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Interdisciplinary K-12 Control Education in Biomedical and Public Health Applications ⋆

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Abstract:
There is a lack of control education at the K-12 level, and introducing high school students to the wide range of control applications and methods needed for these problems will increase the number of students who later plan to pursue science, technology, engineering, and mathematics (STEM) education and control research or careers. Through our established partnerships with schools in California and Kansas, we have developed educational tools to positively influence the learning and career paths of young high school (HS) students from underserved districts and underrepresented minority (URM) groups. Through the development of new curricula, teaching modules, and shared resources that are made broadly available to other school districts, this work has the potential to impact a large number of K-12 teachers and students. We have been working to train HS teachers to create connections between the STEM subjects they teach students with advanced topics, such as artificial intelligence (AI), that are often taught only post-HS. It creates a context where students can see how their STEM skills can be applied and a pathway of continuing STEM education from secondary to post-secondary. As a result, there is the potential to improve student interest and self-efficacy in STEM and to encourage them to pursue STEM careers. Furthermore, AI is key to understanding and making use of data and solving many control problems. We aim to help students learn the fundamentals of how AI algorithms are applied in contemporary neuroscience.

Keywords: Control education, biomedical control systems, stochastic control, machine learning, artificial intelligence, databases, medical applications.

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1. INTRODUCTION

There is a great need to bring control education to K-12 students and teachers. There is a lack of control education at this level, and introducing younger students aged 5-18 to control and its applications, especially through hands-on workshops, will lead to more students pursuing studies and careers in control areas. The types of methods that we have used effectively for this purpose have led to the development of innovative and accessible science, technology, engineering, and mathematics (STEM) curricula using machine learning (ML) and artificial intelligence (AI) methods with biomedical and public health applications, including traumatic brain injury (TBI), epilepsy, and COVID-19. ML and AI methods can be useful tools for complex control problems, which is why we have focused on training students in these methods and explaining the broad range of potential applications. Teachers and students have partnered with university-level labs to have the opportunity to work with real data and engaging, novel tools that teachers incorporate in their classrooms to motivate students to study STEM.

2. OUTREACH BACKGROUND

We have established 28 years of a sustainable model of workshops for Kansas K-12 students and teachers at the University of Kansas (KU) after advocating for an outreach program at the Kansas Senate. One coauthor offered to teach probability and algebra to 17 students at Sunset Hill Elementary School in Lawrence, Kansas. That group of students were continuously taught after school from 3rd through 6th grade. The goal was to teach them problem solving using American, French, and Polish math textbooks and use innovative approaches to teaching math. These students then won the Kansas math competition in problem solving and became presenters at the KU workshops for 4th and 5th graders to teach math. The KU outreach program has been highly recognized by the Kansas community. Every year there is a proclamation of April as Mathematics and Statistics Awareness Month (MSAM) by the Governor of the state of Kansas and by the Mayor of the city of Lawrence. MSAM activities include a math competition for 3rd to 12th grade levels as well as workshops for 5th grade students and their teachers. This KU STEM workshop became a sustainable model for collective and collaborative efforts of faculty, undergraduate, and graduate students in sharing their passion and skills for STEM disciplines and control problems. This model has also been used in control technical professional organizations, such as the Conference on Decision and Control (CDC), the American Control Conference (ACC), and IFAC conferences.

3. ARTIFICIAL INTELLIGENCE EDUCATION IN K-12 SCHOOLS

The emergence of AI technology, and specifically ML, has greatly contributed to biomedical and public health applications. However, there is often a lack of understanding of the fundamental ideas behind these methods, which has resulted in widespread interest in AI and ML instructional units in schools at all levels Evangelista et al. (2018); Temitayo Sanusi (2021); Touretzky and Gardner-McCune (2021). There has been a recent push to incorporate AI and ML topics into the curriculum of undergraduate, graduate, and medical students and faculty, especially those who are not specializing in computational subjects Pucchio et al. (2021); James et al. (2021); Shapiro et al. (2018); Rajkomar et al. (2019); Brouillette (2019). While a majority of literature discusses teaching AI in higher education settings Marques et al. (2020); Wollowski et al. (2016), K-12 AI and ML programs are becoming increasingly popular to expose students to these complex topics as early as possible Vartiainen et al. (2020); Master et al. (2017). A pilot study in Romania demonstrated the successful development of an ML curriculum for students ages 13-19, and eventually a workshop for elementary-aged children, that students found motivating and achievable regardless of experience programming Mariescu-Istodor and Jormanainen (2019). In a survey of 98 high school students, an overwhelming majority had not previously heard of ML but still had a strong interest in learning more about the topic Evangelista et al. (2018). Even with a growing interest in learning ML, this is not currently reflected in high school (HS) programs. In the United States, only 45% of public high schools offer a computer science (CS) course Code.org (2019). In California and Kansas, where the coauthors teach, only 47% and 27% of public high schools offer a CS course, respectively cod (2021). These numbers continue to decrease in schools with a greater portion of diverse students. In 2019, it was reported that 42% of schools with a 0-25% minority population offer a CS course compared to schools with 75-100% minority population where only 27% offer a CS course cod (2021). Therefore, improving these statistics by correcting misinformation and providing a comprehensive education in these topics to younger generations of underrepresented students is of great importance.

Several recent studies discuss the value of introducing AI and ML to teachers and students alike. In a worldwide mapping of AI or ML instructional units in K-12 schools, Marques et al. Marques et al. (2020) systematically identified 30 programs with published information from 2009-2019. Of these 30 instructional units, 19 were from the year 2019 alone Marques et al. (2020), highlighting the recent movement to teach AI concepts in K-12 schools. The concepts covered vary from program to program; however, a strength of these instructional units was the utilization of active learning with a focus on real-world applications Marques et al. (2020). We have used similar methods to ensure a productive learning process for K-12 teachers and their students. Interestingly, most of these units were also not directly incorporated into the curriculum; instead, they were predominantly taught as extracurricular activities, workshops, or individual activities Marques et al. (2020). The same study specifically identified lack of training for instructors as an unmet need for the widespread adoption of ML education Marques et al. (2020). Computational methods are often not included in programs for K-12 teachers. For example, in 2016 only 75 teachers graduated from university with training in CS cod (2021). Compared to the 12,528 math and 11,917 science graduates equipped to teach students, it is evident

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that there is growing demand for AI-literate teachers cod (2021).

Exposure to AI at an early age promotes future STEM careers. The scientific impact of AI is becoming more prominent, with applications such as socially-assistive robots to enhance the social and educational development of children with autism Clabaugh et al. (2019), virtual reality for rehabilitation in elderly persons with disabilities Rizzo et al. (2011), or the use of ML to diagnose diseases from medical images Bennett et al. (2021); Garg et al. (2022); Liu et al. (2021). While we have focused on control applications primarily in biomedical and public health areas, AI and ML applications extend to other disciplines, so a general understanding of AI and ML can benefit all students and teachers, despite their professional interests.

Underrepresented minority (URM) population groups are traditionally marginalized in several technical fields such as data science, AI, and ML Dierker et al. (2017). This causes disparities in the professional development of these students and threatens their ability to access a technical education. Therefore, an accessible AI and ML education is especially important in URM populations. In the review of 30 instructional units, very few of them included women, ethnic minorities, or economically disadvantaged students Marques et al. (2020).

In this work, we aimed to utilize their backgrounds in mathematics, data science, and control to develop a comprehensive lecture and workshop series for K-12 students. Our lab at the University of Southern California (USC) has engaged K-12 students using real neuroimaging data and interactive tools her lab has developed (Fig. 1), such as the Virtual Brain Segmenter (VBS) (Fig. 2). Despite not having any expected background in these areas, students have participated in individual research projects on biomedical topics, such as COVID-19, TBI, or epilepsy and have made meaningful contributions such as published literature, conference papers, and poster presentations based on the methods and analytic tools they learn in these outreach programs. Further, other aspects of our research are closely related since a strong mathematical foundation is needed for the computing work on these biomedical applications. For instance, cross-disciplinary research on stochastic systems and control Pasik-Duncan (2004); Pasik-Duncan and Verleger (2009); Pasik-Duncan and Duncan (2016); Haas et al. (2003); Pasik-Duncan (2019) is needed to study the brain, one of the most complex stochastic systems Muldoon et al. (2016); Doya et al. (2007); Prados et al. (2006); McKenna et al. (1994); Deco et al. (2009); Wijesinghe et al. (2018); Rolls and Deco (2010). There is also a lack of control education and its applications in HS Karim et al. (2015); Klein (2003); Kolberg and Orlev (2001); Tillman (2013), which relates to the topics described above. A stochastic adaptive control approach based on learning about a system and using that information to find optimal adaptive strategies prepares students broadly for studying and doing research.

4. ADAPTING OUTREACH IN LIGHT OF THE COVID-19 PANDEMIC

The onset of the COVID-19 pandemic in March 2020 resulted in the immediate cessation of in-person learning

Fig. 1. The Virtual Brain Segmenter (VBS) being used to teach how to correct segmentation errors in neuroimaging data.

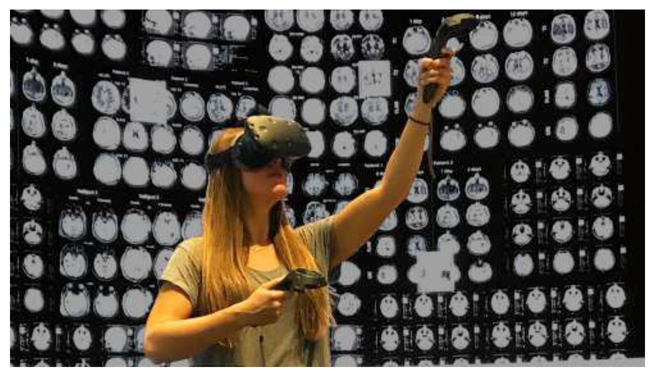

Fig. 2. VBS being used to visualize and select brain MRI.

throughout most of the United States. In the Los Angeles Unified School District (LAUSD), distance, remote, and various hybrid learning modalities were necessarily implemented over the following two years (and continues today) without advance planning or training. While the situation was not optimal and much "learning loss" has been detailed, a number of benefits emerged with the incorporation and mastery of remote learning technologies, increasing the capacity and impact of outside partner organizations to collaborate with instructional personnel to bring expertise, demonstrations, learning activities, curriculum, and materials to classrooms and students who might otherwise not have the opportunity or exposure to real-world professionals in their areas of study. Given the unprecedented situation, the authors developed a partnership program across USC, KU, and LAUSD that would harness digital technologies to expose K-12 students to mathematics, AI, ML, and control education for biomedical and public health applications.

5. IMPLEMENTING CONTROL CURRICULUM IN THE COVID-19 CLASSROOM

In light of the opportunities for expanded virtual outreach enabled by COVID-19, USC first established a partnership with Francisco Bravo Medical Magnet High School (Bravo HS) in LAUSD to establish program feasibility and test curriculum and workshop distribution in the classroom. Later, the methods were expanded to classrooms across LAUSD and Southern California high schools more broadly. The curriculum covered multimodal data analysis techniques, implementing control, ML and AI, and traditional statistical methods. The developed curriculum was designed to be flexible and data driven, allowing teachers to adapt the curriculum based on standardized objectives or student interest. The curriculum was divided into four broad curricular modules: 1) Basics in Computing, Control, and the Scientific Method, 2) Data Science and Statistical Foundations for the Health Sciences, 3) ML and AI for the Health Sciences, and 4) Effectively Communicate Data Findings to a Broad Audience. These modules were adapted from lessons at the undergraduate level to be suitable for K-12 settings.

Modules 1 and 2 were first implemented at the K-12 level for the Science, Technology and Research program and the Engineering for Health Academy (STAR/EHA) programs at Bravo HS. This included specific workshops to identify public datasets through various online databases, including the COVID-19 Data Archive (COVID-ARC)Duncan (2021), Kaggle, and GitHub; aggregating multi-site datasets into pooled cohorts; curating datasets to manage missing data and harmonize multimodal variables; identifying independent and dependent variables for hypothesis-driven analysis; and performing appropriate statistical tests based on variable types selected. These workshops were hosted via Zoom and included both PowerPoint-based lecture materials and an associated online interactive tutorial on Google Colab Notebooks to empower students to develop their programming skills and practice skills learned during the lecture portion.

After students had an initial basis in programming and developing analytic workflows related to public health data, Modules 3 and 4 were implemented through 4 follow-up workshops that specifically addressed student interests and concerns expressed through Modules 1 and 2. The four workshop focuses were: data visualization including graph and figure generation in R, implementation of neural networks for disease classification and prediction, complex algorithmic development, and preparing imaging data for quantifiable analysis.

The STEM workshops and tutorials were followed by a work-based learning experience, where students were provided with exposure to real workplaces through the Computer Science Career Week in December 2021, lined up with National Computer Science Education Week. A PhD student from the USC Stevens Neuroimaging and Informatics Institute, gave students a talk on education requirements for entry into college, graduate school, and STEM fields. Numerous potential pathways for students to continue control, AI and ML, and computer science education more generally were discussed. The interdisciplinary and intersectional nature of computational sciences was also discussed to emphasize that these research skills can be utilized across a vast array of careers in both academia and industry.

6. UTILIZING INTERDISCIPLINARY PEER MENTORSHIP

Workshops and tutorials were, whenever possible, facilitated by students at the undergraduate and graduate level to encourage interdisciplinary peer mentorship. This focus on peer mentorship rather than teaching by more senior research personnel, such as postdoctoral scholars or principal investigators, was implemented to foster greater connection relatability between the K-12 students and curriculum facilitators. In prior outreach experience, students have been more engaged and willing to ask questions of more junior researchers. Through the course of this program, one student who had formerly participated in a year-long research placement through STAR/EHA at Bravo Medical Magnet High School then went on to mentor students in the same program the following year as an undergraduate student.

7. ASSESSING INITIAL PROGRAM IMPACT

Based on student feedback, this curriculum was successful at exposing students to control, ML and AI, and mathematics education that they otherwise would not have been exposed to through their traditional K-12 coursework. After the lecture and workshop series, students demonstrated higher interest in learning programming and pursuing continued studies in STEM. This early exposure is especially important to inform students early in their schooling of information, knowledge, and skills they can then continue to engage with prior to college. We expect this will have downstream effects on undergraduate major selection and encourage further pursuits of graduate education in control. The implemented curriculum approach of integrating key components that combine preparation of rigorous academics with career technical education was effective in motivating students to study STEM and become involved in research at the high school level and beyond.

Peer mentorship also proved to be especially relatable and inspiring for the K-12 audiences. Through post-workshop surveys, quantitative and qualitative feedback were collected. From a series of three COVID-ARC webinars for LAUSD students, an overwhelming majority learned the varied applications of STEM and expressed interest in pursuing STEM or research in the future. Specifically, out of 263 students asked, "Has today's webinar made you think about how many different and varied occupations there are in the healthcare field?", 208 (79.09%) responded yes, 39 (14.83%) responded maybe, and only 16 (6.08%) responded no. Moreover, when the same group was asked "Based on today's webinar, would you possibly be interested in pursuing research in your future career?", 126 (47.91%) responded yes, 112 (42.59%) responded maybe, and 25 (9.5%) responded no. This highlights the positive impact of exposing high school students to interdisciplinary STEM research early in their careers.

These results are supported by student comments such as: "I hope to connect and work with all the like-minded, driven people involved in COVID-ARC! All the presentations were extremely inspiring and reminded me that the applications of AI are truly boundless"; "From today's webinar I am interested in pursuing...research. For instance, one panelist majored in Computer Science, which caught my attention how it can also contribute to research related to COVID-19"; many others noted interest in pursuing engineering or computer science to learn the computational skills required to perform robust health-related research.

The diverse nature of LAUSD also allowed for specific engagement with traditionally URM groups. The most current LAUSD demographic data reveals the following percentages for its 445,000 students: Female-70, Hispanic/Latino-42, White-34, Black/African American-10, Asian-9, Filipino-3.

8. EXPANDING TEACHING METHODOLOGY TO LARGER NETWORK OF SCHOOLS

Based on the success of initial pilot curriculum dissemination to Bravo HS, expansion to larger networks of schools was then implemented. Through Zoom's webinar configuration allowing up to 3,000 attendees to participate in live interactive presentations, additional students and classrooms with the help of the immediate partner institution (Bravo HS) were able to participate in the webinar workshop series presented by students from the USC Stevens Neuroimaging and Informatics Institute working on COVID-ARC, thus expanding the project's educational impact and reach. A number of Career Technical Education (CTE) Health Science and Medical Technology pathway classes at other LAUSD high schools and district CTE personnel along with additional students and classrooms from other Southern California school districts joined in the webinars, contributing questions and feedback via webinar chat and follow-up online surveys to help develop approach and content of successive webinars. The webinar series functioned in several capacities: providing an overview to students of COVID-ARC's scope of work (research, grant writing, peer-reviewed publishing process), communicating the societal and public health importance of academic and specifically data science research, expanding students' understanding of career possibilities in the healthcare field beyond traditional occupations (e.g., doctor or nurse), potentially inspiring students to consider options in areas such as public health, biomedical, or data science as viable careers, and contextualizing the overall work of COVID-ARC for students who participated in our targeted workshops.

We also disseminated content created for these workshops through national outreach programs associated with the Winter Conference on Brain Research (Aspen High School, February 2022).

9. FUTURE WORK

Future work proposed for Bravo HS faculty participants in conjunction with other teachers at Bravo HS and COVID-ARC team members to initially create a series of lessons, projects, and units based upon the research and work of the project to fit broadly into Health Science and Medical Technology (HSMT) and Data Science subject areas curriculum by learning how to apply ML and other analytic tools to the data and interpret the findings within the framework of Public and Community Health. This curriculum is shared and implemented in relevant courses (i.e., Health, Public Health, Patient Care, and Biotechnology-related classes) at Bravo HS and also at other LAUSD schools with related programs during the first year. The goal would be to implement the developed curriculum with students, refine its efficacy, and eventually create a one year course based on the COVID-ARC project to fulfill the need for a CTE Public and Community Health Pathway Capstone Course for LAUSD, a critically needed course that the district currently lacks. A Capstone is the final course in a CTE pathway sequence of two or more courses in the same industry sector. Students completing the pathway are equipped with technical and professional skills for career entry or for continued education in college after high school. Student CTE completion rates are tracked by districts and the state as part of the process of monitoring college and career preparedness. Creating a capstone course emphasizing the computing methods applied to public health would allow high schools throughout the district to offer the pathway, therefore potentially expanding the COVID-Arc project's reach to the approximately 140,000 LAUSD senior high school students, exposing and preparing great numbers of students for careers in computing and health fields. Additionally, the process of writing and submitting a new CTE course to LAUSD also entails submitting the course for University of California (UC)/California State University (CSU) A-G Course List approval and inclusion, signifying that the course is officially considered a college preparatory course. Once a course is accepted for inclusion in LAUSD, it is then submitted to UC/CSU for A-G college entrance requirements designation. The CTE Public and Community Health Pathway capstone course would be submitted for "G" designation as an Interdisciplinary "G" College Preparatory Elective. Once included in the UC/CSU A-G Course List, it would become available for inclusion in any of California's over 400 school districts offering the CTE Public and Community Health Pathway with high schools enrolling approximately 1.7 million students.

10. CONCLUSION

We have developed a variety of innovative educational tools to bring control education to the K-12 level with the aim to motivate students to pursue college and graduate studies in STEM fields and consider research in control theory. During the pandemic, we adapted many of our outreach programs using remote learning platforms and virtual reality to reach a larger number of students and keep them engaged in learning about control education related to biomedical and public health applications. Many of these methods have been successful, and we have seen an increase in interest in students wanting to pursue these research pathways and studies.

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