for playing hangman games, highlighting their features, strengths, and limitations. The platforms analyzed are the following: Rainbow hangman, hangman by Wordwall, hangman of Ethical world, hangman by Edudiver, and Cokitos hangman.

Rainbow Hangman [11] is an online game, where the alphabet appears on the interface, allowing the user to select letters by clicking on them. Those letters that appear in the target word and are correctly chosen turn green, while incorrect letters, which are not in the word, turn red. Players have ten lives, with each incorrect guess progressing the hangman's image. If the player guesses the word, they can choose to play again; if they exhaust all ten attempts, a message shows the correct word. The game lacks of hints and images to help users to guess the words presented.

Hangman by Wordwall [12] is also an online game that requires players to guess words based on a system-provided image. When each letter is selected, a green indicator or a red check mark is shown, depending on whether the letter is part of the word. This version of hangman includes accented letters and displays a timer in the upper left, tracking the time taken to complete the game. After completing 20 rounds, a window

shows the player's score and time taken to complete the game, with options to view the leaderboard, reveal correct answers, or restart the game.

Hangman of Ethical World [13] is an online game, where the aim is to guess the correct word. Players have ten attempts per game to guess each word, and a timer tracks the time taken to solve each word. Users can enable or disable sound, and a hint is provided for each word to help users to guess the word. Upon completing the game, a table displays the remaining lives of the user, score, and time taken. Players can play a game again after finishing.

Hangman by Edudiver [14] offers several customization options to adapt the game to different ages and skill levels. Players can limit the word length for easier guessing and adjust the maximum errors allowed to modify difficulty. The main interface allows three tries to guess the word and provides hints on the type of word (e.g., noun, verb, adjective) and its category. These hints can be activated or deactivated, and players can play the game again if they guess the word correctly.

Cokitos Hangman [15] is an online game designed for young children, featuring a colorful interface to capture their interest. The game includes the alphabet, and selected letters turn green if they are in the target word. Incorrect letters make the hangman drawing progress, and these letters disappear from the board. After each game, players have the option to play another game. Additional features include full-screen mode and the ability to deactivate the background sound.

A more detailed analysis of the platforms examined in this section is carried out in [16], where their features, strengths, and limitations are compared.

3 Development of the Web Platform

This section presents the development of *Educational Hangman*. The modules that compose this web platform are explained, along with some screenshots. The technologies and tools used to develop it are also described.

3.1 Modules

This section provides an explanation of the modules that compose *Educational Hangman*. These modules are in charge of validating users, allowing to play hangman games, verifying words, showing student results, visualizing categories of words, registering new categories, modifying and deleting categories, visualizing words, adding new words, modifying and deleting words, among others.

Access and Validation Module. This module allows teachers and students to access the web platform through a login page. A form is used to enter the access data, which is then validated through a server object; the user is redirected to the corresponding web page. The data entered is checked in the database through a validation method to determine whether the user exists and is valid.

Student Menu Module. This module corresponds to the main menu web page for students, where they can start playing hangman games by selecting a category of words. Figure 1 shows the interface of the student main menu: it has a banner at the top with

the name of the web platform, a left menu with options, and a central panel. The left menu has a set of options, including viewing the student's personal information, selecting categories of words, reviewing the leaderboard, and the option to exit the platform. The central panel shows the categories of words available in the web platform: animals, body parts, biology, and countries. The student can select any of the categories presented; each category takes the student to a hangman game with a set of ten random words corresponding to the selected category.



Fig. 1. Interface of the student main menu in *Educational Hangman*.

Hangman Game Module. This module has an interface that allows students to play a specific hangman game, according to the category selected. Figure 2 shows the interface of a hangman game for the category of animals. The mechanics of the game involves the system providing a randomly selected image, accompanied by a clue, challenging the player to guess the correct word associated with the image and the clue. During the course of the game, if the letter selected by the user is correct, it will be highlighted in green; otherwise, it will be highlighted in red. The player has a limit of five lives,

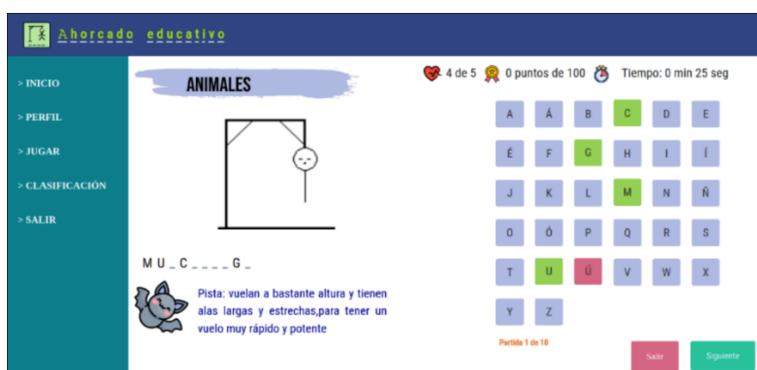


Fig. 2. Interface of a hangman game in *Educational Hangman*.

in addition to keeping track of the score and elapsed time. The goal of the game is to successfully complete the ten assigned games, culminating in obtaining the score and the total accumulated time.

Word Verification Module. This module verifies the progress of the word to be guessed by the student. It gives different colors to the keyboard, depending on whether the selected letter is in the word to be guessed, which means that the letter is correct or incorrect. In addition, this module controls the dynamics of showing the hangman's development with each error made by the student, as well as the random updating of the clue and the image. The integration of these features provides an interactive experience for the students.

Student Results Module. This module allows students to review their performance obtained by completing hangman games for each category. The interface of this module provides students the following information through result tables, one table for each category played: position in the specific table, name and surname of student, score obtained by student, and the time elapsed to complete the ten hangman games for the specific category. Figure 3 shows the interface of this module.

TABLA DE CLASIFICACIÓN - ANIMALES				
Posición	Nombre	Apellido	Puntuación Total	Tiempo Total
1	Fernanda	Orezco	30 de 100	01 min 09 seg

TABLA DE CLASIFICACIÓN - PARTES DEL CUERPO				
Posición	Nombre	Apellido	Puntuación Total	Tiempo Total
1	Fernanda	Orezco	0 de 100	00 min 11 seg

TABLA DE CLASIFICACIÓN - BIOLOGÍA				
Posición	Nombre	Apellido	Puntuación Total	Tiempo Total

TABLA DE CLASIFICACIÓN - PAÍSES				
Posición	Nombre	Apellido	Puntuación Total	Tiempo Total

Fig. 3. Interface of the student results in *Educational Hangman*.

Teacher Menu Module. This module corresponds to the main menu web page for teachers, where they have a view of all users, words, and categories in the web platform. Various options are available in the left menu to perform various actions, such as: view profile, administer users in the web platform, register a new word, view words registered in the web platform in all categories, create a new category, view categories registered in the web platform.

View Categories Module. This module has an interface that allows teachers to visualize all the categories registered in the web platform. In this case, it can be seen that four categories are registered: animals, body parts, biology and countries. This interface is shown in Fig. 4, and for each category, the following information is provided in the table: category id, category name, image, a link for editing the category, and a link for deleting the category.

Word Registration Module. This module allows teachers to select a specific category and add new words to it, each word is accompanied by essential information, which includes the word, a clue to guide the students in their attempt to guess the word, as well as multimedia resources such as images and audio files that complement the learning experience. Once these new words have been created, the teacher has the necessary tools to manage them efficiently. The web platform provides editing functionalities that allow the teacher to adjust or improve the details associated with a specific word. The system also offers the option to delete words, giving the teacher full control over the content of the hangman game.

ID Categoría	Nombre de la Categoría	Imagen	Editar	Eliminar
1	ANIMALES		Editar	Eliminar
2	PARTES DEL CUERPO		Editar	Eliminar
46	BIOLOGÍA		Editar	Eliminar
53	PAÍSES		Editar	Eliminar

Fig. 4. Interface for visualizing the registered categories in *Educational Hangman*.

View Words Module. This module has an interface that allows teachers to visualize all the words registered in a specific category in the web platform. This interface can be accessed by clicking on the *View Words* option in the menu on the left, and then selecting the desired category. In this case, it can be seen that many words are registered for the category of animals: a whale, a hummingbird, a chameleon, a snail, among others. This interface is shown in Fig. 5, and for each word, the following information is provided in the table: word id, category id, word, clue, image, audio file, a link for editing the word, and a link for deleting the word.

Word Edition Module. This module allows teachers to edit the information of a specific word. In this interface, the following information can be edited in the table: the category to which the word belongs, the word, the clue associated with the word, the image associated with the word, and the audio file associated with the word.

3.2 Technologies and Tools Used

There were several technologies and tools used for the development of *Educational Hangman*, which are described in the following paragraphs.

Hypertext Preprocessor (PHP). This is a technology that allows the development of dynamic web pages, combining static HTML with HTML dynamically generated. It was

CATEGORÍA: ANIMALES								
ID	ID Categoría	Palabra	Pista	Imagenes	Audio	Editar	Eliminar	
4	1	ballena	poseen una capa de grasa muy gruesa que las aísla para protegerse del frío					
5	1	colibrí	sus alas se mueven alrededor de 60 veces por segundo					
6	1	camaleón	son famosos por su habilidad de cambiar de color					
7	1	caracol	comen arraigándose, estos moluscos no tienen boca ni dientes					

Fig. 5. Interface for visualizing words of a category in *Educational Hangman*.

designed specifically for building dynamic web applications and is embedded directly into HTML code. PHP runs on the web server and supports a wide variety of databases, making it a versatile technology for building interactive websites. PHP was used for implementing the web platform, specifically for communicating with the database to add, query, update and delete categories and words, and for displaying in web pages the information extracted from the database.

JavaScript. This is an interpreted programming language, designed to make interactive and dynamic web pages. This language is based on objects because it has an implementation of the document object model (DOM), which is a model that translates the structure of an HTML document to a tree of objects when the document is interpreted by a web browser. JavaScript was used for showing the hangman as it was growing, for coloring the letters in the keyboard as they were selected by students, for showing the elapsed time during the games, among other functionalities.

Cascading Style Sheets (CSS). This is a language for styles used to change the presentation of a web page, such as the background color or font size. CSS were used for the presentation of the entire web platform to create hangman games, for all the layout of the menus and the panels, and for the structure of the games.

NetBeans. This is an integrated development environment (IDE), which allows its users to write, compile, debug and execute programs. NetBeans allowed the concentration and creation of all the files of the project, such as PHP files, HTML files, CSS files, JavaScript files, among other files.

Apache HTTP Server. It is a powerful HTTP web server, which implements the latest protocols, including HTTP/1.1; it is configurable and extensible with third-party modules; it provides full source code, and it runs on Windows, Netware 5.x, and most versions of Unix, as well as several other operating systems. This server can be used for relational databases; it allows to set up files, among other features.

MySQL. This is a relational database management system (RDBMS) based on the structured query language (SQL), multi-threaded, multi-user, and multi-platform, which

is widely used for storing data in web applications for different platforms. MySQL was used for the creation of the relational database that was employed for the web platform, which stored the information of users, categories of words, words, results of hangman games, among others.

Moqups. This is an application for creating prototypes for web graphical interfaces, with the aim of showing them to the students and teachers in early stages of the development process. *Moqups* was used to create very quickly interface prototypes, which were used to validate and test the interface.

4 Operation of the Web Platform

This section presents the operation of *Educational Hangman*. Figure 6 shows an example of a hangman game with its different sections: left menu, category, hangman figure, number of lives, score, timer, image, clue, keyboard, and game number. The following paragraphs describe each of these sections. An example of the execution of a hangman game is also presented in this section.

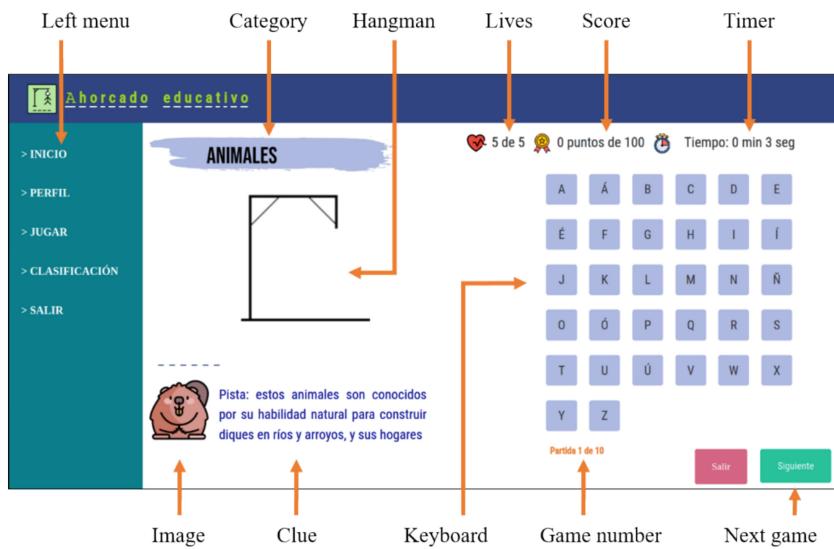


Fig. 6. Interface of a hangman game in *Educational Hangman*.

Left Menu. This is a menu that has the following options: view student's profile, play a hangman game, leaderboard with scores, and sign out.

Category. This section of the hangman game indicates the category that was selected by the student to play the hangman games. In this case, the category is animals.

Hangman. This is an image that represents the hangman, which grows when the student fails to select a correct letter (a letter that is part of the word to be guessed).

Lives. This part of the interface represents the number of lives that the student has for each hangman game. Every game starts with five lives.

Score. This is the number of points that the student accumulates for every hangman game played. The score goes from 0 to 100 points.

Timer. This is the time accumulated taken by the student to complete the hangman games played. In this case, the timer is 0 min, 3 s.

Image. This section is to show the image associated with the word to be guessed. This image is uploaded by the teacher when registering a new word. In this case the image associated with the word shows a beaver (*castor* in Spanish).

Clue. This section is to show the clue associated with the word to be guessed. This clue is added by the teacher when registering a new word. In this case the clue shown in the hangman game is a description of a beaver.

Keyboard. This part of the interface shows a keyboard, with all the letters of the alphabet, including the vowels with accent (A and Á, E and É, I and Í, O and Ó, U and Ú). This section promotes the correct spelling of words.

Game Number. This section of the interface illustrates the number of games that the student has played of that category. This number goes from 0 to 10.

Next Game. This is a button to go to the next word to be guessed. This button should be clicked when the student has completed the current word.

Once the student starts the hangman game, time will start to elapse. If a letter selected is in the word to be guessed, then the letter will be displayed in green; on the other hand, if a letter selected is not in the word to be guessed, then the letter will be displayed in red, the hangman figure will grow, and the lives will decrease.

Figure 7 illustrates a hangman game where a student has already selected seven letters on the keyboard: the letters A, C and T appear in green, because they are part of the word that the student has to guess, they have already been placed in the corresponding spaces of the word to be guessed; the letters J, M, N and W appear in red, as they are not part of the word to be guessed. The current number of lives is one, this is because for each letter selected on the board and not found in the word, one life is lost (four lives have been lost). At the same time, time is running, and the hangman figure has grown due to the incorrect letters. When the student has guessed the word or has lost all their lives, the web platform will show the next word to be guessed, and this will continue for the remaining words contained in each hangman game.

Figure 8 shows the interface of the hangman game when the student has guessed the word, a congratulations message will appear accompanied by an audio corresponding to the guessed word. The student can move on to the next game.

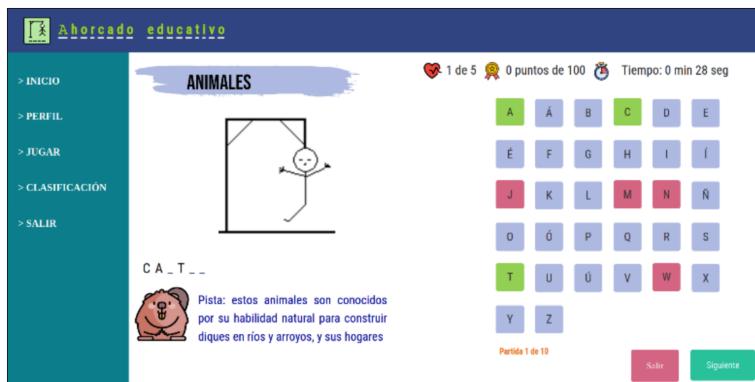


Fig. 7. Interface of a hangman game with three letters found in *Educational Hangman*.

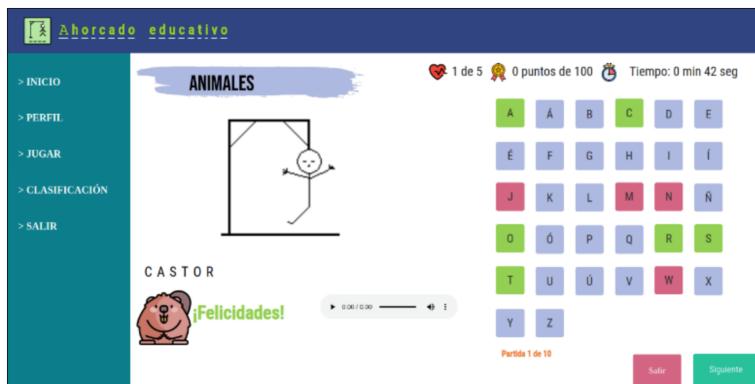


Fig. 8. Interface of a hangman game with the word guessed in *Educational Hangman*.

If the student does not guess the correct letters that conform the word, the hangman will grow until the attempts are finished. The system will inform the student that he has lost the game and will reveal which the correct word was. In addition, an audio corresponding to the word will be played. Figure 9 shows this interface, where it displays the word to be guessed was tiger (*tigre* in Spanish).

Table 1 shows some of the words registered in the category of animals, which are already uploaded to the web platform, with their corresponding audio files. The first column shows the image associated with the word, the second column is the word to be guessed in English (the word in Spanish is in parenthesis), and the third column is the clue associated with the word.

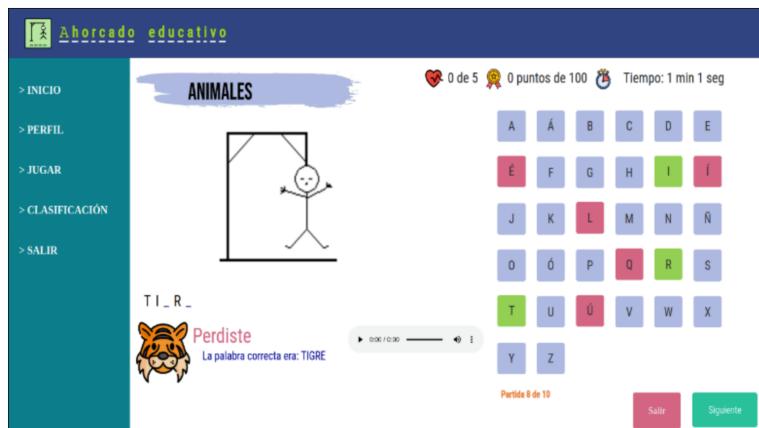


Fig. 9. Interface of a hangman game with the word not guessed in *Educational Hangman*.

Table 1. Examples of words registered in the category of animals.

Image	Word	Clue
	Beaver (castor)	They are known for their natural ability to build dams in rivers and streams, and their homes.
	Whale (ballena)	They have a very thick layer of fat that insulates them to protect them from the cold.
	Tiger (tigre)	They have powerful claws and are the largest feline in existence.
	Bat (murciélagos)	They fly at a fairly high altitude and have long, narrow wings, for a very fast and powerful flight.
	Snail (caracol)	They eat by crawling, these mollusks have no mouth or teeth.
	Dolphin (delfin)	They sleep with their eyes open.

5 Evaluation of the Web Platform

The evaluation of a system can be carried out by observing the user's interaction with the system or by responding to a questionnaire specifically designed to collect feedback on certain aspects. In the case of *Educational Hangman*, the aspects that were considered for the evaluation were aesthetic design, usability and functionality. In order to carry out the evaluation effectively, two different evaluation instruments were developed: one for students and the other for the teachers. The results of these evaluation instruments are presented in this section.

5.1 Evaluation Instrument for Students

This evaluation was carried out with a group of ten students from a primary school, who were asked to carry out the following activities within the web platform.

1. Ask the student to register on the web platform.
2. Ask the student to choose a category and start the hangman game.
3. Ask the student to complete the ten games of the chosen hangman game.
4. Ask the student their score and final time of the game.
5. Ask the student to review the leaderboard and check if they appear in the table.
6. Ask the student to navigate the web platform freely.

Table 2 shows the results obtained after the ten students carried out the requested activities. The first column indicates the activity number; the second column indicates the number of students who successfully completed the activity; the third column indicates the number of students who could not complete the activity; and finally, the fourth column indicates the average time it took the students to complete the activity.

Table 2. Results of the activities carried out by students.

Activity	It was achieved	It was not achieved	Average time
1	10	0	3 min, 25 s
2	10	0	30 s
3	8	2	11 min, 25 s
4	9	1	35 s
5	8	2	1 min

The evaluation of the functionality of the platform was carried out by observing the interaction that the students had with it. Based on this observation with the students, the following nine questions were answered.

1. Which category did the students like the most? The “Animals” category, since they found it more dynamic. They mentioned that they really liked animals, which helped make the experience more attractive for them.
2. How did the students react to difficulties or successes during the game? On some occasions, they asked for help with their classmates or tried to guess the word even when their attempts were exhausted.
3. What was the most difficult category for students? The country category turned out to be the most complicated, since they had limited knowledge about country flags.
4. In which activity did the students find the most difficulties? The modification of information or passwords, some of the students expressed ignorance about how to carry out those procedures.
5. Was the menu navigation easy to understand for students? Yes, since the beginning they mentioned which category they wanted to play and they managed to understand that selecting a category automatically took them to the game.

6. Were there positive or negative comments about the web platform? They were positive since the students really liked the categories of the game and mentioned that the audios and images were very cool.
7. Was there any specific part of the game that generated the most excitement or interest among the students? Yes, even when they could not guess a word, their interest increased and they began to think about what the word in question could be. When it came the time for the score and the final time of the game, they showed enthusiasm to be able to finish in the top 5 scores.
8. What emotions did the students express when carrying out the activities? They showed enthusiasm, joy and concentration during the development of the activities.
9. Were there any suggestions or comments from the students on how the game could be improved? Yes, some children offered suggestions and comments on how to improve the game. Some of the ideas mentioned included the possibility of introducing difficulty levels, and even incorporating interactive elements or special challenges and levels to make the game even more exciting.

5.2 Evaluation Instrument for Teachers

This evaluation instrument was divided into three sections: aesthetic design, usability and functionality. This section presents the questions that were asked to the teachers and the percentages that responded to each of the five options: a) Totally agree, b) Slightly agree, c) Neither agree nor disagree, d) Slightly disagree, e) Totally disagree. Table 3 shows the results of the evaluation instrument regarding aesthetic design; Table 4 presents the results of the evaluation instrument of the usability section; finally, Table 5 shows the results of the instrument for the functionality of the platform.

Table 3. Results of the evaluation for the aesthetic design.

Do you think the organization of the information in the interface is adequate?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Do you find the buttons used in the interface clear and easy to use to navigate?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Do the size, color and font allow you to read the contents without difficulty?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Do you find the button names understandable and easy to use?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Do you think the colors used in the interface are appropriate?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Do you think the interface is adequate in general?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%

Table 4. Results of the evaluation for the usability.

Can you go forward, back and jump to another page at any time?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Is the waiting time between one action and another acceptable?				
a) 90%	b) 10%	c) 0%	d) 0%	e) 0%
Do you consider that the language used in the web platform is understandable?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Do you think that the web platform is easy to use and that you do not need any tutorial or previous experience to use it?				
a) 90%	b) 10%	c) 0%	d) 0%	e) 0%
Do you think that the platform allows to go back and correct any errors made at any time?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%

Table 5. Results of the evaluation for the functionality.

Do you find it easy to add a new category?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Do you find it easy to add new words to the system?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Do you find it easy to edit a category?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Do you think it is easy to delete a user?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%
Do you find it easy to remove words from a category?				
a) 100%	b) 0%	c) 0%	d) 0%	e) 0%

6 Conclusions and Future Work

This paper introduced *Educational Hangman*, a web platform to generate customized hangman games for supporting the learning of vocabulary in primary school children. The *Educational Hangman* web platform was designed for teachers and students. Teachers can register categories based on the topic or subject of their choice, and add words along with clues, images, and audio files. Students can play hangman games generated by the web platform, using the word categories created by their teachers, according to the topic or subject desired.

It was carried out a comparative analysis of five existing online platforms to play hangman games, and the most relevant features were highlighted. It should be noted that all the tools analyzed are static, which means that none of them allows the creation of customized hangman games, none of the applications evaluated allows the creation of new categories or the addition of new words. On the other hand, *Educational Hangman* is a web platform that allows the generation of hangman games based on the categories

registered by teachers with the set of words added; this feature is very relevant to adapt hangman games to any topic or discipline.

The results of the evaluation instruments with students and teachers were very positive. The students' comments reflected a very favorable experience, they highlighted the pleasure of having images as clues and expressed excitement every time they guessed a word correctly. The adjectives that students used to describe the web platform were "Cool system", "Fantastic game" and "Fun hangman game", they also mentioned that the images used were nice. Regarding the evaluation with teachers, the results were also very positive in the three aspects evaluated: aesthetic design, usability and functionality. Teachers said that the creation of new categories was as a very simple process, they also mentioned that it was easy to add words to a certain category, with their corresponding images, clues and sounds.

Further work is needed to put the *Educational Hangman* web platform on a web server so that teachers and students can use it permanently. Additionally, various improvements and adaptations could be explored for the platform, such as: the implementation of difficulty levels that vary the complexity of the words to be guessed, to adapt to different skill levels; multiplayer functionality, so that players can compete against each other, this could include online matches or local games in which several players participate; the incorporation of achievements and challenges to motivate players, this could include virtual rewards, medals or even unlockable items throughout the game; Finally, online chat functionality allowing players to communicate with friends while playing, this not only adds a social component to the game but also allows for collaboration to guess words or exchange clues.

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Blending Computational Thinking and Creativity: Algorithmic Art with Python

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Abstract. This paper explores Python's Turtle Graphics and TigerJython's contribution to mathematical principles, logic, and algorithms in creating visually appealing graphs, images, and patterns. Inspired by the Logo programming language, Turtle Graphics enables geometric drawing, while TigerJython provides an intuitive interface for exploring code-driven visuals. Together, these tools combine computational rigor and artistic creativity, fostering critical thinking and problem-solving skills. The paper highlights the role of generative AI, such as ChatGPT, as a supplementary resource, enhancing learning without replacing foundational competencies. This balanced approach equips learners to navigate complex challenges in a technology-driven world, combining technical expertise with creative expression to make programming engaging and educational.

Keywords: Turtle Graphics · TigerJython · mathematical visualization · algorithmic patterns · generative AI integration

1 Introduction

With its simplicity and versatility, Python has emerged as a top programming language in educational and professional applications. Among its many capabilities, Python offers rich visualization tools that combine logic, mathematics, and programming to create graphical representations. Initially inspired by the Logo programming language developed in 1967, Turtle Graphics is a tool that enables users to produce geometric drawings and intricate patterns through structured algorithms and recursive methods. Similarly, TigerJython is an intuitive software built on Python that expands these capabilities by providing a user-friendly interface to explore visual programming.

When art and programming unite, a unique opportunity to inspire creativity is uncovered, which also aids in developing foundational principles such as mathematics, logic, and algorithms. Tools like Turtle Graphics and TigerJython empower users to visualize mathematical concepts and experiment with innovative designs. From drawing simple shapes to crafting complex recursive patterns, these tools demonstrate how programming can be both educational and artistically rewarding. These dual purposes highlight the versatility of computational thinking in bridging technical skills with creative expression.

This paper explores the integration of Python's Turtle Graphics and TigerJython as platforms for creating algorithm-driven visual art. It demonstrates how these tools introduce programming concepts and serve as a foundation for problem-solving and critical thinking. Students and professionals can transform abstract ideas into visually compelling designs by incorporating mathematical principles, logical sequences, and efficient algorithms. The balance of technical rigor and artistic exploration encourages learners to engage deeply in programming, enhancing their problem-solving abilities while fostering innovation.

Additionally, this paper notes the importance of combining foundational skills with advanced tools like generative AI to form a comprehensive learning framework. AI tools like ChatGPT provide personalized assistance and innovative ideas and are most effective alongside strong mathematics, algorithms, and programming competencies. This interaction prepares learners to tackle the challenges of an increasingly technology-driven world, making programming an essential skill and an accessible and engaging discipline.

2 ChatGPT Proficiency: The Lost Art of Learning Mandarin

You may have heard a story like the one below. Is the story meant to be a joke?

After completing two semesters of Mandarin Chinese language courses at college, a student named Duke received an award recognizing his achievements, including a high GPA.

During the award ceremony, Duke was interviewed and asked, "What is your career goal?".

He confidently replied, "I want to become a Chinese language professor at Stanford University."

Impressed by his ambition, the chair of the college's Chinese Language Department handed Duke her business card, written entirely in Mandarin Chinese. Puzzled, Duke looked at the card and asked, "What language is this written in?".

Thinking it was a joke, the chair smiled and said, "It's Mandarin Chinese."

She asked, "Would you like to introduce yourself in Chinese?".

Duke replied, "I can't introduce myself in Chinese, but I can email you a bio written in Chinese instead."

The chair, surprised, asked, "You want to become a Chinese language professor? What is your strength?".

Duke answered, "ChatGPT. I know how to use ChatGPT."

Even more surprised, the chair asked, "What languages can you speak?".

Duke replied, "Two: English and ChatGPT."

Later, when asked what he had learned over the past two semesters, Duke hesitated, glanced at his phone, and said, "One moment. Oh, OK. ChatGPT says I know how to use ChatGPT."

Let's ask ChatGPT to verify whether the story is authentic.

ChatGPT's Response (5:30 PM on 11/21/2024):

The story is highly unlikely to be authentic and appears to be crafted as a joke or satire. Its exaggerated elements, ironic twists, and humorous tone suggest it is not meant to depict a real-life event. Here's why:

Contradictory Behavior:

Duke's ambition to become a Chinese language professor is implausible given his inability to recognize Mandarin, introduce himself, or demonstrate even basic proficiency after two semesters of study. This stark disconnect seems deliberately exaggerated for comedic effect.

Reliance on ChatGPT:

Duke repeatedly referencing ChatGPT as both a "strength" and a "language" he speaks adds an absurd, modern twist. While reliance on AI is increasingly common, claiming it as a language or a skillset in such a setting is implausible.

Punchline Structure:

Statements like "ChatGPT says I know how to use ChatGPT" and "I can't introduce myself in Chinese, but I can email you a bio written in Chinese" serve as punchlines, which reinforce the idea that the story is meant to amuse rather than describe a factual event.

Conclusion:

The story is not authentic. It is most likely intended as a humorous narrative or satirical commentary on superficial learning and over-reliance on technology.

Remarks

ChatGPT provided a sound analysis. However, according to an unpublished survey of 60 college students, 25% mentioned that the story can be real to some degree.

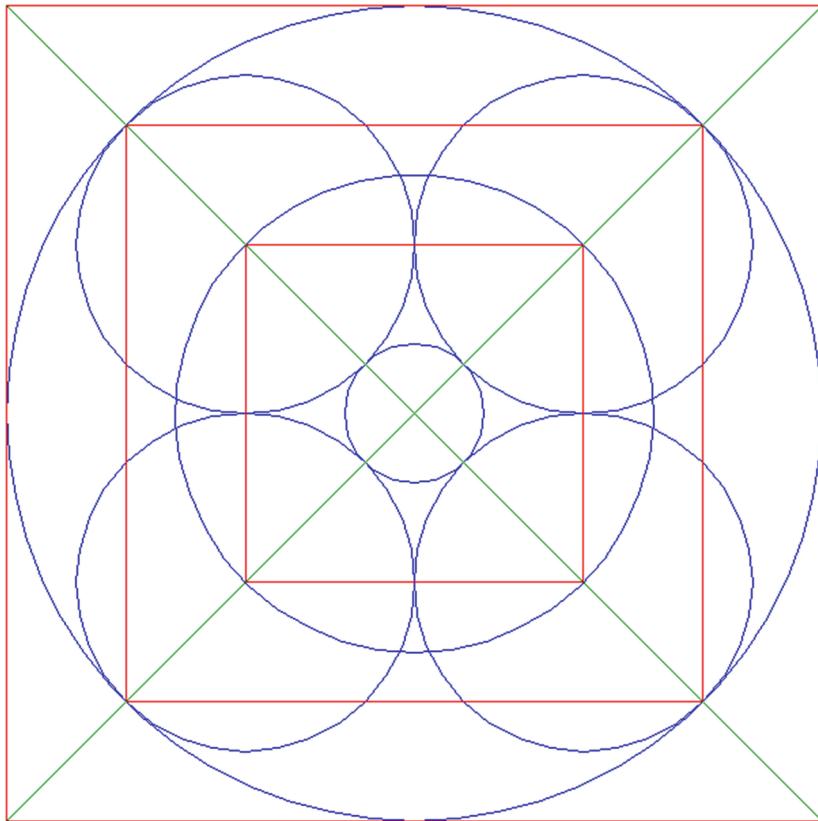
If the story is true, it highlights real issues such as superficial academic achievements, where high GPAs don't translate to practical skills, and overreliance on AI tools like ChatGPT. Duke's ambition to become a Chinese language professor differs sharply from his skill set, namely the inability to read or speak Mandarin, which creates irony. Remarks, like "What language is this written in?" and "I know how to use ChatGPT," resemble punchlines due to their absurdity but likely reflect overconfidence or misunderstanding rather than humor.

The story also underscores broader systemic issues, such as the gap between grades and real-world application and how technology can instill a false sense of mastery. While not crafted for comedy, absurd responses mirror the structure of a joke, making the situation unintentionally humorous despite its serious undertones.

3 Turtle Graphics

3.1 Creating a Graph

How do you make a Python Turtle Graphics program to create the following graph?



The following is the Python program.

```
import math
import turtle
turtle.speed("fastest")

def circle(x, y, radius, color):
    turtle.penup()
    turtle.goto(x,y)
    turtle.pendown()
    turtle.pencolor(color)
    turtle.circle(radius)
    turtle.penup()

def square(x, y, size, color):
    turtle.penup()
    turtle.goto(x,y)
    turtle.pendown()
    turtle.pencolor(color)
    for k in range(4):
        turtle.setheading(k*90)
        turtle.forward(size)

def connect(x1, y1, x2, y2, color):
    turtle.penup()
    turtle.goto(x1,y1)
    turtle.pendown()
    turtle.pencolor(color)
    turtle.goto(x2,y2)

circle(0, -300, 300, "blue")
circle(0, -300*math.sqrt(2)/(1+math.sqrt(2)), 300*math.sqrt(2)/(1+math.sqrt(2)), "blue")
circle(300/(1+math.sqrt(2)), 0, 300/(1+math.sqrt(2)), "blue")
circle(-300/(1+math.sqrt(2)), 0, 300/(1+math.sqrt(2)), "blue")
circle(-300/(1+math.sqrt(2)), -600/(1+math.sqrt(2)), 300/(1+math.sqrt(2)), "blue")
circle(300/(1+math.sqrt(2)), -600/(1+math.sqrt(2)), 300/(1+math.sqrt(2)), "blue")
circle(0, -300*(math.sqrt(2)-1)/(1+math.sqrt(2)), 300*(math.sqrt(2)-1)/(1+math.sqrt(2)), "blue")

square(-300, -300, 600, "red")
square(-300/(1+math.sqrt(2)), -300/(1+math.sqrt(2)), 600/(1+math.sqrt(2)), "red")
square(-300, -300, 600, "red")
square(-150*math.sqrt(2), -150*math.sqrt(2), 300*math.sqrt(2), "red")

connect(-300, -300, 300, 300, "green")
connect(-300, 300, 300, -300, "green")
```

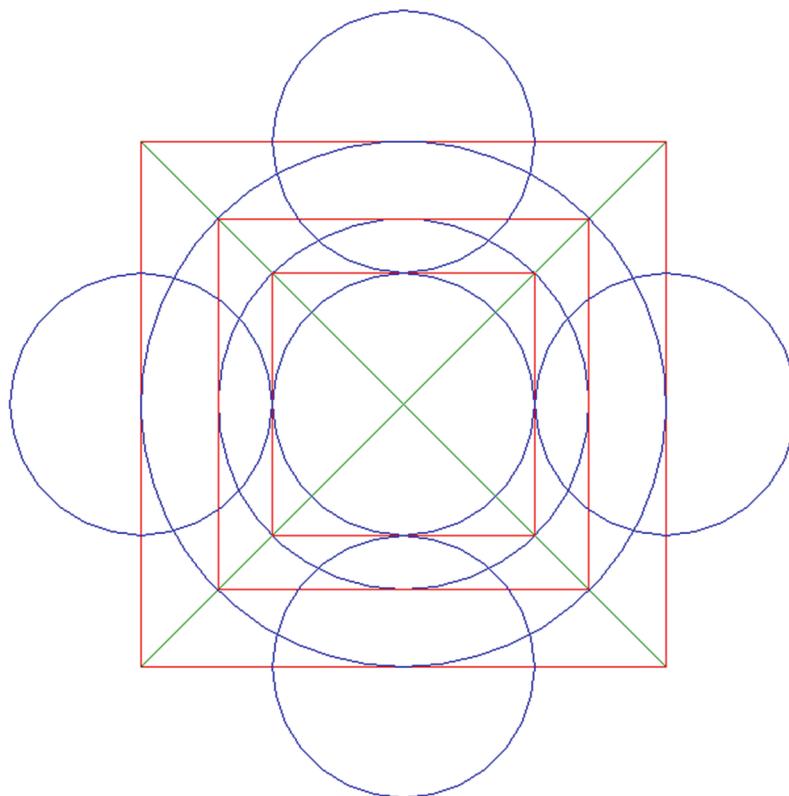
Remark

The following is the mathematics behind the graph.

Let the radius of the large circle be R , then the radius of the medium circle is $\frac{\sqrt{2}R}{1+\sqrt{2}}$, the radius of the small circle is $\frac{R}{1+\sqrt{2}}$, and the radius of the smallest circle is $\frac{(\sqrt{2}-1)R}{1+\sqrt{2}}$. The size of large square is $2R$. The size of medium square is $\sqrt{2}R$. The size of small square is $\frac{2R}{1+\sqrt{2}}$.

ChatGPT's

After we uploaded the above graph/image to ChatGPT, we asked ChatGPT to create a Turtle Graphics program to replicate it. We repeated this ten times. The following image is the best among the 11 programs that ChatGPT provided. The number of lines of code in the program is twice that of the program we created.



3.2 Creating Art

How do you make a Python Turtle Graphics program to create the following graph?

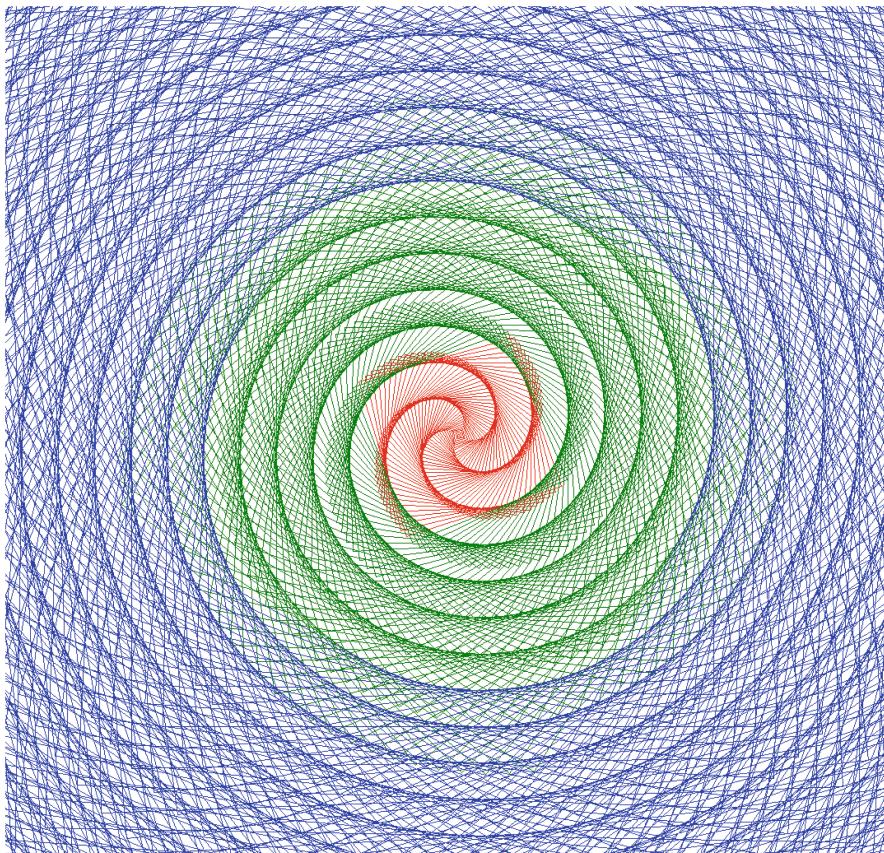


The following is the Python program.

```
import turtle
turtle.speed("fastest")
turtle.pensize(3)
colors = ['red', 'purple', 'blue', 'green', 'yellow', 'orange']
for x in range(600):
    turtle.pencolor(colors[x % 6])
    turtle.forward(x)
    turtle.left(59)
```

3.3 Creating a Pattern

How do you make a Python Turtle Graphics program to create the following graph?

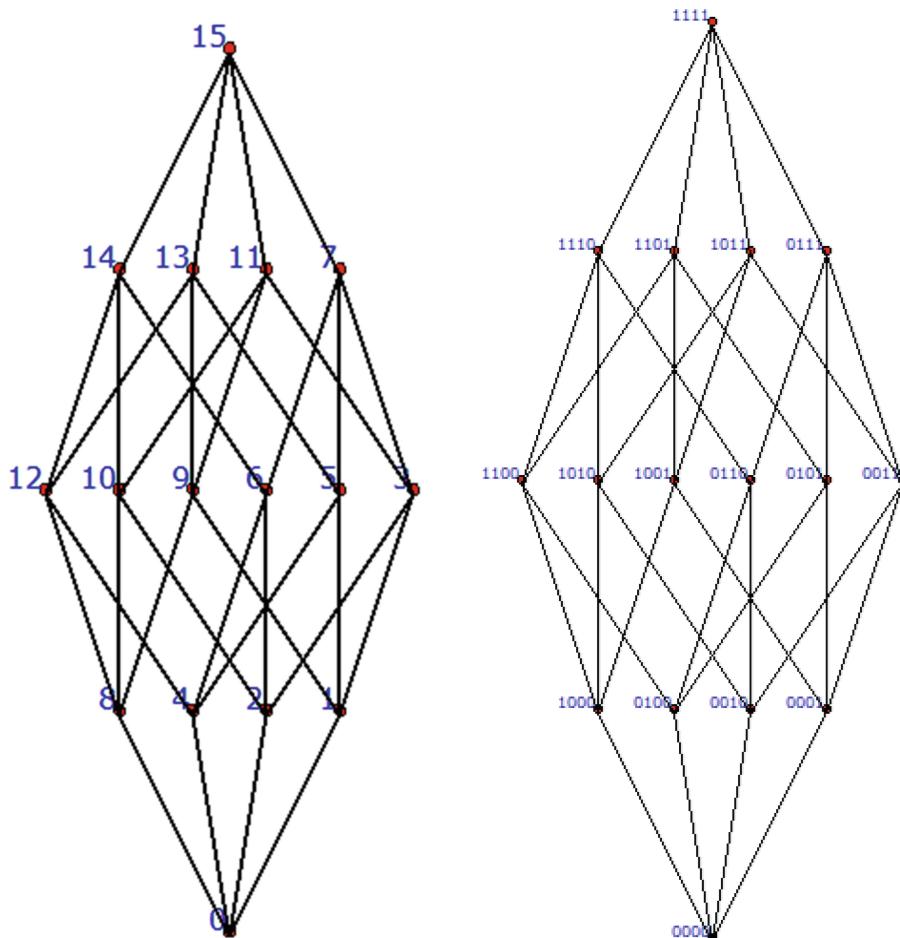


The following is the Python program.

```
import turtle
turtle.speed("fastest")
for i in range(1600):
    if i < 200:
        turtle.pencolor('red')
        turtle.forward(i)
        turtle.left(91)
    elif i < 600:
        turtle.pencolor('green')
        turtle.forward(i)
        turtle.left(91)
    else:
        turtle.pencolor('blue')
        turtle.forward(i)
        turtle.left(91)
```

3.4 A Problem for Our Readers

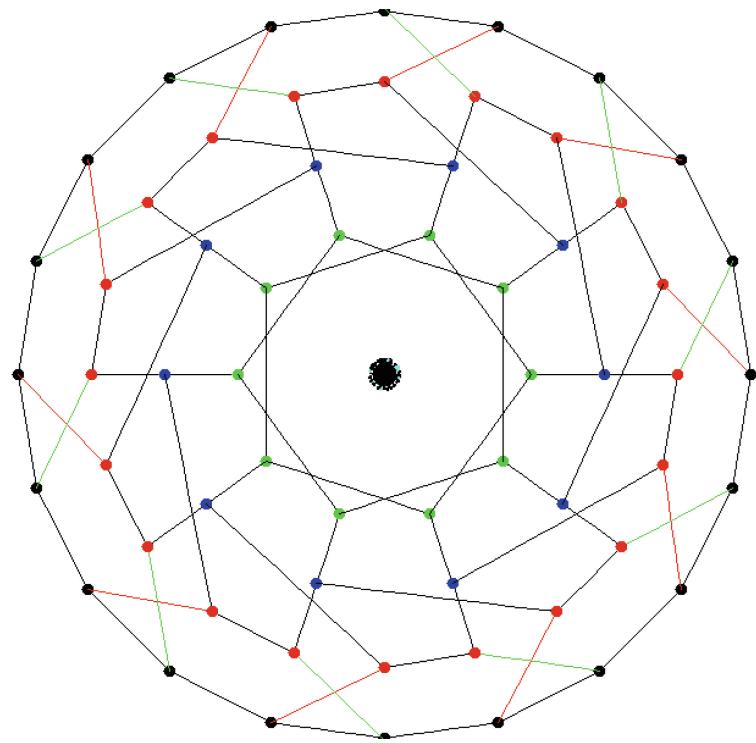
Please make a Python Turtle Graphics program to create the following images.



Su et al. (2024) discuss the dominion properties of grids and their applications in network analysis. We encourage our readers to construct the various graphs in the paper.

4 TigerJython

How do you make a TigerJython program to create the following graph?



The following is the program.

```
from gturtle import *
from gpanel import *
import thread

def circle1(t,isLeft):
    t.penUp()
    #1
    t.moveTo(0.0,-298.0)
    t.penDown()
    t.dot(10)
    #2
    t.moveTo(92.70509831248425,-285.31695488854604)
    t.dot(10)
    #3
    t.moveTo(176.33557568774197,-242.7050983124842)
    t.dot(10)
    #4
    t.moveTo(242.70509831248424,-176.3355756877419)
    t.dot(10)
    #5
    t.moveTo(285.3169548885461,-92.7050983124842)
    t.dot(10)
    #6
    t.moveTo(300.0,1.8369701987210297e-14)
    t.dot(10)
    #7
    t.moveTo(285.31695488854604,92.70509831248424)
    t.dot(10)
    #8
```

```
t.moveTo(242.70509831248424,176.33557568774194)
t.dot(10)
#9
t.moveTo(176.33557568774194,242.70509831248424)
t.dot(10)
#10
t.moveTo(92.70509831248422,285.31695488854604)
t.dot(10)
#11
t.moveTo(3.6739403974420595e-14,298.0)
t.dot(10)
#12
t.moveTo(-92.70509831248428,285.31695488854604)
t.dot(10)
#13
t.moveTo(-176.335575687742,242.7050983124842)
t.dot(10)
#14
t.moveTo(-242.70509831248427,176.33557568774188)
t.dot(10)
#15
t.moveTo(-285.3169548885461,92.70509831248417)
t.dot(10)
#16
t.moveTo(-300.0,-5.510910596163089e-14)
t.dot(10)
#17
t.moveTo(-285.31695488854604,-92.70509831248427)
t.dot(10)
#18
t.moveTo(-242.7050983124842,-176.33557568774197)
t.dot(10)
#19
t.moveTo(-176.3355756877419,-242.70509831248424)
t.dot(10)
#20
t.moveTo(-92.70509831248418,-285.3169548885461)
t.dot(10)
t.moveTo(0.0,-298.0)
t.penUp()
t.setPos(0,0)
t.penDown()

def circle2 (t, isLeft): #2
    for k in range(20):
        t.penUp()
        t.setPos(0,0)
        t.setHeading(18*k)
        t.forward(240)
        t.penDown()
        t.setFillColor("red")
        #t.begin_fill()
        #t.circle(4)
        t.dot(10)
        #t.fillCircle(4)
        #t.fillPath()
```

```

#t.end_fill()
x1 = 240*math.cos(math.pi*((18*k)%360)/180)
y1 = 240*math.sin(math.pi*((18*k)%360)/180)
t.setPos(x1,y1)
t.setPos(x1, y1)
t.penDown()
letter = str(20+k+1)
t.setTextColor('red')
#t.write(letter, align="right", font=("Verdana", 13, "normal"))
t.setTextColor('black')
t.setPos(0,0)

def line1(t, isLeft): #5
    for k in range(0,19,2):
        t.penUp()
        x1 = 300*math.cos(math.pi*((18*k)%360)/180)
        y1 = 300*math.sin(math.pi*((18*k)%360)/180)
        t.moveTo(x1,y1)
        t.penDown()
        t.setPenColor('red')
        x2 = 240*math.cos(math.pi*((18*k+18)%360)/180)
        y2 = 240*math.sin(math.pi*((18*k+18)%360)/180)
        t.moveTo(x2,y2)
        t.setPenColor('black')
    for k in range(0,19,2):
        t.penUp()
        x1 = 240*math.cos(math.pi*((18*k)%360)/180)
        y1 = 240*math.sin(math.pi*((18*k)%360)/180)
        t.moveTo(x1,y1)
        t.penDown()
        t.setPenColor('green')
        x2 = 300*math.cos(math.pi*((18*k+18)%360)/180)
        y2 = 300*math.sin(math.pi*((18*k+18)%360)/180)
        t.moveTo(x2,y2)
        t.setPenColor('black')
    t.setPos(0,0)

def line2(t, isLeft): #6
    for k in range(1,20,2):
        t.penUp()
        x1 = 240*math.cos(math.pi*((18*k)%360)/180)
        y1 = 240*math.sin(math.pi*((18*k)%360)/180)
        t.moveTo(x1,y1)
        t.penDown()
        x2 = 240*math.cos(math.pi*((18*k+18)%360)/180)
        y2 = 240*math.sin(math.pi*((18*k+18)%360)/180)
        t.moveTo(x2,y2)
        t.setPos(0,0)

def line3(t, isLeft): #7
    for k in range(10):
        t.penUp()
        x1 = 180*math.cos(math.pi*((36*k)%360)/180)
        y1 = 180*math.sin(math.pi*((36*k)%360)/180)
        t.moveTo(x1,y1)
        t.penDown()

```

```
x2 = 240*math.cos(math.pi*((2*18*k)%360)/180)
y2 = 240*math.sin(math.pi*((2*18*k)%360)/180)
t.moveTo(x2,y2)
for k in range(10):
    t.penUp()
    x1 = 180*math.cos(math.pi*((36*k)%360)/180)
    y1 = 180*math.sin(math.pi*((36*k)%360)/180)
    t.moveTo(x1,y1)
    t.penDown()
    t.setPenColor("blue")
    t.dot(10)
    t.setPenColor("black")
    x2 = 240*math.cos(math.pi*((2*18*k+54)%360)/180)
    y2 = 240*math.sin(math.pi*((2*18*k+54)%360)/180)
    t.moveTo(x2,y2)
    t.setPos(0,0)

def line4(t, isLeft): #8
    for k in range(10):
        t.penUp()
        x1 = 180*math.cos(math.pi*((36*k)%360)/180)
        y1 = 180*math.sin(math.pi*((36*k)%360)/180)
        t.moveTo(x1,y1)
        t.penDown()
        x2 = 120*math.cos(math.pi*((36*k)%360)/180)
        y2 = 120*math.sin(math.pi*((36*k)%360)/180)
        t.moveTo(x2,y2)
        t.setPos(0,0)

def line5(t,isLeft): #9
    for k in range(0,10,2):
        t.penUp()
        x1 = 120*math.cos(math.pi*((36*k)%360)/180)
        y1 = 120*math.sin(math.pi*((36*k)%360)/180)
        t.moveTo(x1,y1)
        t.setPenColor("green")
        t.dot(10)
        t.setPenColor("black")
        t.penDown()
        x2 = 120*math.cos(math.pi*((36*k+72)%360)/180)
        y2 = 120*math.sin(math.pi*((36*k+72)%360)/180)
        t.moveTo(x2,y2)
    for k in range(1,10,2):
        t.penUp()
        x1 = 120*math.cos(math.pi*((36*k)%360)/180)
        y1 = 120*math.sin(math.pi*((36*k)%360)/180)
        t.moveTo(x1,y1)
        t.setPenColor("green")
        t.dot(10)
        t.setPenColor("black")
        t.penDown()
        x2 = 120*math.cos(math.pi*((36*k+72)%360)/180)
        y2 = 120*math.sin(math.pi*((36*k+72)%360)/180)
        t.moveTo(x2,y2)
    t.setPos(0,0)
```

```
tf = TurtleFrame()
turtle1 = Turtle(tf)
turtle1.setColor("black")
turtle1.setPenColor("black")
turtle1.wrap()
turtle2 = Turtle(tf)
turtle2.setColor("red")
turtle2.setPenColor("red")
turtle2.wrap()
turtle3 = Turtle(tf)
turtle3.setColor("blue")
turtle3.setPenColor("blue")
turtle3.wrap()
turtle4 = Turtle(tf)
turtle4.setColor("green")
turtle4.setPenColor("green")
turtle4.wrap()
turtle5 = Turtle(tf)
turtle5.wrap()
turtle6 = Turtle(tf)
turtle6.setColor("black")
turtle6.setPenColor("black")
turtle6.wrap()
turtle7 = Turtle(tf)
turtle7.setColor("black")
turtle7.setPenColor("black")
turtle7.wrap()
turtle8 = Turtle(tf)
turtle8.setColor("black")
turtle8.setPenColor("black")
turtle8.wrap()
turtle9 = Turtle(tf)
turtle9.setColor("black")
turtle9.setPenColor("black")
turtle9.wrap()

thread.start_new_thread(circle1,(turtle1, True))
thread.start_new_thread(circle2,(turtle2, True))
thread.start_new_thread(line1,(turtle5, True))
thread.start_new_thread(line2,(turtle6, True))
thread.start_new_thread(line3,(turtle7, True))
thread.start_new_thread(line4,(turtle8, True))
thread.start_new_thread(line5,(turtle9, True))
```

5 Problem-Solving with Python: A Computational Perspective

Problem-solving using Python integrates logic, reasoning, mathematics, algorithms, and generative AI to address complex challenges across diverse domains. Python's flexibility and comprehensive libraries make it a preferred language for tackling mathematical and computational problems (Gao et al., 2023a). By combining traditional algorithms with modern AI capabilities, Python facilitates both theoretical exploration and practical applications.

Python excels in implementing algorithms for matrix operations, such as Strassen's algorithm for efficient matrix multiplication. Studies comparing implementations in Python environments like IDLE, Jupyter Notebook, and Colab demonstrate its capability to handle computational tasks with varying performance metrics (Gao et al., 2023b). These explorations enable researchers to evaluate trade-offs between computational speed and accuracy in problem-solving scenarios.

Another critical area is numerical sequence generation, such as Fibonacci and Pell numbers. Python provides a straightforward approach to compute these sequences, which are foundational in mathematical research and cryptographic applications (Gao et al., 2022a; Gao et al., 2023c). By leveraging Python's built-in libraries, researchers have achieved efficient implementations, making it accessible for educational and professional use.

Furthermore, Python's integration with generative AI has revolutionized problem-solving by automating reasoning tasks. The interplay between AI and human logic, as explored in recent research, illustrates how Python serves as a bridge between mathematical rigor and AI-driven insights (Gao et al., 2024a; Gao et al., 2024b). For instance, Python's machine learning libraries enable predictive modeling and optimization, enhancing decision-making processes.

In addition to traditional algorithms, Python supports advanced topics like graph theory and combinatorial mathematics. Researchers have applied Python to analyze the dominion and domination of graphs, revealing its utility in theoretical and applied settings (Gao et al., 2023d).

In summary, Python's adaptability and robust ecosystem make it an indispensable tool for computational problem-solving. Its applications span algorithmic development, matrix operations, numerical sequences, and AI integration, establishing it as a cornerstone of modern computational methodologies.

6 Using Generative AI Wisely

Generative AI tools, such as ChatGPT, have rapidly gained traction as valuable resources in educational and computational contexts. Their ability to provide instant feedback, personal assistance, and creative insights positions them as significant assets for learners and professionals. However, these tools must be integrated thoughtfully to maximize their benefits while avoiding over-dependence. A robust foundation in mathematics, logic, algorithms, and programming remains indispensable for fostering problem-solving skills and ensuring effective use of AI (Gao et al., 2023a; Gao et al., 2024a).

Generative AI complements computational disciplines by assisting in tasks like debugging, algorithm optimization, and conceptual visualization. For instance, in Python

programming, AI can streamline processes, allowing students to focus on mastering key concepts rather than repetitive tasks. Gao et al. (2024b) highlights the interplay between AI and human reasoning, emphasizing that when learners possess strong analytical and algorithmic thinking skills, AI tools catalyze deeper exploration and innovation.

One illustrative use case is numerical sequence generation, such as Fibonacci and Pell numbers, where Python's computational capabilities are enhanced by AI's ability to suggest optimized solutions and verify results. This approach bridges theoretical understanding with practical application, as noted by Gao et al. (2022) and Gao et al. (2023c). Similarly, AI-driven insights can augment problem-solving in advanced topics like matrix multiplication, where Python implementations of algorithms, such as Strassen's, benefit from AI-assisted optimization and performance comparisons (Gao et al., 2023b; Gao et al., 2024a).

Despite these advantages, overreliance on AI poses risks. A dependence on AI for fundamental tasks may erode critical thinking and problem-solving independence, as warned by Gao et al. (2023a). To mitigate this, educators and professionals should adopt a balanced approach, integrating AI as a supplementary tool rather than replacing traditional learning methods. By leveraging AI to enhance understanding and innovation, learners can develop versatile skills to navigate complex challenges.

Generative AI is most effective when it complements, rather than supplants, foundational problem-solving skills. A harmonious integration of AI tools with strong logical reasoning and algorithmic proficiency prepares learners to thrive in an increasingly technology-driven world. As noted by Gao et al. (2024b), this balanced strategy ensures that learners can harness the strengths of AI while maintaining the intellectual rigor needed for innovation and adaptability.

7 Conclusion

This paper underscores the critical role of mathematics, logic, and algorithms in designing graphs, images, and patterns using Turtle Graphics and TigerJython. These tools empower users to visualize concepts and experiment with creative designs, bridging the gap between computational rigor and artistic expression. Mathematics provides the foundation for precision and symmetry, while logical constructs streamline workflows, enabling automation and iterative refinement. Algorithms are the backbone, translating abstract ideas into functional and visually appealing outputs.

Turtle Graphics and TigerJython foster an engaging approach to learning, making programming accessible and enjoyable for learners of all levels. Students develop a deeper understanding of geometric relationships, recursive patterns, and computational efficiency by integrating these tools with core problem-solving disciplines. The ability to transform mathematical concepts into visual representations enhances technical proficiency and sparks creativity.

Generative AI tools, such as ChatGPT, complement this process by offering guidance and feedback, but they should remain supplementary. This balanced approach ensures that technological shortcuts do not overshadow foundational skills, preserving the integrity of independent critical thinking.

Ultimately, this paper advocates for harmonizing foundational problem-solving skills and advanced technologies. This approach equips learners to navigate complex

challenges, fostering innovation and adaptability in an increasingly technology-driven world.

Data Availability. The data used to support this study's findings are available from the corresponding author upon request.

Conflicts of Interest. The authors declare no conflicts of interest.

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Virtual Reality in Education: Opportunities and Challenges

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Abstract. This paper presents a state-of-the-art review of virtual reality (VR) and augmented reality (AR) technologies in enhancing classroom learning. It explores how immersive environments and interactive experiences offered by VR and AR can improve student engagement, comprehension, and retention. By analyzing recent studies and applications in education, the review highlights the benefits, challenges, and potential of these technologies as supplementary tools for modern teaching methods. The paper offers a comprehensive overview of the current research and future directions for AR and VR in education.

Keywords: Virtual Reality (VR) · Educational Technology · Immersive Learning

1 Introduction

Virtual reality (VR) is cutting edge technology that allows users to interact with 3-D digital environment applications. The beginnings of VR were started over 50 years ago. Since then, numerous uses of VR applications have been developed. Some examples of VR are gaming, multiple applications in education, sciences and language learning. Challenges such as the global pandemic have made VR a pivotal tool, allowing museums to continue flourishing by offering virtual tours, engaging students and teachers through distance learning, and fostering innovation worldwide. While growth in this area has primarily come from gaming, other numerous advancements have been made from virtual tours to VR for individuals with disabilities. Without VR some individuals would be limited in their experiences because of location or environments that are not accessible to them. This niche group has challenges that require more empathetic and creative solutions that will benefit all users. In addition, studies show there is an improved quality of self-worth from individuals with disabilities using virtual reality for learning¹. Studies show an increase in self-esteem directly correlates to academic engagement. This academic motivation leads to higher commitment, in turn, helping students achieve more success, academically [2].

In each application explored in this paper it is apparent that VR will provide each user with a new appreciation for the technology, a different perspective, and a rich user experience. Virtual Reality applications explored in this paper will be VR's use in classrooms, science labs and language learning. There are also challenges for VR

such as cost, training, and limitation of users, especially for users with disabilities. The challenges that will be discussed such as cost for adopting new technology, sensory constraints for some users, and ethical implications from VR's use in classrooms.

2 Motivation

Technology is rapidly changing the world we live in and how we interact with digital landscapes. Virtual Reality (VR) is a technology that has many applications in the classroom and distance learning. A few areas where VR excels in enhancing academic motivation include providing a new medium of interaction in classrooms, facilitating virtual field trips, and offering personalized tutoring. The authors of "*Virtual Reality and Augmented Reality for Education*" describe how using programs like TeachLiVe can allow teachers to understand environmental issues that are impacting students' academic performance in their class by recording the class. In addition, the paper details an academic approach that helps both students and teachers adopt processes for using VR technology in the classroom successfully [3]. A San Antonio Northside Independent School District teacher was consulted for insight on adopting VR technology in the classroom with her students. From this interview it was gleaned that without an implementation process, adopting VR technology may become more of a distraction than a tool for academical motivating students [4]. More on this topic will be discussed in the *Challenges* section.

The authors of "*Virtual reality in education: The promise, progress, and challenge*" also cite an increase in engagements for students using VR. In addition, another benefit seen with VR is how it provides a different perspective. Such alternative perspectives include empathy and spatial memory [5]. This is important because again it helps show how students may be motivated through various teaching methods. The authors of "*Intelligent Virtual Reality and its Impact on Spatial Skills and Academic Achievements*" demonstrate how two individuals with disabilities saw increased math scores when using VR. The study was intended to show how VR could improve students with disabilities math skills. The researcher used virtual reality (VR) to allow the participants to play the puzzle video game Tetris as a reward. What they found in this study is very important, as it shows the connection between self-worth, which was measured in this study, and how it increased academic engagement. The method used for this increased engagement was allowing participants to play VR Tetris in between solving math scenarios. What they found was that this was enough of a reward, and break, from the regular curriculum, that allows students to become more engaged. This was attributed to an improvement in self-worth for both participants [1].

Additional success has also been seen for using VR in science labs, not only to see the impact but also as a tool for gaining a different perspective. Michael Bodekaer discusses how reimagining education can leverage VR in science labs in his TedTalk titled "*This Virtual Lab Will Revolutionize Science Class*" (October 2015). He leads his talk describing a virtual science lab that allows students to apply dangerous experiments in the safety of a simulation. Another application used was creating practical exercises to keep students engaged in the virtual lab, such as solving "*Crime Scene Investigation*" (CSI) cases. He also mentions the success of Jack Andraka, a 15-year-old, who found a

method for low-cost pancreatic cancer screening. In his story he mentions a challenge Jack encountered was not having access to a real-life science lab to prove out his theories. He ends his talk with a thought-provoking question of how virtual science labs would “empower and inspire a whole new generation of young and bright scientists that would be ready to innovate and change the world” [6]. Additional key point Bodekaer mentions is having support for subsidized adoption programs for VR.

The authors of “*Intelligent Virtual Reality and its Impact on Spatial Skills and Academic Achievements*” discuss the reward of using VR to improve academic motivations. This can be attributed to the rich user experience that VR can provide. Immersion is a great tool for helping students stay focused, engaged, and curious about curriculum. Language learning through VR is a growing area of study. In “*Teaching ASL Signs using Signing Avatars and Immersive Learning in Virtual Reality*” the authors describe a VR application on the *Signing Avatars & Immersive Learning* (SAIL) system that allows hearing impaired participants to interact with guided American Sign Language (ASL) curriculum. This study details an immersive VR application that helps participants through an introductory ASL curriculum in a 3-D environment in which is easily accessible to participants. To perform this study the team used Leap Motion gesture tracking hardware technology to allow avatar users to complete the curriculum. In order to capture this interactive experience, motion capture technology was used to help map the physical gestures to the ASL lexicon. While the team was able to create an application that allowed users to complete an introduction into ASL virtually, there were challenges and improvements discovered from the study. More details on these challenges will be discussed in the *Challenges* section. It was important for the team to work with native ASL signers to capture a more naturalistic avatars for the VR application. The study did show that with current VR technology an augmented reality (AR) may be more beneficial for learning ASL rather than VR [6]. This feedback from the participants in this study shows how rich a user experience can be using VR.

3 Challenges

VR does provide an immersive and rich user experience for multiple applications; it also comes with a heavy financial cost. As Michael Bodekaer mentioned in his TedTalk the cost of implementing VR is cost prohibitive for many institutions, and coupling with corporations may be a way to offset this price [6]. Currently VR gaming apparatuses are expensive but do provide a rich use experience. Cost was a center point topic of the interview acquired for this report. Many local schools are struggling with meeting current demands and without special subsidized programs adopting new technologies like VR will be impossible. It is important to adopt a program instead of only technology to assist new users in grasping all concepts of using the new tool. When adopting new processes this should include evaluation, training, implementation, and ongoing training/support. Without all these components, adopting new processes and technologies becomes an overwhelming challenge for institutions and students.

Another challenge raised by the interviewed instructor was the necessity of training staff (teachers and tech support) will need to undergo to help implement processes detailed in “*Virtual Reality and Augmented Reality for Education*”. In this paper the

authors discuss how initial training programs for teachers and staff should be through using VR and Augmented Reality (AR). This approach will help new VR users adopt techniques for working with difficult students and gives them hands-on experience on what the students may be experiencing during VR sessions [5]. Michael Bodekaer also discusses the importance of training in adopting VR as a tool for young academics [6]. This is important because young minds need a guide to learn new things until they are at a point of confidence to be more autonomous users.

One last topic point is the limitations of the users. Like any technology, the end users can only use the tool if they know how and what applications it is applicable. While code can be developed as seen in all the material covered, end users may have physical disabilities that may interfere with the use of VR. For example, some users have sensory issues and wearing a device on their head may also be uncomfortable. Some users may be vision impaired, necessitating different hardware to accommodate listening or touch. In “*Virtual Reality and Augmented Reality for Education*” the authors describe a phenomenon called cyber sickness, where end users become physically sick from the motion software of VR [3]. New methods are being developed to mitigate this phenomenon; however, it still exists and is a good point of consideration for what type(s) of learning opportunities are explored with VR. Like all technology it has limits based on the end user. For example, in “*Intelligent Virtual Reality and its Impact on Spatial Skills and Academic Achievements*” participants were not expected to make exponential progress in their math skills, but were expected to make improvements, which was demonstrated in the study1. Technology is a tool that we determine its application, effectiveness, and continued use for solving problems. One last concern for the limitation of users is the unknown psychological impacts of VR still being researched today. The long-term impacts of VR on users and learning are currently unknown.

4 Future Directions

Virtual Reality in education for students is shown to be a powerful tool for science and math. The adoption of VR in schools or other education applications has its own challenges not only for students, but adults as well. Teachers must continually find new ways to keep students from being distracted by smartphones and other personal devices. Younger students developing minds may be impacted by VR, that is still being studied. Future work should include the psychological and neurological impacts of VR on students long-term. Perhaps adopting VR is not the most beneficial solution and instead AR may be a better choice. The authors of “*Virtual Reality and Augmented Reality for Education*” report that adopting AR is a cost-effective option for institutions. In fact, they recommend having students use their smartphones for connecting into this AR, since 73% of students have them3. This approach would integrate technology with the curriculum the students are participating in to enhance the experience. Also, this does purpose an ethics question on should students be volunteering their property to further education and what policies will be implemented for students who don’t participate in these programs or have smartphones. Additional studies on how this implementation plan is effective across different regions and cultures would be interesting in understanding alternative methods and additional beneficial applications for AR/VR.

As artificial intelligence (AI) becomes a growing part of the world we interact with the question of ethics continues to be raised. VR is not separate from this discussion. The authors of “*Virtual Reality and Augmented Reality for Education*” report that some institutions are now using VSpatial, a VR software that allows for a 360 degrees classroom view. The type of VR application can help students and teachers have an idea of what was going in the classroom that may impact student performance. This is also a form of surveillance and creates ethical and privacy implications. Some participants will marvel at the utility of having 360 video available. How it can help students remove distractions and may even help others focus. While others may want to preserve their privacy and request to not participate or purposely misbehave because they are on camera. This ethical and behavioral implication should also be considered for future work to help understand physical and emotional responses from long term surveillance. Another aspect is the cost of storage and security of content, such as the video recordings from the classroom. Additional consideration for ethics is VR can be used as a tool to escape reality or become dissatisfied with the physical world without VR/AR.

Additional future work should also include how semi-VR can be used to assist emergency first responders during medical emergencies. The authors “*Virtual Reality and Augmented Reality for Education*” purpose how tactical immersive experience may be helpful in making this a reality. By “taking in process and operations for achieving results in success” [3] software developers could create opportunities for VR using AI to assist first responders in assessing multiple patients requiring medical intervention, and what the priority intervention should be for triaging. By using AI to assess a situation(s), first responders can focus on ensuring they have the appropriate medical equipment and can coordinate additional support for lower priority patients, that may even be coordinated through AI and other orchestrator computer-based applications.

5 Conclusion

In conclusion, VR can enhance the user experience for educators and students. This enhanced user experience can lead to higher motivation and self-worth. Studies have shown that higher self-worth directly correlates with improved understanding of new material and academic success. When students are properly engaged and motivated a better understanding of material will occur. Such applications for VR/AR for students are virtual field trips, science labs, and language learning. With multiple applications it is important to understand who the end users are, the goal of using VR, and continuing to evaluate if VR/AR is a beneficial tool for those end users. The example of language learning software for ASL, illustrates how continued improvements are necessary to maximize VR applications.

In that same theme, VR/AR may not be as beneficial of a tool as is hoped. That is because there is a significant cost for entry for VR based on hardware. To overcome this challenge, subsidizing the adoption of new technologies and providing training will be essential for bridging the gap between VR and education. One proposed plan is adopting AR instead of VR as a low-cost solution. However, this raises concerns for ethics around privacy for end users using their smartphones. In addition to privacy concerns, VSpatial technology also poses a concern about surveillance. While policies are currently in place

to address these concerns, it is crucial to determine how they can be effectively applied to directly enhance the classroom experience with VR technology. Implementing VR in education requires not only addressing the existing challenges but also ensuring that these policies support the seamless integration of VR to enrich student learning, foster engagement, and provide immersive educational experiences.

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Creating Better Group Projects in Higher Education

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Abstract. This pilot study on ($n = 126$) information technology (IT) students' perceptions of group work was conducted at a state university in the southeastern United States. The study modified a pre-existing validated survey, focusing on factors contributing to perceptions of student group work. A systematic random sample of undergraduate IT students (868) were surveyed 42 questions, with six addressing demographics and 36 using a Likert scale to gauge perceptions. The findings suggest that IT students generally prefer not working in groups or teams, with 53.1% of respondents expressing negative attitudes toward group work. Additionally, students did not perceive group work as beneficial for mastering course objectives or achieving benefits towards achieving higher course grades. However, a slight majority (34.4%) agreed that group work is socially rewarding. The study's results align with prior research, highlighting common criticisms of group projects, including unequal workload distribution and grade inflation for underperforming students. The study concludes that while group work is not valued for academic purposes, it may provide social benefits, particularly for more introverted students.

Keywords: Groups · peer · mentors · collaborative learning · interpersonal skills · study groups

1 Introduction

Almost any project can benefit from group endeavors ranging from sharing the workload, providing a differing opinion on how to accomplish a task, increasing the level of expertise in a specialized area, attempting projects of a larger scale, or simply assisting in troubleshooting and problem-solving. To re-state the idea in John Donne's (1624) words, "No man is an island entire of itself ...," and who can omit the common idiom, "two heads are better than one." Suppose one subscribes to the belief that the potential benefits of working in groups are apparent. In that case, it is natural to ponder why so many students and educators dread using group assignments and projects in the classroom. Suppose only the positive aspects of group interaction are realized. In that case, the overall quality of projects should be better, the workload on individuals should be reduced, delays relating to problem-solving should be decreased in time, and group morale should flourish (Ludlum, Conklin, & Tiger, 2021). However, negative aspects such as teacher and student laziness, group bullies, group think, inequity in grades

received versus the amount of work expended, mismatch of personalities and work modalities, and overall inconvenience can creep into the perception of group work and overshadow the positive aspects to produce a net negative opinion (Grzimek, Marks, & Kinnaman, 2014; Ludlum et al., 2021). This paper is arranged in the following order of presentation: introduction, potential favorable perceptions in group projects, potential negative perceptions in group projects, proposed study, methodology, conclusions and limitations, discussion, and future research.

This study aims to illuminate the various factors and perceptions that lead faculty and undergraduate students to view group work as beneficial or detrimental to the college classroom experience. This can also be stated as a question: How can educators and students manage the negative perceptions of group work to create an improved attitude toward group projects in the college classroom? If these factors can be understood, promoted, or mitigated appropriately using interventions, benefits can be increased while drawbacks are reduced (Hamer & O'Keefe, 2013).

2 Literature

Collaborative learning groups often provide students with real-world engagement opportunities that enhance the learning objectives (Hernández-Leo et al., 2005). Through team or group learning, students learn accountability, roles and responsibilities, and interdependence (Dillenbourg & Tchounikine, 2007). The group educational experiences help motivate learners and enrich their academic experiences and engagement levels (Csikszentmihalyi & Larson, 2014). Learning course objectives in groups through assignments that enhance the understanding of information, objectives, or assignments by utilizing groups through structured activities helps target students' psychological flow on information assimilation or cognition that traditional learning methods may impede (Gao et al., 2019). The group learning actions help students through reduced anxiety and an increase in problem-solving of constructs of subject matter at greater mastery (Dogan et al., 2022).

Most people would like to believe that teachers and course designers implement group projects in a class offering to attempt to achieve a list of perceived favorable conditions. These conditions may be as simple as demonstrating concepts larger than what can be assigned to an individual student or a series of processes leading to a more significant or extensive concept. Teachers who take a step back and focus on the larger picture may use groups to help students build interpersonal skills, experience the benefits of diversity, or build study groups that will last through the semester or an entire program (Ludlum, Conklin, & Tiger, 2021). In a 2024 study, researchers noted the flow of information in groups or engagement experiences by utilizing a collaborative application for a learning environment, information absorption had a high level of ease in participants, and the action demonstrates a relationship between learners' flow and experience assimilating information (Lobo-Quintero et al., pp. 8–13). It is likely that few, if any, people will ever have a job where they do not have to work with others. Human contact may be minimal in some instances, but everyone occasionally interacts with someone. Given the necessity of interpersonal skills throughout life and the workplace, teachers should strive to create assignments that promote growth in this area while

attempting to mitigate any negative aspects that could be experienced in the process (Ludlum, Conklin, & Tiger, 2021). Collaborative learning groups often provide students real-world engagement opportunities that enhance the learning objectives (Hernández-Leo et al., 2005; Lobo-Quintero, 2024, pp. 1–2).

When designing a course or putting together assignments for an existing course, teachers often pour over a list of Student Learning Outcomes (SLOs) or topics to be covered in the class. This frequently leads the teacher to explore the verbiage used in the SLO and consult Bloom's Taxonomy to determine the type or modality of assignments that should be offered in the course (Harris & Patten, 2015). While many teachers may have polarized opinions on group projects, teachers should view the creation of a group project as a challenge that can yield benefits to all participants (Grzimek, Marks, & Kinnamon, 2014; Ludlum et al., 2021; Vaughan & Grace, 2019).

2.1 Potential Positive Conditions in Group Projects

Groups can be used effectively to manage scale when considering tasks that may be handled by a team or department in the workplace (Guzman, S., 2018). For example, demonstrating a small network can be accomplished by a single student or a small group while demonstrating enterprise-level infrastructure and interactions are better suited to larger groups or even an entire class of students working for a whole semester. In the study of programming, projects that are larger in size or complexity can be undertaken when the writing of code, creation of logic and program flow, and debugging of code are spread over several team members, thus creating a checks and balances procedure in the process (Marks, M. & O'Connor, A., 2013).

Many college programs, from baccalaureate to doctoral level, utilize cohorts to keep students progressing and provide a support/study group. If one believes that group activities on this scale are beneficial, it is easy to see how one can view individual group projects as a miniature attempt to achieve the same goal (Hamer & O'Keefe, 2013; Marks & O'Connor, 2013). Cohorts, group projects, and peer study groups can encourage students when they struggle, foster retention, and drive progression through various parts of an academic program. Many students view group projects as a safety net that indicates they are not alone in an uncomfortable field. This is supported by the belief that the team will keep the project on track. Students often express that group members offer the potential for understanding a concept or question in a better fashion than their understanding allows (Harvey, et al., 2019). While many students do not necessarily like group projects, most believe that group projects offer a chance to learn skills needed in the workplace (Ludlum, Conklin, & Tiger, 2021).

Recently, people have been forced to re-evaluate how they learn, work, interact, and socialize while acting responsibly during the COVID pandemic. Students who have found themselves isolated in one way or another may be willing to embrace group work because they are becoming more accustomed to meeting and interacting in new ways. For example, virtual appointments with a doctor would have been unheard of for many before COVID-19, but are routine everyday activities for those attempting to avoid contracting and spreading the disease (Bakir et al., 2020; Bonaccolto-Topfer & Castagnetti, 2024). Since change is generally seen as altering the status quo, the injection of the COVID-19

pandemic into daily life has produced students responding to a world of change and being forced to accept new modalities in how they experience education (Islam, 2023).

Many students who are open to learning to work in and benefit from group projects have expressed a desire for increased control over the process. Increased control may come in the form of being able to self-organize, select team composition, remove group members who are disruptive or don't participate, and choose the format used to communicate (Vaughan, Yoxall, & Grace, 2019). The ability to select the method of communication is a crucial benefit for group work. Group members can communicate virtually to remove spatial barriers that prevent group interaction, and they can select the most convenient time to meet to remove temporal barriers that a scheduled class meeting may impose. For example, group members in a healthcare-related learning assembly attest to greater accountability in collaborative learning settings. Students in groups find themselves engaged with content to contribute more to the needs of the collective. Students report they "prepare thoroughly and contribute all they can" in a group setting because they want the team to succeed (Michaelsen et al., 2023).

A diverse composition of group members can bring many advantages to the resulting group project. Diversity strengthens the group because every member brings their (own) work, personal, and cultural experience to the group, creating an extensive breadth of consideration for many issues (Ludlum et al., 2021). While non-native speakers bring the advantage of a different culture, they also experience the benefit of interpretation in the native context from native speakers in the group. In simplest terms, diversity allows a group to become more than the sum of its members and produce a better-resulting product (Marks & O'Connor, 2013). This is especially true when an individual member is knowledgeable in a specialized area about the task at hand.

Problem-solving and troubleshooting are further assisted by adding a fresh set of eyes. When a person looks at a problem for extended periods, it becomes more difficult to "see" the issue because it has begun to appear to be something that belongs in the project. Someone fresh to troubleshoot or analyze the problem is not subject to the appearance of "belonging" that someone immersed in the situation for extended periods has become victim to perceiving. Additionally, members fresh to troubleshooting or problem-solving are more likely to think outside the box when formulating solutions (Ogata et al., 2020).

2.2 Potential Adverse Conditions in Group Projects

In the process of reviewing available literature on the nature of using group projects in the classroom, it is not shocking that most studies have commonalities with a few differing factors to clarify the researcher's position or view as to what is considered a potentially harmful aspect of using group projects in the classroom. As one might expect, the most common negative aspect of using group projects is the observation that, in some cases, an individual shirks their duty to participate in group activities or work equally (Marks & O'Connor, 2013). This belief is usually expressed in the observation that underperforming students tend to neglect their participation in the project, believing that higher-performing students will make up the difference in workload (Guzman, 2018). This may also take the form of students believing that if they are placed in a group of size = n, their workload should equal the total amount of work in the assignment divided by n.

This is rarely the same way the instructor views the assignment implementing the group project. Most instructors would argue that each team member is equally responsible for the entirety of the project (Hasan & Ali, 2007). If the student is not at the least acquainted with all aspects of the project, then a message is sent that all of the project is not important (only the piece that the student is engaged with completing). This observation may leave many saying that this approach undervalues some concepts taught or assigned relative to other concepts because the student focuses primarily on what they, the student, feel is necessary.

Another criticism of group projects stems from an unequal share of the workload. It comes in the form of people believing that group projects inflate the grades of underperforming students by allowing this group to benefit from the work of their more motivated team members (Guzman, 2018). In some cases, this idea leads to other opinions, such as the need for equity in grading, the motivation for using group assignments, the question of the value of information versus padding a class with a certain amount of “busy” work, and the inflation of grades (Harvey et al., 2019).

In higher education, a lot of time, effort, and money is rightfully expended to guarantee that each student has an equal opportunity to achieve a quality educational experience without bullying, discrimination, or prejudice. While the benefits of group projects are evident in most cases, the assemblage of a group can create the population needed to allow a bully or predator to infiltrate a group of students (Ludlum et al., 2021). Teachers and fellow students must be ever-vigilant to police and monitor group interactions if a safe learning space is to be provided. Students should never feel that they are “asked to just stick it out for the length of a project, and it will soon be over” (Hamer & O’Keefe, 2013).

The desire on the part of many people to avoid “confrontational” or uncomfortable situations, such as confronting bullies or disagreeable group members, may easily explain the negative perceptions of group work espoused by many students. This is also more likely to occur if the student inhabits a subset of the student population and is more likely to encounter certain types of bullying behavior or misconduct. At first, the idea that a student or instructor should have to monitor the behavior of another adult seems foolish. Still, employees are indoctrinated or taught the social behavior expected in their business environment by colleagues and organizational culture (Cummings & Janicki, 2020; Hamer & O’Keefe, 2013).

Many students and instructors have a distaste for group projects because they feel a lack of equity when assigning grades. In other group projects that result in each member of the group receiving the same grade presupposes that each member contributed the same amount of time, effort, and productive contribution. As explained earlier, this is only sometimes the case. In cases where the contribution is unequal, the team members have earned different grades (Harvey et al., 2019). Many faculty account for this discrepancy by including group peer evaluations as a part of the grade to flush out information regarding underperformers, shirkers, or bullies. While this sounds like an appropriate solution, it can only succeed if a group ends up with bullies that work together or the group contains a member, for whatever reason, that is simply unpopular within the group. The group uses peer review to “impose” a punishment (Guzman, 2018).

Many students dislike group projects because they assume teachers use them to lessen their workload and reduce the required grading. These students feel that the instructor is then using a group project to avoid effectively providing direct instruction and feedback to individuals. While each case is different, some teachers would counter that the overhead of effectively and productively managing a workgroup and assigning an equitable grade requires more work than individualized assignments (Bong & Park, 2020).

3 Methodology

This study is intended to shed light on students' perceptions of groupwork, projects, or how each contributes to negative and positive opinions of participants' reflections towards group activities. To conduct the research, a systematic random sampling was drawn from an undergraduate population of students attending a state university in the southeastern United States. The state university has five campuses containing a total of 8,409 students. Institutional Review Board approval was obtained after obtaining permission from the researchers, Ludlum, Conklin, and Tiger, to use the survey created for their study in 2021 (Ludlum et al., 2021). The survey was adapted and changed to add demographic information (Appendix 1), which was sent to the entire information technology student population 868. The university's information technology student list-serv email account was utilized to decimate the survey link, which Survey Planet hosted. Usable responses were collected from 126 (n = 126) respondents. The demographic information for the respondents can be seen in Table 1.

The survey was composed of 42 questions in total. Six demographic questions asked respondents to identify the students' current year in the 4-year program, gender, marital status, age range, and whether they are rearing children or have served in the military. The other 36 questions are Likert-scaled, having values of 1—5 (1—strongly disagree, 2—disagree, 3—neutral, 4—agree, 5—strongly agree). The respondents were free to end the survey at any time with no threat of repercussion. Students could select to express no opinion by choosing a value of 3 or neutral. To remain congruent with Ludlum et al. (2021) the researchers have grouped the participants' response to normal the results reflecting strongly disagree and disagree as one factor and agree and strongly agree as a second affirmation. Additionally, neutral responses were eliminated for further congruency to the hypothesis discussion. No incentives were promised or given for successfully participating or completing the study.

3.1 Hypotheses

H_{0a} : Students prefer to work in groups or teams on class projects, as opposed to working independently.

H_{1a} : Students do not prefer to work in groups or teams on class projects, and prefer to work independently.

H_{0b} : Students prefer group projects because it's perceived they will have better mastery of course material from working with peers.

Table 1. Demographic Information of Respondents (n = 126)

Year of College		
	Freshman	10
	Sophomore	21
	Junior	24
	Senior	68
Gender		
	Male	93
	Female	32
	Other	1
Marital Status		
	Married	50
	Single	76
Age		
	18–25	50
	26–34	28
	35–44	25
	45–54	22
	Over 55	2
Rearing children		
	Yes	40
	No	86
Military service		
	Yes	12
	No	114

H_{1b} : Students prefer not to work on group projects because it is perceived they will have a decreased mastery of course material from working with peers.

H_{0c} : Students perceive group work as benefiting their grades.

H_{1c} : Students perceive group work as negatively benefiting their grades.

H_{0d} : Students perceive working in groups as a positive activity in classes.

H_{1d} : Students perceive working in groups as negative activity in classes.

H_{0e} : Students believe that group work should be conducted more often in classes.

H_{1e} : Students believe that group work should be conducted less often in classes.

H_{0f} : Students find group work as socially rewarding.

H_{1f} : Students find group work as not socially rewarding.

4 Results

SPSS Statistical software organized the data to run the frequency distribution of values (Table 2). Upon analysis, the researchers reject Ha accepting the null and demonstrate students prefer not to work in groups (53.1% strongly disagree to 18% agree). Similarly, students perceived group work as not having positive benefits towards mastering course objectives (34.4% strongly disagree to 31.2% agree). Again, the researchers accept the null hypothesis in Hb. Additionally, the researchers accepted the null hypothesis in Hc (28.9% strongly disagree to 21.1% agree), Hd (32% strongly disagree to 35.2% agree) and He (21.1% strongly disagree to 46.1% agree).

Table 2. Frequency distribution of statistical values

Question	Agree and Strongly Agree	Disagree and Strongly Disagree
Ha I prefer to work in a group or team on class projects, as opposed to working independently	18%	53.1%
Hb Working in a group results in better mastery of course materials	31.2%	34.4%
Hc Group work benefits my course grade	21.1%	28.9%
Hd I enjoy working in groups in my classes	32%	35.2%
He Group work should be used more often in classes	21.1%	46.1%
Hf I find classroom group work socially rewarding	34.4%	32.8%

Finally, in the last hypothesis (Hf), the researchers accept the hypothesis, noting that students accepted group work as being a positive socially rewarding aspect by a slim margin of less than 2% (34.4% strongly disagree to 32.8% agree).

5 Discussion

After a review of the frequency distribution of values, the research accepts the null in all the hypotheses except the last question, whereby students perceived group work as having rewarding social experiences. This hypothesis finding is comparable to the literature (Guzman, 2018; Ludlum et al., 2021; Marks & O'Connor, 2013). This concept is interesting as it reflects the idea in Marks & O'Connor (2013) that group work can benefit students as the sum of its members and can produce better-resulting products through communication building and overall diversity in sharing knowledge. Ludlum

et al. (2021) and this research shared a nearly congruent finding with a nearly 40% neutral aspect from students. The neutral is mentioned as it's not a part of the frequency consideration but a notable consideration that most participants can't decide the positive or negative effects of group work and its social contributions to learning.

Additionally, the findings contrast all other areas, noting students fail to perceive group work as having benefits over working independently. In this aspect, Ludlum et al. (2021) observed a lower descent than the researcher's (5.1%) area of difference. This sediment was reflected oddly in students' perceptions of group work being needed in courses (46.1% in current research and 6.5% lower in Ludlum et al., 2021). Additionally, hypothesis (Hb) had a slightly higher rejection of value toward mastering course objectives than Ludlum et al. (40.6% to 34.4%). Interestingly, participants found that working in a group can benefit their grades nearly equally (28.9% to Ludlum's 29%). The participants' overall perception of group work is negative in all aspects except the ability to connect socially.

As noted in the literature, criticism of group projects stems from an unequal share of the workload and lack of overall perceived benefits. Additionally, participants believe that group projects inflate the grades of underperforming students by allowing this group to benefit from the work of their more motivated team members (Guzman, 2018). In some cases, this idea leads to other opinions, such as the need for equity in grading, the motivation for using group assignments, the question of the value of information versus padding a class with a certain amount of "busy" work, and the inflation of grades (Harvey et al., 2019, which might be the overall disconnect from the participants value proposition of groupwork in totality. However, the loan aspect of value stemming from social value might be driven by the fact that group work provides introverted students with the appearance of "belonging" and having more empowerment to problem-solving or being more likely to think outside the box when formulating solutions (Ogata et al., 2020). In simplest terms, diversity allows a group to become more than the sum of its members and produce a better-resulting product (Marks & O'Connor, 2013).

6 Limitations and Conclusions

The study reflects an interesting connection to how Generation Z students prefer to submit their work online and desire to have their courses and courses work available in an asynchrony online environment, including technology that incorporates videos, books, and websites online (Buzzetto-Hollywood & Quinn, 2024). The researchers in this study acknowledge the literature on the generations from Generation X to Z as having a culture, especially post-COVID-19, ingrained in silence through technology and a desire to not be integrated into socially connected groups but having their academic learning focused on online technologies to remain in a world alone together (Campbell, 2021).

Although the findings from this pilot study of participants note group work is not valued, the research suggests further studies to determine if group work is valued at an academically higher status, such as the master or doctoral level courses that are focused on leadership and team building constructs rather than skill building. Additionally, the researchers suggest further research is geographically diversified in construction and

that the pilot study from its small population is not generalizable outside of its domain. However, the researchers contend that the pilot studies' findings offer a significant need in the literature gap and propose further studies in information technology and computer science to uncover new knowledge about group work.

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Appendix A: Survey Instrument

Opinion of Using Group Assignments in Information Systems Classes in Higher Education – Questionnaire

There are no correct or incorrect answers when completing this survey. The survey is intended to collect the opinions, perceptions, and facts regarding the use of group assignments in teaching Information Systems in higher education. You may opt out of answering or providing an answer to any question by selecting "Neutral" as an answer thus indicating no opinion. You are free to stop taking the survey at any time with no threat of repercussion.

All answers to questions will be accomplished by providing a ranking on a 5-point Likert Scale with the middle value indicating indifference or no opinion (1—strongly disagree, 2—disagree, 3—neutral, 4—agree, 5—strongly agree).

1. Group assignments introduce students to their peers in the class.
2. Group assignments create associations that often continue after the assignment or class.
3. Groups used in assignments are dominated by students with stronger personalities.
4. It is more difficult to express my opinions when working on group assignments.
5. People with less passionate opinions are bullied by students with strong opinions when working on group assignments.
6. Group assignments lead to the creation of impromptu study groups.
7. Group assignments allow students to avoid work and place the load on others.
8. Group assignments allow underachieving students to score higher grades.
9. Teachers use group assignments to lessen the grading load.
10. Teachers use group assignments to progress underachieving students.
11. Group assignments allow stronger students to act as peer mentors.
12. Group assignments allow students to focus on single areas thus producing a better overall product.
13. When possible, I avoid taking classes that are known to contain group projects.
14. When groups are used in the classroom, group composition should be randomly chosen.
15. When groups are used in the classroom, students should be allowed to create their own groups.

16. Students should be allowed to select a group leader.
17. Groups should be allowed to fire/remove members viewed as not adequately participating.
18. The use of group activities in the classroom builds interpersonal skills that will translate into the workplace.
19. It is important to learn to work with other people.
20. I think that the use of groups in the classroom adds extra value to assignments.

Demographic Information:

1. Gender: Male, Female, Other
2. Age: less than 20 years old, 20 – 30 years old, 30 – 40 years old, and over 40 years old
3. GPA: Estimate GPA between 0 and 4
4. Year Ranking: less than 2 years, 2–4 years, 4–6 years, and greater than 6 years

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The Applications of Smart Contracts in Classroom Teaching

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Abstract. This paper explores applications of blockchain and smart contracts in classroom teaching. The automatic grading system based on smart contracts enabled secure, transparent, and efficient grading, while providing students hands-on experience with blockchain technology. Digital NFT certificates were issued upon successful completion of modules. The results demonstrate the potential for blockchain to streamline educational assessments.

Keywords: blockchain · smart contracts · classroom teaching

1 Introduction

Blockchain technology, originally developed to support cryptocurrencies, has expanded into various fields, including education, due to its decentralized, transparent, and immutable nature [1]. These characteristics make blockchain well-suited for addressing challenges such as enhancing data security, ensuring academic integrity, and streamlining administrative processes [2]. One of the most promising applications of blockchain in education is the use of smart contracts—self-executing programs that automate processes based on predefined conditions [3]. This paper explores the implementation of smart contracts in classroom teaching, focusing on automatic quiz grading and the issuance of digital certificates using NFTs (Non-Fungible Tokens).

The smart contract-based grading system enabled secure, transparent, and efficient assessments of multiple-choice quizzes. It eliminated the manual grading process, ensuring fairness by immutably recording grades on the blockchain. Students interacted with the smart contract to submit their answers, gaining hands-on experience with blockchain technology in the process [4]. This provided both practical exposure and an understanding of blockchain's real-world applications.

Additionally, NFT-based digital certificates were issued to students upon successful completion of course modules. These certificates were securely stored on the blockchain, providing tamper-proof, verifiable credentials that could be shared with external parties like employers or other educational institutions [5]. This approach showcased blockchain's potential to enhance educational credentialing through decentralized, verifiable records.

In the educational context, blockchain's decentralized ledger ensures that once a record—such as a grade or certificate—is added to the chain, it cannot be altered [6]. This

immutability is crucial for maintaining academic integrity and fairness. Smart contracts further enable the automation of tasks such as grading, enforcing deadlines, and issuing certificates. In this implementation, the automatic grading system evaluated students' quiz submissions based on predefined answers, while the NFT certificates provided a secure and verifiable proof of academic achievement [7, 8]. Together, these applications demonstrate how blockchain technology can streamline educational processes, improve transparency, and offer students practical experience with emerging technologies.

2 Main Result

In my introductory blockchain course, several smart contracts were implemented to help students learn, including an automatic grader of multiple-choice quizzes and a ERC721 contract issuing digital certificate in the format of NFT tokens upon successful completion of course modules. This provided students with a firsthand understanding of how blockchain can be applied in real-world educational scenarios. This not only streamlined the grading process but also gave students valuable insights into the mechanics of smart contracts [8].

The smart contracts were developed using Solidity, a popular programming language for writing Ethereum-based contracts, within the Remix Integrated Development Environment (IDE). Remix provided an accessible platform for students to write, test, and deploy their smart contracts directly onto the Ethereum blockchain. Metamask, a browser-based cryptocurrency wallet, was utilized to manage the deployment process and interact with the blockchain. By connecting to Sepolia, an Ethereum testnet, students could deploy their contracts in a low-risk environment that mimicked the main Ethereum network. Once the contracts were successfully deployed and verified on Sepolia, students were able to retrieve the Application Binary Interface (ABI) of the contract at its unique contract address. The ABI allowed them to interact with the contract via the Remix environment, giving them direct access to its functions and capabilities.

After deployment, students would use the contract to submit their quiz answers. The contract automatically graded each quiz based on predefined answers embedded within the smart contract code. The grading process was entirely automated, and each student's score was permanently recorded on the Sepolia blockchain, ensuring that the results were immutable and secure. Students could query the blockchain using a transaction from their Sepolia addresses to retrieve their grades at any time, promoting transparency and real-time feedback. On the other hand, the instructor, who held the ownership privileges of the contract, had the ability to monitor the performance of all students (Fig. 1).

This enabled the instructor to review quiz results efficiently while ensuring that the grading process remained accurate, tamper-proof, and completely decentralized.

Similarly, NFT digital certificates were implemented using Solidity and deployed on the Sepolia testnet, offering students an additional layer of blockchain experience. Metamask wallets were again employed to handle interactions with the contracts. After a student completed the required course modules, the instructor, acting as the contract's owner, initiated the process of minting an NFT (Non-Fungible Token) certificate for each eligible student. The NFT certificates were unique digital assets, stored permanently on

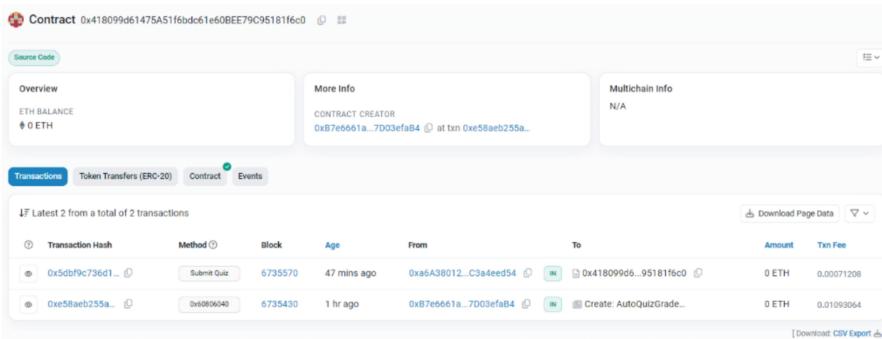


Fig. 1. A grading smart contract deployed on Sepolia

the blockchain. The decentralized nature of blockchain ensured that once these certificates were minted, they could not be altered, deleted, or duplicated, guaranteeing the integrity of each credential.

Each student was assigned a unique token that represented their digital certificate. This token was tied to the student's identity and academic achievement, providing them with a permanent and verifiable record of their course completion. The certificates could be publicly verified on the blockchain, allowing external entities such as potential employers or academic institutions to easily confirm the legitimacy of the student's credentials. This system eliminated the need for centralized record-keeping or traditional paper certificates, drastically reducing the risk of forgery or credential manipulation. By leveraging the transparency and security of blockchain, the NFT certificates offered a modern, tamper-proof solution for academic credentialing.

3 Conclusion

In conclusion, the use of smart contracts for automatic quiz grading and NFT digital certificates significantly enhanced the learning experience for students, providing them with hands-on exposure to blockchain technology. These applications not only streamlined administrative tasks like grading and credentialing but also motivated students by giving them practical examples of how blockchain can be used in real-world scenarios.

In the future, additional blockchain-based applications, such as decentralized attendance tracking, peer review systems, and tokenized reward mechanisms, could be explored to further engage students and automate classroom processes.

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Improving the Effectiveness of Undergraduate Students' Core Competencies Using the Google Classroom

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Abstract. This experimental research aimed to (1) develop active learning applications for Google Classroom to enhance core competencies of vocational students, and (2) measure and assess students' core competencies after using these applications. The study focused on Quizizz as the active learning tool. Participants included 61 undergraduate students from the Department of Microbiology at Suan Sunandha Rajabhat University, enrolled in the 2023 academic year. Data were collected through observations, pre- and post-tests, and self-assessments. Results showed that the post-test average was 15.60 points ($SD = 2.05$), compared to a pre-test average of 11.05 points ($SD = 1.92$). The t -value was 18.03, and the $Sig.$ Value was 0.006, indicating a statistically significant improvement. The overall core competency score was 80.39%, classified as very good. Computing & ICT Literacy scored the highest at 90.45%, followed by Communication at 84.52%, and Critical Thinking and Problem-Solving at 79.10%. Creativity scored the lowest at 71.05%. These findings aligned with the self-assessment results, which also rated Computing & ICT Literacy highest and Creativity lowest.

Keywords: Core competencies · Improving · Google Classroom

1 Introduction

Today's world is changing and developing rapidly including economy, technology, communication, transportation, trade, and others. Humans must adapt and develop into a population that has the potential and quality to drive the country further. It is important to equip the new generation with necessary skills, including thinking skills, communication, cooperation, and creativity. These skills help to adapt to survive in a changing society. Teaching must be learner-focused, focusing on developing skills used to solve complex problems that will be faced in life, which are core competencies. Core competencies include critical Thinking and problem solving, creativity, communication, collaboration and computer skills. Teachers have a duty to encourage learners to have such knowledge and skills on their own through hands-on actions to create true learning, or what is called active learning.

Learning in universities has evolved from only classroom lectures. But at present, there is a mix of onsite and online teaching. However, higher education still faces the

problem of students lacking motivation to study and the importance of subject content. Therefore, creating an environment where learners are engaged and entertained using various media has been implemented. Learners respond positively to teaching methods that incorporate age-appropriate activities. This leads to greater participation and willingness to express opinions.

Google Classroom is Google's Educational Toolkit. It's like an aerial classroom that facilitates teaching and learning. Teachers can create worksheets, design lessons, and keep records with this application without wasting money, various resources and time. Teachers can create folders in their Google Classroom to keep each student's work files. It is organized to help students follow the learning topics, assignment date and time for submitting work. Students can also personally ask and answer questions from teachers or post questions on the page to exchange knowledge as well. However, Google Classroom, as a virtual learning platform, lacks engaging teaching materials, particularly tools that support active learning. The absence of tools that encourage students to practice core competencies and facilitate interactive, enjoyable discussions often results in disengagement. Consequently, students may feel bored, uninterested, and unmotivated, showing little enthusiasm or willingness to participate. This lack of diverse assignments and creative opportunities hampers development, leading to inefficiency and lower academic achievement. Therefore, it is necessary to increase additional applications to enhance the efficiency of teaching and learning.

Quizizz is a free online application that works on a variety of internet connected devices. Quizizz is developed by Ankit Gupta and Deepak Joy Cheenath [1]. It is similar to Kahoot and Socrative, but differs in that testers do not need to play simultaneously and each player's questions appear in a different order. Quizizz is suitable for application to making pre-class and post-class exams to measure student learning results or organize game-like activities to increase fun in learning. It is a simple program that looks like a quiz game. Students will feel excited about taking the exam. It's easy to use by entering Quizizz's website and the attender will be greeted with a 6-digit number entry page. Once enter the room, the attender will be asked to enter name and later a random profile will be given. Students play by choosing the correct answer according to the question's instructions. Learners will be informed of exam results immediately and teachers receive a report of exam results and can save it on the computer. Teachers can also set the date and time of the test to assign as exercises or homework as individual practice. Benefits of this online test creation application is.

- Arranging the questions differently prevents copying.
- It is not necessary to have a main computer to display the questions or to open the questions from the main computer of the host who is asking the questions. This allows playback where there is no projection device, such as a TV screen or projector screen.
- It is a tool in the form of a multiple choices question game.
- Supports large numbers of players, up to 500 people.
- Display test scores immediately.
- Include images and sound effects.
- Learners can take the test through various electronic platforms connected to the Internet, such as computers, laptop, tablet, or smartphone.

Therefore, the researcher is interested in using the Quizizz, active teaching application, to organize teaching activities to make learning more interactive and fun for students. This is to obtain information on whether the addition of proactive teaching applications for Google Classroom can increase the effectiveness of students' core competencies or not.

2 Related Work

It was found that the working model of Google Apps for teaching helps students gain access to information as well as apply knowledge by themselves to gain benefits in many areas and it also encourages students to work as a team. Participate in working together even if stay in different places. There are people who have studied the use of Google Classroom in teaching at every level in order to find information about the benefits of Google Classroom. Railean [2] studies the use of Google app in terms of its effect on the teaching and learning effectiveness of science classrooms around the world from elementary school to university level. The study by Hussaini et al. [3] indicates that Google Classroom effectively increases student access and engagement in learning. In addition, the knowledge and skills gained through Google Classroom promote student engagement enthusiastically because it is a digital tool thus providing meaningful feedback to both students and parents. Mafa [4] conducted a study on the use of Google Classroom with students in higher education science training. The results showed that students taught using this platform expressed satisfaction with the learning activities conducted through Google Classroom. Shaharanee, Jamil and Rodzi [5] studied teaching with the Google Classroom application. The research results found that Most students who received instruction and guidance from teachers in the classroom were satisfied with using the Google Classroom application.

In addition to research on the use of Google classroom, there are also researches on the use of other applications to promote student learning. Kunyanuth [6] has conducted research on using Augmented Reality (AR), a technology that combines the real world with the virtual world, and game-based learning in science subjects to increase students' abilities. Data collection done from questionnaires and from e-Learning class activities. The results showed that the mean score of the post-test was significantly higher than the pre-test and the mean score of the exercises was high. Suci Dahlya Narpila et al. [7]'s study focused on finding out the effectiveness of the Quizizz application as a learning assessment tool in a mathematics curriculum. This study used a questionnaire for data collection. The answers of the students found that 57.2% of students give excellent and 42.8% give good scores. Moreover, the study found that more than 75% of students agreed that the Quizizz application was an effective learning assessment tool. Wiwin Handoko [7] used Quizizz on midterms examination which attended by 29 students of the information systems department. The use of Quizizz has a positive impact. 66% of the attender prefer Quizizz than paper and google forms.

3 Research Objective

The propose of this paper is.

1. To develop Google Classroom by adding active teaching applications for enhancing students' core competencies.
2. To evaluate the effectiveness of the core competencies of students who used the active teaching application for Google Classroom.

4 Research Methodology

This research is descriptive, focusing on describing characteristics or behaviors of a subject solely based on observed data, typically collected through surveys, observations, or records. It aims to provide insights into the subject without attempting to establish causal relationships or make predictions.

4.1 Sample Group

61 undergraduate students of microbiology department, Faculty of Science and Technology, Suan Sunandha Rajabhat University who enrolled in the first and second semesters of the 2023 academic year.

4.2 Create Class

The instructor begins by creating a class within Google Classroom, a feature available through Google Apps for Education. This process involves following a series of specified steps, such as setting up the class name, section, and subject. Once the class is established, the instructor proceeds to add students. This is typically done by sending out invitations via email, using the email addresses provided by the educational institution. The invitation process is straightforward, allowing students to join the class with just a few clicks. Students can then access the class at any time, depending on the teacher's setup and preferences, enabling a flexible and organized learning environment. This streamlined approach ensures that both instructors and students can easily connect and engage in the virtual classroom (Fig. 1).

When students join the class and study the content, students then participate in active teaching activities through the prepared add-on application by taking a test in which they can check their scores by themselves.

4.3 Data Collection

The researchers set up an experiment to compare the effects before and after using the add-on. Application and data collection follow the research plan (Tables 1 and 2).

1. The researcher evaluated students' core competencies by observing their work and participation in activities during class. Then record the results in the evaluation form.
2. When teaching is complete, a post-test is performed and the data is recorded to find learning achievement and then analyzed using a statistical program.
3. Students completed self-assessment of their learning management using the Active Learning Application for Google Classroom.

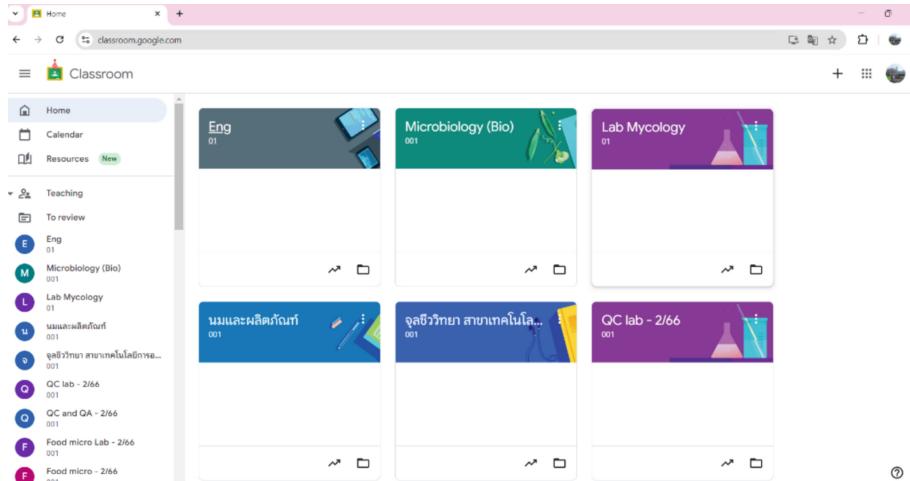


Fig. 1. First and second semesters Google Classroom of the 2023 academic year

Table 1. Measurement of achievement in the experiment

Research tools	Application	Measurement method
Learning achievement test	Google Form	Post-Test and evaluation during class
Core competencies evaluation form	Quizizz	Rating Scale
Self-assessment form	Google Form	Rating Scale

Table 2. Evaluation of research tools

Research tools	Application	Core competencies measurement
Learning achievement test	Google Form	Analytical thinking and ICT usage
Core competencies evaluation form	Quizizz	Analytical thinking, creative thinking, participation, Communication and ICT usage
Self-assessment form	Google Form	Communication and ICT usage

4.4 Statistics for Data Analysis

Statistics for Academic Achievement. Analyze the academic achievement data by using program one sample t-test SPSS. The score data obtained from pre-test and post-test.

Statistics for Self-assessment. Analyze student self-assessment data by finding the average score and standard deviation.

5 Results and Finding

5.1 Sample Group

The sample of 61 students consisted of 55 females and 6 males, clearly dominated by female students. All participants were undergraduate students who enrolled in Microbiology. 60.66% ($n = 37$) were between 19–20 years of age, while 39.34% ($n = 24$) were between 21–22 years of age.

5.2 Development Model

The objective of this research aims to examine the performance of the Google Classroom platform after integrating the Quizizz application to make the learning format to an active learning style. The aim is to improve undergraduate students' core competencies. Start from Login to Google Classroom at <https://classroom.google.com>, create a class. Then create a game through the online test creation program, Quizizz, set the name of the test and select the format in the play mode. When the design is complete, it will appear on the stream page to prepare for proactive teaching and learning activities (Fig. 2).

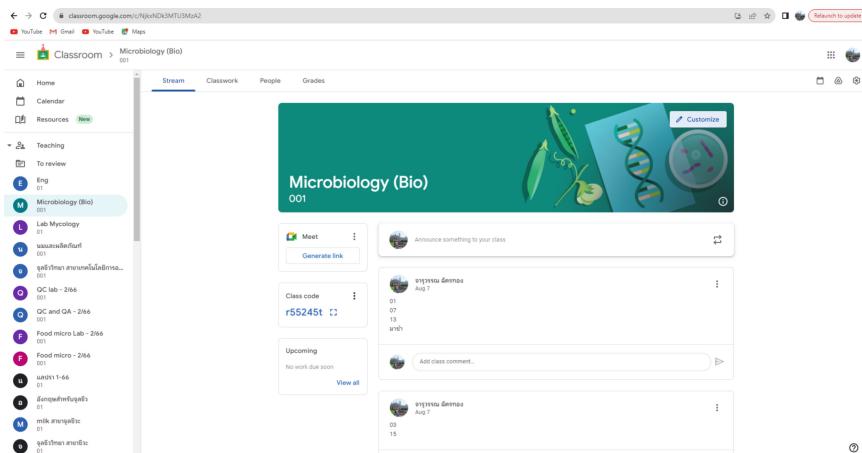


Fig. 2. Sample of class that was created

After that, students log in with the user `@ssru.ac.th`, user of Suan Sunandha Rajabhat University, and join the class by using the specified code (Fig. 3).

Once students join the class, they can study the posted lessons and can also do activities as specified by teacher (Figs. 4, 5 and 6).

In addition, students can also play an online quiz game, Quizizz. A quiz can take various forms, such as multiple choice, fill-in-the-blank, and matching (Figs. 7, 8 and 9).

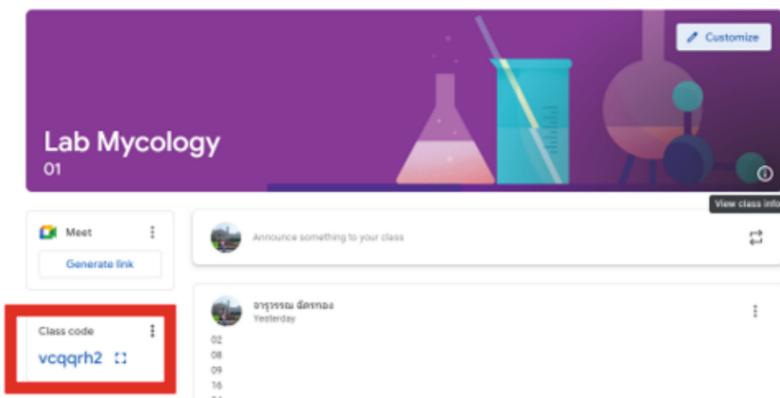


Fig. 3. Specified code use to join class.

5.3 Comparison of Students' Academic Achievement

After organizing learning by proactively adding applications in Google Classroom to increase the effectiveness of students, it can be seen that the results of the post-test achievement test of the experimental group were higher (Table 3).

5.4 Assessment of Core Competencies

It was found that the overall percentage of students' core competency assessment equal to 80.39, which is at a very good level. When considering each aspect, computing & ICT literacy had the highest percentage value of 90.45, followed by Communications, critical thinking and problem solving, and Collaboration and teamwork, respectively. The lowest value was creativity (Table 4).

5.5 Self-Assessment

The results of the self-evaluation of learning with additional active learning Google Classroom found that the overall satisfaction was at high level, with mean score of 4 and standard deviation of 0.8. When considering each aspect, it was found that the greatest satisfaction was in the computers and information technology skills with a mean of 4.58 and standard deviation was 0.78. The lowest average was creative skills. The mean is 3.34 and the standard deviation is 0.90. The result is consistent with Assessment of core competencies.

The figure consists of two vertically stacked screenshots of the Google Classroom interface.

Top Screenshot (Microbiology (Bio)):

- Left Sidebar:** Shows a list of classes and assignments:
 - Teaching: Eng 01, Microbiology (Bio) 01, Lab Mycology 01, vacuolecellulose 001, QC lab - 2/66 001, QC and QA - 2/66 001, Food micro Lab - 2/66 001, Food micro - 2/66 001, sanit 1 66 01, សិក្សាអនុសាសនា សាខាអង់គេង 01, milk នគរបាល 01, សិក្សាអនុសាសនា សាខាអង់គេង 01, QC and QA 001.
 - To review: Eng 01, Microbiology (Bio) 01, Lab Mycology 01, vacuolecellulose 001, QC lab - 2/66 001, QC and QA - 2/66 001, Food micro Lab - 2/66 001, Food micro - 2/66 001, sanit 1 66 01, សិក្សាអនុសាសនា សាខាអង់គេង 01, milk នគរបាល 01, សិក្សាអនុសាសនា សាខាអង់គេង 01.
- Stream:** Shows a post by 'សិក្សាអនុសាសនា សាខាអង់គេង' (Jul 31) with a PDF attachment 'IDM_4.ការអនុសាសនាអង់គេង 1-66.pdf' and a link to 'IDM_4.ការអនុសាសនាអង់គេង 1-66...'. It has 1 class comment from 'សិក្សាអនុសាសនា សាខាអង់គេង' (Jul 31) and an option to 'Add class comment...'.
- Below Stream:** Shows a post by 'សិក្សាអនុសាសនា សាខាអង់គេង' (Jul 31) with a link to 'IDM_4.ការអនុសាសនាអង់គេង 1-66...'. It has 4 class comments from 'សិក្សាអនុសាសនា សាខាអង់គេង' (Jul 31) and an option to 'Add class comment...'.

Bottom Screenshot (Food micro - 2/66):

- Left Sidebar:** Shows a list of classes and assignments:
 - Teaching: Eng 01, Microbiology (Bio) 01, Lab Mycology 01, vacuolecellulose 001, QC lab - 2/66 001, QC and QA - 2/66 001, Food micro Lab - 2/66 001, Food micro - 2/66 001, sanit 1 66 01, សិក្សាអនុសាសនា សាខាអង់គេង 01, milk នគរបាល 01, សិក្សាអនុសាសនា សាខាអង់គេង 01, QC and QA 001.
 - To review: Eng 01, Microbiology (Bio) 01, Lab Mycology 01, vacuolecellulose 001, QC lab - 2/66 001, QC and QA - 2/66 001, Food micro Lab - 2/66 001, Food micro - 2/66 001, sanit 1 66 01, សិក្សាអនុសាសនា សាខាអង់គេង 01, milk នគរបាល 01, សិក្សាអនុសាសនា សាខាអង់គេង 01.
- Stream:** Shows a post by 'សិក្សាអនុសាសនា សាខាអង់គេង' (Mar 12) with a Word document attachment 'សារណ៍អនុសាសនា.docx' and a link to 'សារណ៍អនុសាសនា.docx'. It has an option to 'Add class comment...'.
- Below Stream:** Shows a post by 'សិក្សាអនុសាសនា សាខាអង់គេង' (Mar 12) with a Word document attachment 'សារណ៍អនុសាសនាអង់គេង.docx' and a link to 'សារណ៍អនុសាសនាអង់គេង.docx'. It has an option to 'Add class comment...'.

Fig. 4. Samples of lesson content that teachers post on Google Classroom.

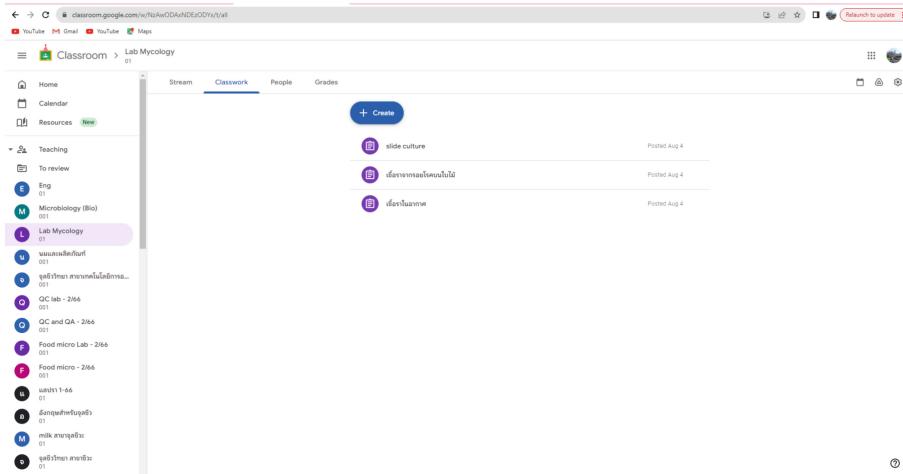


Fig. 5. Assignment content on Google Classroom.

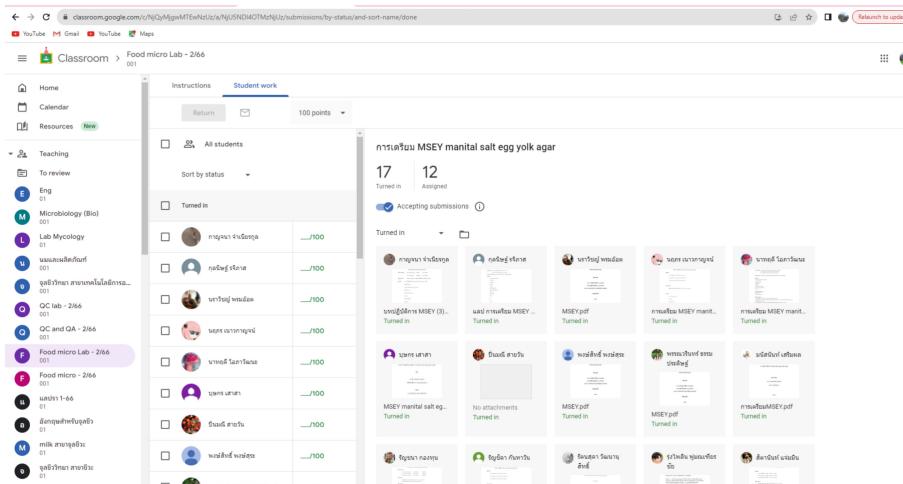


Fig. 6. Student submit work on Google Classroom

The image shows a screenshot of the Quizizz application interface. At the top, there is a search bar with the text 'Microbiology' and a 'Search' button. To the right of the search bar are buttons for 'Create Quiz' and 'Browse'. The main content area displays a search result for 'Microbiology'. The result shows a thumbnail image of a microscope slide with microorganisms, the title 'Microbiology', and a 'View Details' button. Below this, there is a section titled '1. សំណង់' (Questions) with three questions listed:

- 1. សំណង់
Viruses can be cultured using the same methods of bacteria and fungi?
Options: True (green circle) and False (red circle).
- 2. សំណង់
Pasteur Developed a vaccine for what virus?
Options: Chicken pox (red circle) and Rabies (green circle).
- 3. សំណង់
...

On the right side of the search result, there is a sidebar titled 'Discover' with several quiz cards:

- Microorganisms (1.8K views)
- Immune System Quiz (1.1K views)
- Immune System (3.2K views)
- Microorganisms (2.2K views)
- Disease and Immunity (1.1K views)
- Immune and Adaptive Immunity (4.1K views)
- Immune System (879 views)

At the bottom of the main content area, there is a 'Logout' button.

Below the search results, there is a separate window titled 'Immune System' with a purple background and a Quizizz logo. The window contains a small image of a hand holding a stethoscope.

Fig. 7. Tests available in Quizizz application

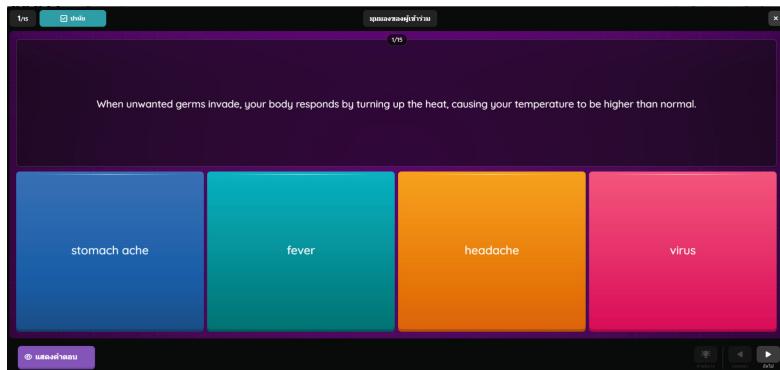


Fig. 8. A form of multiple choice

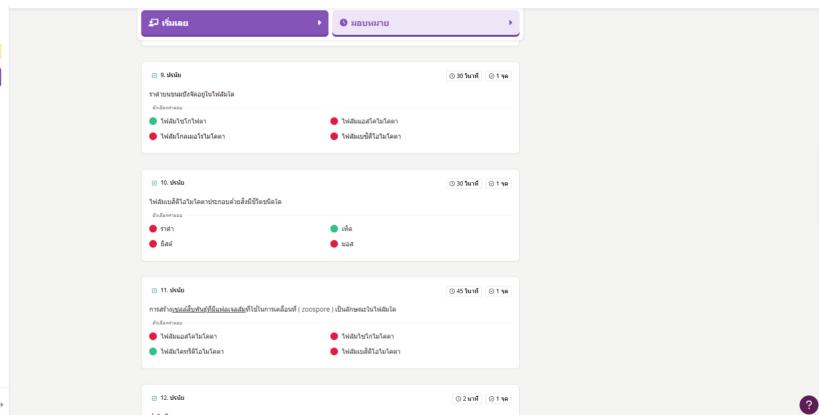


Fig. 9. Other form of multiple choice

Table 3. Assessment results, before and after using combine application Google Classroom.

Data	Pre test	Post test
sample group (n)	61	61
Average	11.05	15.60
standard deviation	1.92	2.05
Df	19	
T	18.03	
Sig	0.006	

* $p < 0.05$.

Table 4. Assessment results, before and after using combine application Google Classroom.

Assessment topics	Percentage	Variation
Critical thinking and problem solving	79.10	Very Good
Creativity	71.05	Good
Collaboration and teamwork	76.81	Very Good
Communications	84.52	Very good
Computing & ICT literacy	90.45	Very good
Overview	80.39	Very good

6 Conclusion

From the development of proactive teaching applications, learners are enthusiastic, determined to learn, and have the courage to express themselves. The media is interesting, exciting, and encouraging. Students practice analytical thinking processes in solving a variety of problems. The application's features foster an engaging learning process that stimulates interest and presents challenges. As a result, students who use the Active Teaching Application for Google Classroom achieve higher academic performance. These can indicate that the Quiziziz application is an effective learning evaluation media.

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Experiencing Android App Development and Connecting Students Together

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Abstract. This research aims to create a convenient way for college students to connect with their peers and get educational help for their classes. In an age of social media and introversion, students can struggle to get study assistance, whether it be through professors or classmates. This research links those needing study partners and those willing to help. The research app, “StudyBuddy”, was developed in Android Studio. User information was created and stored in an unencrypted local SQLite Database as a temporary solution for the registration and login part of the app. SQLite was found to be easy to work with in Java and has a low barrier of entry for those new to the service, assuming one already has a basic understanding of SQL. Research was done on Android sensors, and the app contains a Google Maps activity that utilizes location sensors to help users find potential “Study Group” locations on campus. Research with the Android Studio emulator found that Google Maps needed to be launched and the location updated before it would work correctly within the StudyBuddy app. The research results found database utilization within Android Studio and Java to be efficient, specifically that local databases and SQLite are better suited for smaller amounts of data. It was also found that Android location sensors can be beneficial for developers in terms of user data and integration but can bring some privacy concerns and complications when using emulators. **Keywords:** Android app. Education app, Android Sensors application.

Keywords: Android application · Education application · Android Sensors application

1 Introduction and Background

College and university students are often portrayed as loud, social, party-goers with not a care in the world. While such a depiction may be accurate for some, the opposite is true for others. Those who are reserved and shy are not as likely to go out and socialize; they might not even seek help when they are struggling academically. Many college classrooms are filled with quiet students who have no intention of talking to anybody around them. Whether this is caused by social anxiety, depression, or social media, is another problem. The fact of the matter is that those who do not participate in social acts with their peers will most likely not be communicating with their professors or

tutors. This way of life works perfectly for some; others may struggle with understanding important concepts but are too reserved to speak up. This app was created in an attempt to make it easier for students to connect socially whilst improving their academics. Similar approaches already exist to solve this issue. There is already an app on Apple's App Store with the same name and purpose as this one. Such existing solutions are criticized for displaying the precise location of their users. This feature is understandable in the context of the app, but it can lead to safety concerns and potential danger. Unfortunately, the lack of users for these apps means there is less testing of features and less user feedback. This may not be solved with the research being presented; however, it does impact the amount of "do's and don'ts" that can be learned from existing solutions. With more marketing and a larger team, this could be improved upon. Since there were no completely viable solutions to this problem, this research was to try and provide one [1–4].

2 Related Works

Isrokutun et al. [5] designed an Android application to provide learning steps, such as analyzing, obtaining information, asking questions, and arriving at conclusions. The application included analyzing the materials, designing the application with a smart application builder, and testing it by consulting media and materials experts. This Android-based learning application is used to train critical thinking skills in primary school students. Lee J et al. [6] created an Android app to provide multiple beneficial health features for the user as well as using some sensors to collect useful information. Y. Miao et al. [7] developed an Android platform application to help students learn English. The main purpose of such a study was to analyze and evaluate the effectiveness of the application in improving students' English language skills. The app is designed for everyone, any age, and any gender. The app is developed using Android SDK version 4.0 (API level 15), with a minimum of 1GB RAM and 512MB storage space. The touchscreen device is running Android 2.2 or later, and Java 5 or later is installed on the computer. Hinze, A et al. [8] surveyed research students at a New Zealand university using an online questionnaire to gain insight into the use of mobile applications in teaching and research in higher education. They concluded that mobile applications are mainly used by academics and students for both teaching and research. Both students and academics reported that institutional support and flexibility were likely to provide motivation and lead to increased use of the app for both research and teaching. Oliveira, D.M.D et al. [9] analyzed cases to collect mobile application usage data records from students with an undergraduate degree. The research relied on a grounded theory approach that aims to analyze records from university access points. From the data collected, a profile of mobile device use during classes was drawn. The study concluded that students agreed that they had a misperception about their use of online applications during classes. S. Hassan et al. [10] highlighted the importance of performing peer application analysis by showing that it can provide a unique perspective on performing global analysis of applications. The study suggested that future efforts might pay more attention to conducting and supporting application analysis from a peer group context.

3 Proposed System

The Android app is created using Java and XML inside Android Studio. Although the design for the app was not fully developed, there were some groundwork plans for how it would be organized. The work first started by creating the visuals for a “Login” screen and a “Register” screen using XML. Android Studio provided certain features for similar uses, such as an “Enter Text” element and an “Enter Password” element. These were used for their respective purposes, along with a new button to confirm signing in or creating an account. Once the design was done, the next task was to store user data. Initially, Firebase was selected since it is a popular, trusted, and free way to store data on the cloud. However, SQLite API is more appropriate due to its simplicity and locality. SQLite was a much easier solution for data storage. Using a YouTube video by freeProgramming Camp (2021) and the official Android documentation (Android & Google, 2024) to help with the setup of the database and data collection, the process went smoothly and a local database was created with a ‘users’ table that contained four columns: email, password, firstname, and lastname. The column names are descriptive of their content and are all in simple TEXT format. This is a vulnerability of the utmost importance if the app were to be published live, due to user information not being encrypted. This is one of the important changes to add in the future, which will be discussed later. For the moment, plain text without encryption is being used to simplify the development process. Figure 1 shows a sample of the ‘users’ table.

	email	password	firstname	lastname
	Filter	Filter	Filter	Filter
1	johndoe@gmail.com	abc123	John	Doe
2	mariep@gmail.com	only1	Marie	Pope

Fig. 1. A sample of the ‘users’ table as viewed in DB Browser

To view the data as shown in Fig. 1, a software called DB Browser for SQLite was utilized. This software made the database very easy to open and navigate. It is also possible to edit tables and databases from within the software, but since the database is updated from within the Android app, it is not necessary to make edits within DB Browser.

A key difference that was noted between the setup for the SQLite API + DB Browser and the setup for a Firebase cloud connection was the simplicity of the former compared to the latter. This research found the SQLite API to be more concise and to the point which fit the necessary use cases perfectly. On the other hand, while attempting to set up the Firebase connection, there was an excess of complicated steps and changes which can make it difficult for first-time users. There is merit to the fact that Firebase may be better suited for larger software and companies that require bigger databases and more secure connections. However, in terms of this research, one who is creating smaller applications on their own and storing smaller amounts of data will prefer the SQLite package. It was quick, easy to work with within Java code, and fulfilled the job that was needed. Use what works and fits, and scale when necessary.

4 Result

4.1 Google Maps Location Activity

An important feature of the app that differentiates itself from other solutions is the implementation of Google Maps within the app. As previously mentioned, another app on the App Store with the same purpose as StudyBuddy also contains a map feature, however, it shows each student's precise location on the map. For this research, an alternate approach is used for safety and privacy reasons. A few potential solutions were brainstormed, such as making location visibility a toggled action, enabling visibility based on proximity, or only allowing users to see their friends' locations. Instead, a viable workaround was to create several location markers on campus, labeled as "Study Groups". Each had a unique number. This was the preferred method to display meet-up locations for students to use to study together. This reduces safety risks by keeping users' locations private and would only allow those communicating with each other to know where they are going to meet and study.

To create this activity, Android Studio contains a built-in Google Maps Activity which can be used for this exact purpose. To accomplish this, the app was linked to a Google Cloud account and project using the SSH key. Next, an API key was generated for the Google Maps activity, which was necessary to ensure the maps activity worked. This was surprisingly easy, and once the activity was confirmed to be working, instructions via YouTube were followed to create a search bar to pinpoint locations around the world. The video by CodingZest (2023) showcased the step-by-step instructions on the creation of the search bar using XML, followed by the Java code to add functionality to the search bar.

Once that was achieved, the next step was to incorporate the user's current location and display it when the Maps Activity was launched within the app. The setup was not difficult, due to another CodingZest (2023) tutorial on how to grab the user's current location. Despite following instructions correctly, the code displaying no errors, and the app running without crashes, the activity continued to display the current location as the default marker at Google HQ in California. Numerous searches were done to try and troubleshoot the problem, yet there were no articles or forum posts that provided a solution to the problem. Instead, what proved to work was enabling specific location settings within the emulator's settings (to be clear, this is referring to the 'Settings' app within the emulator, same as a settings app on a phone; not the emulator settings of Android Studio) and then opening Google Maps before running the StudyBuddy app. This way, the Google Maps API would accurately display the current location that had been set in the emulator settings, since it was updated within the emulator's Google Maps app first. Unfortunately, this is not a very convenient way to update the location if the app were to be on a real user's device. It is believed, with some uncertainty, that with a physical device, the current location would be accurately displayed on the app, without needing to open Google Maps beforehand. Lastly, the finishing touches were setting location markers at several locations on campus for students to group up and study at. This is a safer way to integrate Google Maps into the app, instead of displaying precise user location to other users, which might have safety risks and privacy concerns.

Next, the visuals of the homepage and profile page were set and updated, which involved some XML that was learned from working on the previous visuals. It was decided to stick with one color theme throughout the app; a blue-white gradient, with white text and white buttons for better readability.

4.2 Course Search and Select Using RecyclerView

The next main page was the ‘Search for Classes’ page, where one could find a course they are taking or have taken, and add or remove it from their list of courses. A vertical ScrollView to display the list of courses was incorporated. The app only stores the core classes required for a Computer Science degree at Worcester State University for simplicity. However, it was found that when filled with many elements, the ScrollView lagged and stuttered while scrolling. It was also not a convenient way to add elements to the ScrollView, as developers would need to manually input each course, each with a horizontal LinearLayout to contain the text and button(s). This would make it a challenge to scale the app upwards to include all the courses in a school’s system.

Research for a better alternative to ScrollView found that using a RecyclerView was better for longer lists of elements. Instead of loading off-screen elements, a RecyclerView only simulates and displays the ones necessary to fill the screen. When the user scrolls through the list, the element moving off the screen is ‘recycled’ and then reused with the new data that is moving onto the screen to be displayed. This is more efficient for the app and can save development time when working with a large number of elements.

To get the RecyclerView to work, a few different XML files and Java classes were created. First, an XML file called RecyclerViewRow was created; this defines the visuals of each element in the RecyclerView. In this case, a horizontal rectangle was the base shape of the element. This rectangle contained the course ID at the top left, the course name in the middle, and a toggle button on the right labeled as ‘Add’ or ‘Remove’ depending on its current state. Next, an array of strings containing course IDs was defined in Android Studio’s ‘strings.xml’ file, and then the same for the list of course names. A Java class was created to set up the RecyclerView. This class had an ArrayList with the course IDs and course names so they could be referred to throughout the file. The RecyclerView setup process was achieved by referring to instructions from a YouTube tutorial by PracticalCoding (2021) on how to create and set up the RecyclerView so that it would bind the data as the user scrolls through. This was relatively simple to develop, although there were some issues with the XML not displaying correctly, which were easy fixes. The toggle button was set so that whenever it was clicked, the course ID string and course name string were read from that element, then added to an ArrayList, and that ArrayList was sent to the Profile page activity. Progress then came to a halt as more issues arose.

The ArrayList was being passed through to other activities by using a Bundle object, with which any variables could be added, and then the Bundle would be passed through the Intent when launching a new activity. However, some information was having a difficult time reaching the next page. After some continuous debugging to no avail, a different approach was deemed fruitful; instead of passing the ArrayList through various intents, the code would call a method from the DatabaseHelper class and pass the list of

courses to that method, to which it would then add or remove the courses from a new table called ‘enrolled’.

Two new tables were created alongside the currently existing ‘users’ table: ‘enrolled’, and ‘courses’. The ‘enrolled’ table would contain two columns: user_email and course_id. The ‘courses’ table would also contain two columns: id (the course ID) and title (the course name). In DatabaseHelper, a new method was created to check for user enrollment, and it would search the ‘enrolled’ table for a record containing the user’s email address and the passed course ID. If the user was not enrolled, then a new record would be added to the system with that course ID, and the toggle button on that element in the Search For Classes activity would be set to “Remove”. If the user was already enrolled, then the record with that course would be removed, since the user would have been pressing the “Remove” version of the toggle button. The button would then revert to “Add”. The new method made the functionality of the Search for Classes activity much easier and made displaying the user’s enrolled courses on their Profile page simple. The database could keep the state of the user’s added courses and profile so that whenever the app was launched and the user logged in, their courses would be saved instead of a blank slate every time. Although the bundle had its uses, the research found that using the database was more efficient and convenient for inserting, removing, and checking for data.

Figures 2, 3, 4, 5, and 6 show some pages from the proposed app. Figures 4 and Figs. 5 show the map with some existing study groups. The location of the student is shown as “My Location”, while the location of the study groups appears in red colors.

5 Conclusion and Future Works

The results showcase the efficiency of local database utilization through Java applications along with the benefits of using Google Maps sensors to determine current location in an app. Both were found to be intriguing to work with and although they may have their challenges, they have many benefits and features that can be applied if researched and implemented correctly. The limits of APIs and software can be pushed to reach new heights previously thought unachievable.

In terms of future work, it is better to fully develop the profile system to be more customizable for users to add a personal bio and profile picture. Alongside this, adding a search and messaging function to the app so that the users can find classmates by course or by name, and then add them as friends so they can begin communicating with one another and start studying. Furthermore, include the encryption of user data in the database to make it safe and secure and to learn the ins and outs of encryption.

Acknowledgments. The authors of this work acknowledge the support from the Worcester State University, Dr. Imoigele Aisiku Research Fellowship Program.

Appendix

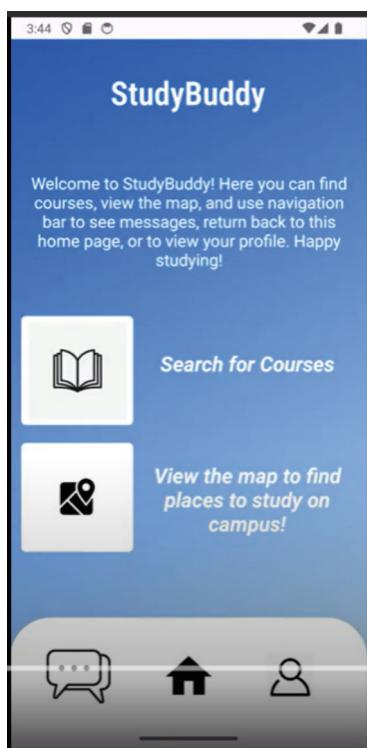


Fig. 2. The home page of the proposed app.



Fig. 3. The 'Find Courses' page.

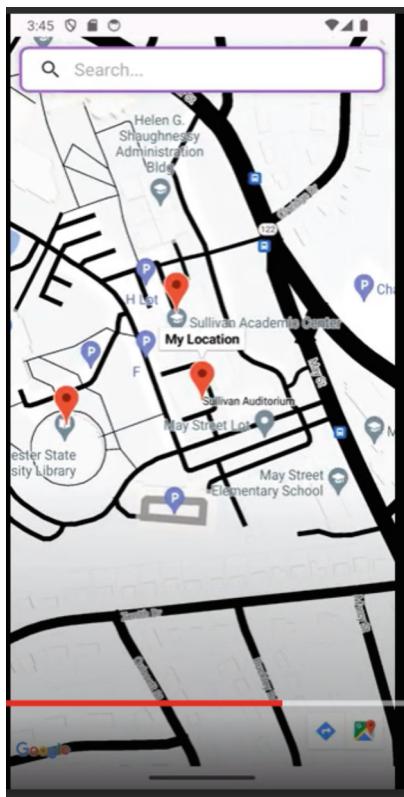


Fig. 4. The Map page.

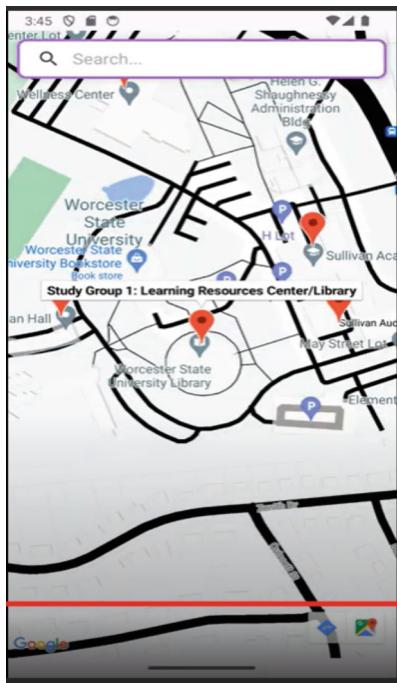


Fig. 5. Click on a study group location marker to get more information about that location.

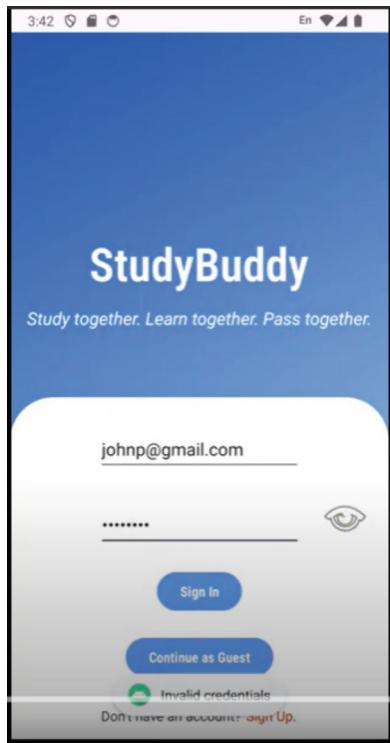


Fig. 6. Sign up/in page.

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Author Index

A

Ahmed, Dewan Tanvir 59
Allagan, Julian 165
Alsallami, Nada 338
Aukkanit, Nuntaporn 117, 240

B

Beasley, Shannon W. 310
Boonseng, Chongrag 225
Bowen-James, Alan 3

C
Chen, Yu 144
Chopvitayakun, Shutchapol 117, 240
Choupani, Roya 304
Churrtong, Jaruwan 326
Clouse, Scarlet 304

D

Donald, Aurelia M. 165, 285

E

Erickson, Varick L. 41
Eyob, Ephrem 165

F

Fife, Joshua 338
Freislich, Mary Ruth 3

G

Gao, May J. 285
Gao, Shanzhen 165, 182
Gao, Weizheng 165, 182
García-Mendoza, Betzabet 269

Garza, Diego E. Trueba 192
Garza, Diego Trueba 131

H

Hall, Leah 165
Hou, Yunfei 144

J

Jaimez-González, Carlos R. 269

K

Kucukkaya, Goksel 84
Kularbphettong, Kunyanuth 117, 225, 326

L

Langenderfer, Robert 159

M

Maurer, Peter M. 71
Maxwell, Katia 255
McGill, Monica 12, 209

N

Nyantakyi, Joshua 165

O

Orozco-Tapia, Fernanda 269
Ozer, Murat 84

P

Poyraz, Omer Ilker 84

R

Raksuntorn, Nareenart 225
Rattanasiriwongwut, Montean 240
Reihanian, Iman 144

Roonrakwit, Pattarapan 225

S

Sang, Janche 29

Sangsuwon, Chanyapat 117

Schwarzaupt, Robert 209

Sirichokworrakit, Supatchalee 117

Solo, Ashu M. G. 103

Spangler, S. C. 310

Spivey, Yvette 304

Su, Jianning 165

T

Thigpen, Laycee 12, 209

Tise, Joseph 209

Trevino, Diego E. 192

Y

Yilmaz, Muhittin 131, 192

Z

Zhang, Yong 322

Zheng, Yifei 144