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CAP-B: A New Teaching Methodology for STEM Education Using Project-Based Learning and Blended Practical in a Cognitive Apprenticeship Framework

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Although the demand for STEM (Science, Technology, Engineering, and Mathematics) personnel continues to raise in the U.S. workforce, it has been revealed that STEM education is not providing the necessary supply. Graduates with a STEM education are below their counterparts internationally. This paper seeks to introduce a new teaching methodology, based on a merger of Project-Based Learning (PBL), Hands-on Learning (HOL), Simulation-Based Learning (SBL), and the Cognitive Apprenticeship (CA) framework, aimed at improving learning in STEM education. The methodology aims to address three of the four main causes for the STEM paradox, namely (i) shortage of graduates with Soft Skills, (ii) lack of qualified technicians, and (iii) untapped pools of talent while increasing students' self-efficacy. It has been implemented as a case study for the past four years in four courses. Analysis of results has shown that, for all courses, students (i) acquired and increased their domain knowledge, procedural and processed knowledge while solving problems, in given scenarios resulting in their expertise level increasing. These results also showcased an increased their self-efficacy as well as their Soft Skills, especially Higher Order Thinking Skills (HOLS) competency levels.

Keywords: STEM education, cognitive apprenticeship, project-based leaning, simulation-based learning, hands-on learning

Introduction

The technological innovations and discoveries of the 20th century have ushered in a digital transformation resulting in the Fourth Industrial Revolution (4IR). Technology is now an integral part of life resulting in an increasing dependence on it. The success and competitiveness of a country can now be measured by its inspirational discoveries and transformative technological advances (STEM Workforce, 2020). This is because innovation-invention, development and deployment of technology is now crucial to the economic development; for example nearly 70% of the U.S. Gross Domestic Product (GDP) depends on such activities (STEM Workforce, 2020). These activities all depend on an effective STEM (Science, Technology, Engineering, and Mathematics) education that determines whether a country becomes a leader among nations in solving challenges such as security, health, climate, and environmental protection.

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This paper seeks to present a new teaching methodology that is designed to increase students' expertise in STEM. Its implementation has been, for the last four years, in an undergraduate Computer Science Department in a Historically Black University (HBCU). Section 2 defines STEM education and examines its worldwide importance. Sections 3 and 4 introduce the teaching methodology while Section 5 examines implementation and presents qualitative evidence showing effectiveness. Conclusion is found in Section 6.

What Is STEM Education?

STEM education, which looks at the instructions in Science, Technology, Engineering, and Math, as a coherent package, has always been one of the driving forces for the innovative sector and the future wealth of countries. It aims to provide training to a technocratic elite: scientists, engineers, and technicians capable of solving the problems of the current stage of development of a country, oriented towards the technological path. Some authors call this approach an educational phenomenon and one of the main trends in world education (Mikhaylovsky et al., 2021).

The original definition of STEM education, however, can no longer be accepted in this 21st century. The traditional means of learning where students memorize is now inappropriate. Knowledge can no longer be passively received either through the senses or by way of communication. It is instead created by active participation in the learning process (Anand, 2021); as a result, students of this era are more "why" and "how" than "what" in their learning. They use prior knowledge to help them understand and learn. STEM education must now be an interdisciplinary, experimental approach to learning that allows students to apply their ("what") (the knowledge, attitudes, and values associated with the disciplines) and ("how") (the skills to apply that knowledge, taking account of ethical attitudes and values in order to act appropriately and effectively in a given context) to solve relevant real-world problems based on their ("why") (understanding of the knowledge usage and relevance). This is echoed by the U.S. Department of Education (DOE) that states

> In an everchanging, increasingly complex world, it's more important than ever that our nation's youth are prepared to bring knowledge and skills to solve problems, make sense of information, and know how to gather and evaluate evidence to make decisions. (Hom & Dobrijevic, 2022)

STEM education must now be an engine of advancement propelled by knowledge and research (Puranik, 2020). As such it must transcend fields of study to include an environment that supports peer collaboration and ongoing innovative thinking and design. To do this, STEM education must now be grounded in the tenets of constructivism and cognitive science. This will make learning active while contextualizing student's prior experience, knowledge, and beliefs, learning strategies, and the needed expertise to create an effective learning environment.

Importance of STEM Education

Economic modeling has consistently identified a relationship between direct measures of cognitive skills in Math and Science with long-term economic development. UNESCO goes on to refer to Science and Technology as being the critical drivers and lynchpin for achieving sustainable development and gaining access to the relevant knowledge and positive attitudes to address global challenges (Giovannini et al., 2015). This may explain why, internationally, there has been an increase in both STEM enrollment and degrees.

To showcase the importance of STEM education, Atkinson and Mayo (2010) cautioned that without the right number and quality of STEM-educated citizens innovation will falter, and with it, economic opportunity for all. They went on to suggest that nations should follow China, recognizing that STEM is more important than other subjects because the overall societal contribution from a STEM graduate exceeds that of a social sciences or humanities major. Without STEM graduates, a country does not innovate or, consequently, create jobs based on innovation (Atkinson & Mayo, 2010). The GDPs of countries have shown support for this interrelationship. For example, an analysis report in 2020 by a consortium of major scientific professional organizations found that STEM jobs accounted for 2/3 of U.S. jobs, nearly 70% of the nation's Gross Domestic Product (GDP) and generated over $2.3 trillion in tax revenues annually (STEM Workforce, 2020). Another research reported after analyzing the economy of different countries that as more STEM graduates are produced in a country, the larger the GDP growth rate (Podobnik et al., 2020). Ultimately, the purpose of driving STEM education is not principally to create economic opportunity for individuals. Rather, it is to provide the "fuel" necessary for powering a technology-driven economy.

There is a STEM paradox however as there is a crippling shortage of STEM professionals in most countries that threatens to undermine economic growth and hold back the scientific advances needed to meet the world's most urgent challenges. For example, in Sub-Saharan Africa and the United States they cannot meet the demand for STEM workers, yet, paradoxically, the number of STEM graduates worldwide increases every year (Rubinstein, 2018). Research has shown that there are four main causes for this paradox, namely:

1. Shortage of graduates with Soft Skills,
2. Lack of qualified technicians,
3. Loss of high-skilled workers,
4. Untapped pools of talent.

Researchers have suggested that to solve these problems there needs to be a strong ecosystem which includes a strong education system that combines classroom learning with real-world experiences to provide students with both the technical and personal professional skills they need to succeed.

This research presents a teaching methodology that seeks to provide students with this environment and addresses the first two causes as it is tested in a HBCU which addresses the fourth cause.

Shortage of graduates with Soft Skills. A requirement from employers' state that graduates should have competencies in Soft Skills called 21st Century Skills, especially Higher Order Thinking Skills (HOTS), that includes the 4C's (Critical Thinking, Creativity, Communication, and Collaboration), problem solving, innovation, decision-making, and metacognitive thinking (Walters-Williams, 2022). With these skills students will be able to understand concepts, connections, and big-picture thinking, analyze and evaluate complex information, categorize, manipulate, and connect facts, troubleshoot for solutions, problem solve, ideate and develop insightful reasoning (Walters-Williams, 2022) so that they can find answers that do not exist while providing the proper judgement based on determine criteria.

Employment reports and surveys have constantly shown, however, that graduates consistently fall below the desired competency levels (World Economic Forum, 2020; Lobosco, 2019; NACE, 2021) and in 2019 only 13% of graduates were considered Soft Skill ready at the time of employment (Webber, 2019). The Wiley Education Services and Future Workplace 2019 survey also shows that the deficiency in desired competency levels has widened from 54% in 2018 to 64% in 2019 (Wiley, 2019). Employers feel that education has yet to fully address this shortage (Wilkie, 2019) as students have been taught content ("what") but not the application ("how") or importance ("why") of this knowledge (Wilkie, 2019) resulting in the skills gap being a serious challenge to "traditional [learning] establishments".

Lack of qualified technicians. STEM graduates are required to have *a level of expertise* to be competitive in the 4IR workplace. Graduates in the past generally acquired content knowledge but typically lacked practical experience (novice level). Current graduates need the ability and skills to organize this knowledge, as well as be able to analyze new contexts to fit into and increase this knowledge (proficient level). With this graduates will be able to use their knowledge to interpret information, analyse situations, and develop solutions to problems. As such, the curriculum must be designed to help novice-level students take the journey to increase their expertise levels.

To increase their level of expertise students need to acquire *practical experience*. In the past, most STEM courses were taught by the traditional Hands-on Learning (HOL) approach that require costly hardware-laden laboratories. HOL however may present students with obsolete or damaged devices and may even limit their practice time due to the limited number of devices. Simulations-Based Learning (SBL) was introduced to offer students practical experience that is less costly and more flexible. Students do not work in device-dependent labs but still receive "practical experience of the theoretical concepts [while learning] the complex material in a simple, flexible and relaxed manner" (Prvan & Ožegovć, 2020, p. 7). In so doing Simulations-Based Learning (SBL) overcomes the limitations of learning in real-life situations while developing complex skills and enhancing theoretical concepts (Chernikova et al., 2021). In STEM however professional success is directly related to the ability to transfer knowledge gained in the academic environment to real-world situations. Acquisition of these manipulative skills is only possible through the use of real instruments and real experimental data. SBL and HOL by themselves do not provide the much needed graduates.

Untapped pools of talent. Women and minority ethnic groups are currently underrepresented in STEM fields in both developed and developing countries. Women represent just 30% of the world's STEM workforce. In the Unites States African Americans are about 18% (NSF, 2023). This lack of participation of underrepresented or disadvantaged groups in STEM not only limits gender and income equality, but also impedes innovation and economic advancement as large swaths of talent are under-utilized. As such there is a diversity gap in STEM which needs to be addressed.

Finding a Solution

Increasing HOTS—Project-Based Learning (PBL)

Research has showed that a student-centered classroom that supports open expression of ideas, provides active modelling of thinking process, develops thinking skills, and motivates students to learn is a major factor to increase HOTS competencies. This is what Project-Based Learning (PBL) provides (Walters-Williams, 2022) as it creates opportunities for students to (Eliyasni, Kenedi, & Sayer, 2019):

1. make decisions through a systematic framework, having problems whose solutions are not limited,
2. design the process of activities,
3. build knowledge based on real experience,
4. find information and solutions,
5. work collaboratively on projects,
6. conduct ongoing evaluations of solution,
7. evaluate each other to find mistakes and make changes, and
8. assess resulting product.

In short, “it empowers students to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem” (Walters-Williams, 2022, p. 2882). In so doing PBL integrates learning with training allowing students to be more independent in building their own understanding. It also creates opportunities for analysis, categorization, and expertise development required to address realistic scenarios, while enhancing students’ leadership abilities, listening skills, coordination, and strategic thinking skills (Walters-Williams, 2022).

Increasing Expertise—Cognitive Apprenticeship Framework

To improve STEM graduates’ expertise there needs a method that provides assistance to have less-skilled (novices) increase their level of expertise. This is what the Cognitive Apprenticeship (CA) framework offers by providing content experts (faculty) who guide these novices. This framework creates a learning environment that encompasses not only the classroom but also the outside community. In the classroom CA introduces three of its four dimensions:

1. Content strategies—different types of knowledge (domain, procedural, process) and thinking strategies required for expertise,
2. Teaching methods—synthesising different teaching methods (modeling, coaching, scaffolding) with different learning methods (articulation, reflection, exploration), and
3. Sequencing approaches—explicating the thoughtful ordering of activities to promote expertise (increasing complexity and diversity).

The fourth dimension—the sociology of a learning environment, examines ways of creating a cooperative community of learning that fosters legitimate peripheral participation using real-world activities (situated learning) (Kurt, 2021).

The framework therefore provides ways to help students obtain knowledge from more experienced individuals through multiple cognitive and metacognitive skills and processes. It assumes that novices are unable to initially accomplish learning on their own and must seek support from experts; thus by using guided support they are able to gain practical and cultural knowledge, gain motivation, and eventually wrestle with the ambiguity and uncertainty of complex tasks. CA was also designed to encourage students to explore questions and challenge existing solutions providing novices the opportunity to develop expertise (Kurt, 2021; Walters-Williams, 2022). It therefore supports the three stages of skill acquisition: (i) cognitive where the student develops their knowledge, (ii) associative where any mistakes and misinterpretations learned are corrected while critical elements involved in the skill are strengthened, and (iii) autonomous where the skills are fine-tuned to expert level (Walters-Williams, 2022).

Providing Practical Experience—Blended Practical Learning

Despite of the advantages of SBL, HOL remains tremendously important in STEM education as learning occurs when mental activity is suffused with physical activity (Gokhale, 1996). The success of STEM students is directly related to their ability to transfer knowledge gained in the academic environment to real-world situations. Acquisition of manipulative skills is only possible through the use of real devices. Success cannot be met fully by neither SBL nor HOL; thus it is best to teach using both, capitalizing on their benefits: from SBL, the critical and strategic thinking skills and the knowledge and understanding of concepts and from HOL the manipulative and technical skills from physical manipulations (Brinson, 2015). Researches by the DOE and others (Prvan & Ožegovć, 2020) have shown that a blend of HOL and SBL produces students who meet more learning outcomes than traditional methods alone (Brinson, 2015) as SBL amplifies the real experience in HOL (Aebersold, 2018).

Untapped Pools of Talent—Teaching in a HBCU

In the United States, Historically Black Colleges or Universities (HBCUs) were created to meet the need of educating the black minority. Presently they comprise eight of the Top 10 baccalaureate-origin institutions colleges, and make up 19 of the Top 50 institutions, and 11 of the Top 20. The prominence of HBCUs is apparent across STEM—in the Physical and Earth Sciences, all five of the top institutions were HBCUs; HBCUs claim four of the Top 5 spots in the Life Sciences, Math, and Computer Science and two of the Top 5 in Engineering (Nietzel, 2022). In fact, although just 3% of the nation's educational institutions, they account for 41% of all Black (HBCU Lifestyle, 2023) and 46% of all Black women who earned degrees in STEM (UNCF, 2023).

Proposed Solution—CAP-B

Examination of CA shows that it is based on the theory of Situated Learning where knowledge is acquired and contextually tied to the settings and situations in which it is learnt. PBL has been shown to increase expertise levels by providing an authentic experience through the use of real-world projects. Merging these two would result in an increase in students' understanding of the concept of the subject matter as CA would provide expert guidance through structures and examples which are provided by PBL. Using the real-world examples offered by PBL, content experts (faculty) would be able to demonstrate and explain necessary skills and knowledge (modelling). Students would then be able to (i) practice these observed methods and skills on complex real-world problems (explore) using HOL and SBL, with faculty guidance (scaffolding, coaching), (ii) express their thoughts (articulate) as well as (iii) compare their ideas/thoughts to those of their peers and faculty (reflection). In so doing the combination of CA and PBL creates a custom environment that scaffolds to mastery of real skills directly applicable to the student (Walters-Williams, 2022) fostering critical thinking and problem-solving skills typically found in expert practice.

The researcher in 2022 showed that a merger of CA and PBL can be successfully used (Walters-Williams, 2022) and research has already shown the success of a HOL and SBL merger (Brinson, 2015; Prvan & Ožegovć, 2020) but there is no known research that shows the implementation of the merger of PBL, CA, HOL, and SBL. This research seeks to showcase such, in a methodology called CAP-B (Cognitive Apprenticeship (CA) Framework with Project-Based Learning (P), and Blended Learning (B)).

Introducing CAP-B

In CAP-B, the practicality of PBL (assessment, and real-world exercises) is grounded in CA (teaching and learning methods that increase students' expertise). It is guided by the William and Flora Hewlett Foundation (2010) concepts of "deeper learning" and "student-centered pedagogies" that include "models of teaching and learning that are project-based and collaborative that foster knowledge building, [PBL] while requiring self-regulation and assessment [CA]" (Walters-Williams, 2022, p. 2886).

Setting up Environment

To give students the chance to move from a novice level the classroom must mirror the social nature of real world where the acquired knowledge will be applied (Walters-Williams, 2022). The classroom environment designed for this method is based on the HPL (How People Learn) theoretical framework that aims to create a learning environment where all of the important factors that influence how students learn are present and in balance for learning (Iris Center, 2021). As such, a CAP-B's classroom is a merger of the four learning environments with the aim of:

- helping students make connections between their past knowledge skills, interests, attitudes, beliefs, and their current academic tasks creating Culturally Responsive Teaching (learner-centered).
- building on students' current knowledge and skills, rather than simply presenting new facts, creating a method of Teaching for Depth & Progressive Formalization (knowledge-centered).
- providing continual feedbacks to students so as to provide them with opportunities to revise and improve the quality of their thinking and learning (assessment-centered).
- connecting learning to the larger community through real-world projects and exercises (community-centered).

In so doing CAP-B creates an environment that should be a continuous process of discovery and improvement for each student and for the course at large.

Delivery Mode

In this 21st century the traditional way of communicating knowledge to students (face-to-face) is not always possible, e.g., during the COVID-19 Pandemic. Students are now technological savvy and teaching much adapt. As such teaching methodologies need now utilize modes of delivery that once were considered esoteric. CAP-B is designed to adapt and allows a continuum of technology-based learning (Figure 1). Research for the US Department of Education (DOE) supports this, stating that blended instruction has been more effective than others (Toyama Means, Murphy, Bakia, & Jones, 2009). CAP-B is therefore designed to be delivered using:

- Face to face (f2f): the traditional mode of delivery where both students and instructor are in a permanent physical environment.
- Blended learning: a mixture of f2f and remote instruction using online technology. It is sometimes called flexible delivery. Like f2f students have a permanent environment but also have access to online material and activities used to complement the content discussed f2f.
- Remote learning: similar to f2f but has a permanent virtual environment instead of a permanent physical one.

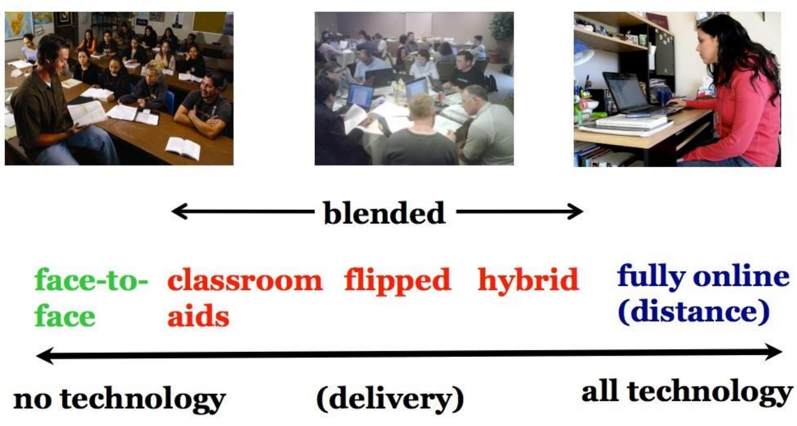

Figure 1. The continuum of Technology-Based Learnings (adapted from Bates, 2019).

Teaching in the Method

CAP-B seeks to answer four main questions about the course's content: (i) What will be taught? (ii) How will it be taught? (iii) How will it be organized? (iv) How does it relate and apply to real-world situations? To do this it utilizes the three teaching and three learning methods presented in CA while applying PBL real-world problems to:

1. present students with subject-related problems or challenges,
2. solicit students' thoughts and ideas about how to solve problems, and
3. ask students to explain the reasons behind their thinking.

The methodology is divided into two sections that focuses on teaching and students' activities.

Section 1—Teaching. Students become sufficiently competent by acquiring and developing the course knowledge (domain, procedural, process), concepts, procedures, and skills needed through appropriate activities. Knowledge is delivered using one of the mode of delivery in "Delivery Mode" where previous learning is revisited at the beginning of each class to create a sense of continuity and students' understandings of concepts are checked using "hinge-point questions" and quizzes. Concepts are taught using real-world examples with increasing complexity that are applied to different scenarios. The following steps are implemented.

- Step 1: Faculty expert delivers course knowledge while providing demonstration(s) of the thought process to find solutions to problems with the aim of not demonstrating features but instead showing students how to approach the solution (Modeling).
- Step 2: After observing demonstrations, students work on similar exercises applied to different situations (Increasing Diversity) with the expert's guidance so that correct approaches are applied to develop solution(s) (Coaching). Guidance is important so that corrections are can be made to any deviation quickly by reminders, or feed-backs. In this step students start to develop their course knowledge and procedures as well their course skills.
- Step 3: To increase students' competency, students work on exercises with increasing levels of difficulty with the aim of leading them to more complex challenges (Increasing Complexity). As these exercises progress, the guidance and support are gradually removed until students have practically no need for them and are able to work on their own (Scaffolding).

By the end of these three steps students should have acquired the required course knowledge and skill sets through practice, observation, and guidance.

Section 2—Learning. Students are able to exercise their initiative and creativity in designing and creating their projects and solutions independently. In this section students work on their PBL projects. Each project is assigned to allow student collaborations that will foster cooperative problem solving. These projects demand that each student actively communicate about the project as well as be engaged in the skills required for solution development. The following steps are implemented with the aim of externalizing students' thinking processes that are usually internal, not explicitly explained. Once this thinking is made visible, it can be more easily reproduced and in fact, the thinking process itself learnt.

- Step 1: Students provide justification for their approach to PBL project solutions and other exercises. In so doing they reveal their knowledge, reasoning, and problem-solving processes. Articulation is oral, digital, and written helping to solidify the students' learning in their minds. As students reveal their thinking process, faculty experts analyze the process and provide appropriate feedback to correct, clarify, or reinforce concepts and skills (Articulation).
- Step 2: Each student evaluates other students' solutions and performance as well as their own. This evaluation is done after each main learning experience and looks at group members, the student, and other groups performance with the aim of providing feedback (Reflection).

These two steps help students focus their observation of expert problem solving and gain conscious access and control of their own problem-solving strategies.

- Step 3: Students are encouraged to try new and novel approaches and move into the mode of problem solving on their own where they will no longer need faculty support but develop independent thought. In so doing students in this step were encouraged to have autonomy, not only in carrying out expert problem-solving processes but also in defining or formulating the problem to be solved (Exploration).

Assessment

CAP-B sets high standards where students are expected to excel as there are opportunities created for each student to meet them. There are frequent opportunities for feedback, reflection, and revision, in order to enhance the quality of learning. These opportunities are made available through (i) continual feedback using formative assessment that measures the learning progress in order to encourage reflection and revision and (ii) summative assessment that measures the results of learning. These assessments allow students to showcase their own interpretations of the course material while assessing acquired knowledge and evaluating the accuracy with which they are able to execute different functions within given real-world content-related scenarios.

- Formative assessment. Different formative assessment methods can be executed throughout the semester. These assessments are:
- Self-assessment: Student examine and evaluate their progress at different times throughout the semester. This allows students to: (i) answer reflective questions about what they are learning, where they are struggling and what they need to do next; (ii) examine self-assessment rubrics that provide data on their individual progression based on specific descriptions in various categories.
- Peer assessment: Students receive feedback from PBL project group members as well as other students to help them see different views as well as learn how to articulate their ideas. Three different methods can be utilized: (i) the 3-2-1 Structure where students are told three strengths, two weaknesses, and one question that needs to be answered; (ii) the feedback carousel where students leave anonymous sticky notes feedback to different groups other than their own; (iii) group members rubric where students rate their group members based on specific categories.
- Teacher assessment: Students receive feedback from the faculty expert. This includes (i) quizzes that show students their progress in learning, understanding, and applying taught concepts; (ii) observations reports that show how students were performing during practical exercises and on their PBL project.
- PBL project milestones: evaluation of specific reports and deliverables that cover different aspect of the project throughout the course timeline based on correctness (non-existence of errors), clarity (properly written, clear diagrams…), adaption (fulfilment of rules, simplicity of solution…), understanding, and usage of course concepts related to each deliverable.
- Discussion forum: Students have dialog on content, share their ideas, challenge and teach each other, clarify assumptions, experiment, and learn new knowledge, skills, and ideas.

Summative assessment. Different types of summative assessment methods can be executed at the end of the semester. These assessments are:

- Examinations: continuous evaluation of students learning progression through quizzes, labs, and tests which assess students under-standing of course concepts, and their real-world applications in order to optimize learning. Students can be tested at the beginning of each course that shows the students their base network knowledge, again mid-way through the course, and finally at the end of the course.

- PBL project evaluation: evaluation of students' PBL solutions to see "what" they have learned, how effectively they apply it to problem-solving, and how well they articulate their solutions orally, digitally, and written.

CAP-B Implementation and Evaluation

Although some high school graduates transition directly to the STEM workforce, most STEM enterprise depends heavily on recipients of higher education degrees in these fields (National Science Board, 2022). As such CAP-B was tested in a university to showcase its impact on increasing STEM education at the highest educational level. It was also tested in a HBCU to meet the desire to produce graduates who can fill the diversity gap.

CAP-B has been implemented since Spring 2019, employing an exploratory case study approach to investigate its impact on students' knowledge and skills in four undergraduate courses in a South-East HBCU. These courses are:

- Introduction to Networks (Network): Spring 2019-Spring 2023,
- Concepts of Communication Networks (DataCom): Fall 2020-Fall 2022,
- Computer Organization & Architecture (COA) I: Fall 2020-Fall2022, and
- Computer Organization & Architecture (COA) II: Spring 2021-Spring 2023.

The primary objective of these courses was to prepare students with the necessary basic theoretical knowledge and skills in basic networking, data communication and computer architecture design. Each course consisted of 45 hours of teaching, assignments, examinations and blended labs all supported over a 16-weeks period. PBL projects were given in each course and aligned with the delivery time of related content.

Different CA teaching methods were employed throughout the semester, with the goal of building students' expertise and facilitating the transfer of knowledge to real-world situations and problems. Students learnt by watching, e.g., how to disassemble/assemble a computer, build a patch cable or a logic circuit, and reset a switch (*modeling*) then practising these techniques and tasks through classwork, assignments, PBL project, hands-on, and simulation labs. During this time the researcher observed the students providing feedback (*coaching*), help, and guidance where necessary (*scaffolding*) while increasing the complexity and diversity of assessments as the semester progressed. In each course students utilized PBL projects so as to discuss with others their ideas, knowledge, and thinking (*articulation*), compared and evaluated themselves and their peers (*reflection*), while they proposed and developed solutions (*exploration*).

Labs sessions were divided into hands-on exercises and simulations. Simulations were designed to act as the practical component of the lecture so that students received practical understanding of taught concepts. To further cement their practical experience and knowledge students work on hands-on exercises that require them to utilize abstract concepts which are usually hard to understand practically but shown in simulations.

The number and type of PBL projects varied according to course. In the Network and COA II courses students were given two real-world PBL projects—one SBL and one HOL. For the DataCom and COA I courses students were given only one semester long project. For the COA I course there was an individual SBL project while in the DataComm course it was a HOL team-based project.

Qualitative support was collected from students' performance based on their (i) declarative knowledge that shows their retention of facts, principles, and their interrelationship; (ii) procedural knowledge that looked at knowledge/skills students acquired while executing simulated and hands-on activities; and (iii) retention that examined how much declarative and procedural knowledge students had retained at the end of a course. For the studied university the acceptable pass rate is C.

Increase in Expertise—Fixing Lack of Qualified Technicians

In this research students' expertise growths were evaluated using the PBL project, discussion forums, lab assignments, peer/self-assessments, and examinations. Since students learnt from both direct instructions and practice assessment using the PBL project, expertise levels were measured based on the Dreyfus Model for Skills Acquisition (Figure 2).

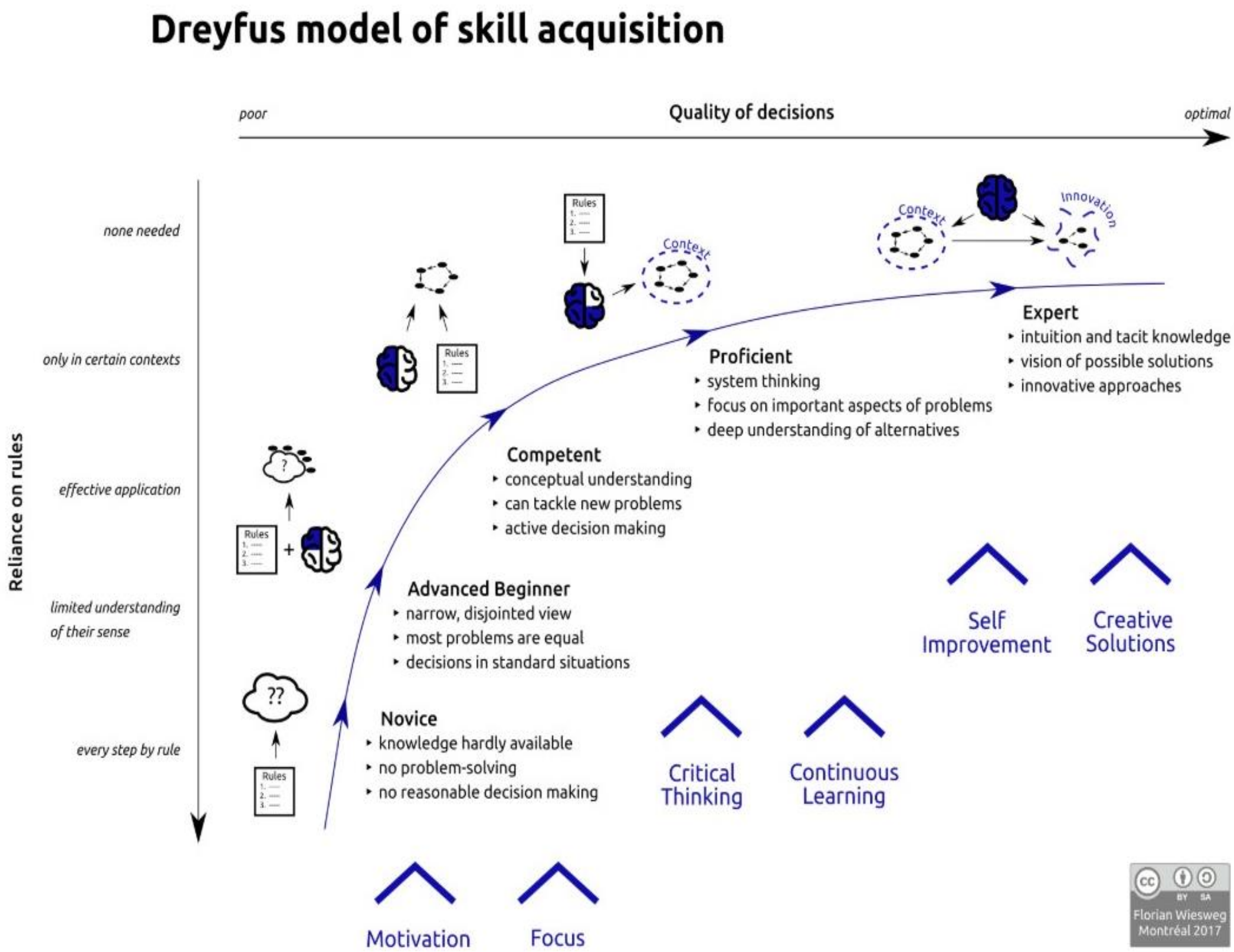

Figure 2. A visual summary of the Dreyfus Model (adapted from Thackray, 2018).

At the start of each course each student can be considered a novice, having basic knowledge and awareness. As students received instructions, they were able to understand guided context applications as they were exposed to real-world situations (Advanced Beginner). The PBL project allowed students to organize knowledge by developing routines, and selecting rules and tasks considered most important to achieve their solution goals while taking responsibility for their mistakes and making necessary corrections (Competent Level). As they sought to make corrections and design solutions students were allowed to rely on intuitive diagnosis, and the insight that they had gleaned from real world examples. In doing so, they applied, based on their own judgement, appropriate skills in designing and building their solutions (Proficiency Level).

Network results.

Overall retention. This is the pilot course and Table 3 shows the overall performance of students in each year since 2019. It shows that for the first four years there has been no failures in the course implying that student retention is good. The Year 2023 reported its first failure due to the constant absence of the students and not the failure of CAP-B. Further investigations were executed on students' performance in both their declarative and procedural knowledge to determine the effectiveness of CAP-B.

Declarative knowledge. To test students' change in their declarative knowledge a pre-assessment is administered during the first week so as to provide a base. This was then compared to students' performance in both their midterms and final examinations. For the five years there has been constant score increases as can be seen in Table 1, from pre-assessment (Mean = 55.8 [2019], 5.6 [2020], 42.2 [2021], 40.85 [2022], 40.77 [2023]) to midway with midterm (Mean = 92.3 [2019], 58.4 [2020], 63.5 [2021], 84.94 [2022], 67.3 [2023]) to the end with final examination (Mean = 97.7 [2019], 83.9 [2020], 82.6 [2021], 88.48 [2022], 85.69 [2023]). This implies that students were able to retain much of the theory and its applications, thus being able to answer questions more accurately by the end of the course.

Procedural knowledge. As this course offered two PBL projects, performance in procedural knowledge examined students results for final simulation (Mean = 87.4 [2019]; 86.9 [2020]; 80.6 [2021]; 89 [2022]; 87.50 [2023]) and hands-on (Mean = 87.2 [2019]; 71.8 [2020]; COVID [2021]; 92.5 [2022]; 96.24 [2023]) projects. Results show that there is not much difference in their means. This implies that students were able to attain the same skill level in both hands-on and simulations. This shows that the results from the simulation are functionally equivalent to the hands-on results. The overall student performance can be seen in Table 2. At the end of the course students were asked the question "Please identify what you consider to be the strengths of the course"—90% stated that having simulations practice and then replicating what is done in the hands-on projects helped them learn the material better. It can therefore be concluded that the skills learnt in the simulation environment were transferred to the physical environment and authentic learning had occurred.

Data communication results.

Overall retention. Investigations into students overall performance (Table 3) revealed that there was a decrease in 2021. This may have been due to the fact that this was during the COVID-19 pandemic and students were not able to receive the desired practical experience from a HOL PBL project that would have helped them in understanding some theoretical concepts. There was 12% increase however in 2022 which may be due to the return to campus and the implementation of different modes of delivery and the HOL project.

Table 1

Students' Mean Declarative Knowledge Performance (%)

Year	Course	Pre assessment	Mid term	Finals
2019	Network	55.8	92.3	97.7
	DataCom (not tested)	-	-	-
	COA I (not tested)	-	-	-
	COA II (not tested)	-	-	-
2020	Network	5.6	58.4	83.9
	DataCom	-	60.99	71.59
	COA I	-	58.42	73.93
	COA II (not tested)	-	-	-

Table 1 to be continued

	Network	42.2	63.5	82.6
2021	DataCom	-	63.41	67.22
	COA I	-	82.98	71.69
	COA II	-	80.52	80.67
	Network	40.85	84.92	88.48
2022	DataCom	-	60.37	72.71
	COA I	-	69.36	75.93
	COA II	-	68.77	82.55
	Network	40.77	67.3	85.69
2023	DataCom (not tested)	-	-	-
	COA I (not tested)	-	-	-
	COA II	-	73.57	77.07

Declarative knowledge. Although there was a decrease in the overall retention for the course, students' declarative knowledge showed constant score increases for the three years of testing, as seen in Table 1, from midway with midterm (Mean = 60.99 [2020], 63.41 [2021], 60.37 [2022]) to the end with final examination (Mean = 71.59 [2020], 67.22 [2021], 72.71 [2022]). Like Network students were able to retain much of the theory and its applications, thus being able to answer questions more accurately by the end of the course.

Procedural knowledge. Examinations of students' performance were collected for Fall 2021 and Fall 2022 after the return to campus. For these two years there has been an increase in the A pass rate—29 [2021] to 33 [2022]. There was also an overall passing increase from 65% to 100% (Table 2) indicating that students were attained levels of competency.

Table 2

Students' Performance in PBL Project (%)

Year	Course	A+, A, A-	B+, B, B-	C+, C	Fail
	Network	-	100	-	-
2019	DataCom (not tested)	-	-	-	-
	COA I (not tested)	-	-	-	-
	COA II (not tested)	-	-	-	-
	Network	34	44	22	-
2020	DataCom (not tested)	-	-	-	-
	COA I	64	17	-	19
	COA II (not tested)	-	-	-	-
	Network	72	22	6	-
2021	DataCom	29	35	-	36
	COA I	47	25	17	25
	COA II	38	29	4	29
	Network	40	50	10	-
2022	DataCom	33	67	-	7
	COA I	86	7	-	-
	COA II	56	12	12	20
	Network	92	8	-	-
2023	DataCom (not tested)	-	-	-	-
	COA I (not tested)	-	-	-	-
	COA II	38	38	14	10

Computer organisation and architecture results. This is a year-long course offered over two semesters. Students who pass COA I in the Fall will take COA II in the Spring of the same academic year.

Overall retention. CAP-B was first implemented in Fall 2020 in COA I and there has been a constant increase in the pass rate over the years (69 [2020], 70 [2021], 86 [2022]). Examination of the 69% who passed COA I in Fall 2020 showed that 80% of them were able to pass COA II in Spring 2021. This trend continued the next academic year—Fall 2021 [70%] to Spring 2022 [96%]. Examination of the current year shows the same pattern with Fall 2022 [86%] cohort producing 86% passing in Spring 2023.

Declarative knowledge. Examination of the means for declarative knowledge (Table 1) shows that there was a decrease in the mean for the final examination in 2021. This may have been due to the fact the course was taught by two professors and CAP-B was not administered for the entire semester. The pass rate however increased in 2022. Examination of the same students' performance for COA II revealed however a constant increase from mid-term (80.52 [2021], 68.77 [2022], 77.57 [2023]) to final examination (80.67 [2021], 82.55 [2022], 77.07 [2023]). For this course each cohort was taught using CAP-B.

Procedural knowledge. For both COA I and COA II students participate in SBL project. For COA I, Table 2 shows a decrease students' performance in 2021. This may also be due to the fact that CAP-B was only taught for half of the semester and so the PBL project was also executed in a shorter time. Performance showed a marked increase in 2022 when the methodology was utilized for the entire semester. The effectiveness of CAP-B can be seen in the said students' performance in COA II. The number of failures decreased (29 [2021], 20 [2022], 10 [2023]).

Table 3

Students' Overall Performance in Four Courses (%)

Year	Course	Pass	Fail
	Network	100	-
2019	DataCom (not tested)	-	-
	COA I (not tested)	-	-
	COA II (not tested)	-	-
	Network	100	-
2020	DataCom	80	20
	COA I	69	31
	COA II (not tested)	-	-
	Network	100	-
2021	DataCom	71	29
	COA I	70	30
	COA II	80	20
	Network	100	-
2022	DataCom	83	17
	COA I	86	14
	COA II	96	4
	Network	92	8
2023	DataCom (not tested)	-	-
	COA I (not tested)	-	-
	COA II	86	14

Increase in HOTS competencies—Fixing shortage of graduates with Soft Skills. As employers continue to seek candidates with uniquely human, or "Soft" Skills to survive and thrive in their future careers, CAP-B seeks to produce students who have increased their competency in these. These skills include personal abilities that improve performance (such as problem-solving or critical thinking), the ability to facilitate personal and professional interactions (by being able to speak publicly, identify written and unwritten business rules and work culture), teamwork and leadership skills, work ethic, intercultural fluency, and digital literacy. CAP-B seeks to increase students' competencies both in their performance and interpersonal skills (HOTS) as well as their teamwork and leadership skills.

HOTS competencies including critical & creative thinking skills, and problem-solving abilities require students to be able to challenge present knowledge and draw conclusions to find solutions to difficult problems. This is what is required to complete a PBL project. In the evaluated courses students were required to (i) compare possible solutions, (ii) classify these solutions based on criteria, (iii) induce and deduce possible particulars for solutions, (v) analyze and fix generated errors, (vi) construct needed support, (vii) analyze different perspectives, (viii) do abstractions, (ix) make the decision on which solution to use, (x) investigate possible pathways, (xi) solve problems, (xii) test solutions, and (xiii) invent and create the chosen solution. All these actions are HOTS (Pasani & Suryaningsih, 2021).

Literature has shown that the use of PBL in teaching increases students' HOTS competencies (Billah, Khasanah, & Widoretno, 2019; Dogara, Bin Saud, Bin Kamin, & Bin Nordin, 2020; Musa, Mufti, Latiff, & Amin, 2012; Walters-Williams, 2022). Table 2 shows for each course yearly there are over 70% of the students having A/B passes in their project. Literature has also shown that there is a linear, positive, and strong relationship between HOTS and students' overall academic performance where students with high HOTS competency levels are expected to succeed in their academic program (Tanujaya, Mumu, & Margono, 2017). It can therefore be said that academic performance is an indicator for students HOTS competency levels. Examination of students' performance as seen in Table 1 for the tested courses shows an increase in the progression throughout the semester indicating increase in HOTS competency level as the course progressed.

Additional benefit—Increase in students' self-efficacy. Self-Efficacy (SE) can be defined as an individual's belief in his or her ability to succeed in a specific situation or accomplish a specific task (Yokoyama, 2019) and literature has repeatedly shown that a measure of students' academic performance reflects their SE levels and it is one of the most important factors in the students' academic success where high scores in SE are more likely to result in higher levels of academic performance (Doménech-Betoret, Abellán-Roselló, & Gómez-Artiga, 2017; Hayat, Shateri, Amini, & Shokrpour, 2020; Rowbotham & Schmitz, 2013; Yokoyama, 2019). The examination of students' academic performance should therefore reflect their SE, being there is a strong correlation between the two: the higher the academic performance, the stronger the SE. Examination of Table 1 shows the positive change in students' academic performance from the pre-assessment test in Network to the final examination for all courses. On average the mid-term for each course shows lower student performance than with the final examination. Examination of students' procedural knowledge performance (Table 2) also shows high performance. Based on the correlation, the conclusion can be made that students having completed the course with these scores have a seen an increase in their SE levels over the semester.

Conclusion

As the world becomes increasingly technological, the success of any country—its wealth and welfare—depends on the ideas, innovations, and skills of its population. These are all influenced by STEM education which will now determine whether a country can become a leader among nations and whether it can be able to solve immense challenges. With the present STEM paradox there is a need to reinvigorate STEM education and this is what CAP-B proposes to do.

Analysis of students' performance, for the examined courses, has revealed that CAP-B has increased students' content (declarative, procedural) knowledge as well as retention levels regardless of their prior knowledge background. With this methodology students were able not only to understand different concepts, but also to apply the learnt skills in different environments as well as solve problems arising from different scenarios and environments. This conclusion was again supported with qualitative analyses that showed there is a strong correlation between the amount of time spent doing simulations and hands-on practices and the increase in students' expertise level. Based on surveys, students perceive that this blend of simulation and hands-on helped them understand the concepts and acquire necessary skills. For these students the use of simulations helped them achieve tasks done in the hands-on exercises.

Based on analysis of five years of data and application in four courses, this study can conclude that using CAP-B has resulted in a significant increase in students' academic performance and by default an increase in students' SE and HOTS competencies. Data will continue to be collected for further analysis. Future research will be conducted to test the transferability of CAP-B to other STEM courses and STEM disciplines that can utilise both HOL and SBL.

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