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Board 240: Computational Thinking in the Formation of Engineers: Year 3

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Dr. Mendoza is a faculty member of Technology Management in the College of Education-Engineering at Texas A&M University. She has worked as electrical engineering professor in Mexico. She recently obtained funds from NSF to investigate enculturation to engineering and computational thinking in engineering students. She is the co-advisor of the Society for Hispanic Professional Engineers and advisor of Latinos in Engineering and Science at TAMU and is interested in computing engineering education and Latinx engineering studies.

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Dr. Russ Meier teaches computer architecture at Milwaukee School of Engineering. He is also the Computer Engineering Program Director. His funded research explores how first year students develop computational thinking. He received the Iowa State University Teaching Excellence Award, the Iowa State University Warren B. Boast Award for Undergraduate Teaching Excellence, and the MSOE Oscar Werwath Distinguished Teacher Award.

He belongs to IEEE and its HKN, Computer and Education Societies, as well as the American Society for Engineering Education and its Electrical and Computer Engineering, Educational Research and Methods, and First Year Programs divisions. In these groups, he helps deliver engineering education conferences, webinars, and certificate programs. He leads teams accrediting engineering degrees as an Engineering Area Commissioner in ABET.

IEEE elevated him to Fellow for contributions to global online engineering education. And, the International Society for Engineering Education bestowed International Engineering Educator Honoris Causa for outstanding contributions in engineering education.

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to be updated soon

Computational Thinking in the Formation of Engineers: Year 3

Over the past three years we have been exploring not only how computational thinking impacts the first-year student experience but also persistence to graduation and enculturation to engineering. Students matriculate to engineering degrees with different academic preparation in mathematics and computing. We began our work by designing a computational thinking diagnostic that can be administered to students as they enter the engineering program in order to determine student's ability to use the principles and practices that are learned by studying computing. We can report that 3584 students were participants during the development of the Engineering Computational Thinking Diagnostic (ECTD) and the last 469 were involved in exploratory and confirmatory analysis.

Engineers use computing to design, analyze, and improve systems or processes. ABET cites computing as a foundational skill for engineering proficiency [1], [2]. The Taxonomy for the Field of Engineering Education Research also reflects the importance of computational thinking as a research area within engineering education [3], [4]. To many, computing equates to programming a computer using a high-level language. However, computing frameworks identify computational thinking as much deeper than just language proficiency. Students must apply critical thinking skills to ***abstract*** problems into manageable units, ***decompose*** the units into solvable problems, learn to use standard ***data representations*** to map and manage data, ***write algorithms*** that manipulate data to solve the problem, and ***evaluate the impact*** of engineered solutions on society [5]–[9]. Engineers often begin learning these skills in introductory engineering or programming classes. The structure of engineering curricula is not standardized but standards are maintained by periodic program accreditation linked to professional licensure.

A challenge for first-year engineers is unequal entry-level preparation. Educational privilege in K-12 STEM training systemically marginalizes students from many groups including first-generation, people of low socioeconomic status, certain racial and ethnic groups, women, and people with disabilities [10]–[21]. To support these populations, our team of researchers developed and validated the ECTD to identify at-risk students so that curriculum interventions or course-level interventions can be applied to enable student success, persistence, and enculturation as professional engineers.

We use both quantitative and qualitative methods to determine how computational thinking is impacting enculturation of first-year engineering students. We seek to understand the many factors impacting professional enculturation. During our investigations we have found that prior programming experience is a privilege that should be added to the long list of previously known privileges that benefit some engineering students, such as calculus-readiness, advanced placement courses, and computing-related extracurriculars like robotics [22].

First Major Result

Our first major result of the past year is validation of our quantitative instrument. Approximately 900 students across the three institutions completed ECTD testing at the start of the 2021-2022 academic year. Our consulting psychometrician used this data to complete confirmatory factor analysis on the ECTD [23]. This confirmatory factor analysis fully validated the ECTD as predictive of student performance in classes containing computational thinking and computer programming. Using the ECTD, instructors can identify at-risk students and plan interventions to help them succeed and enculturate as an engineer.

Second Major Result

Our second major result is the documentation of the impact of a wide variety of privileges on engineering student enculturation. In the past year, we performed semi-structured interviews at all three institutions. The semi-structured interview protocol consisted of prompts designed to encourage conversation about curricular and extracurricular pre-university background in programming, mathematics, and science. The prompts also addressed student motivations for engineering study, reasons behind confidence or lack of confidence in their choice of major, and how social identity was impacting their confidence. Participants were recruited from students that had previously agreed to complete the ECTD. A $25 gift card was offered to incentivize continued participation and as compensation for time. Trained interviewers conducted interviews via teleconference only after participants agreed to audio-only recording for transcription. We then transcribed the interviews, coded the interview transcripts, and performed a qualitative thematic analysis of the data. We found many forms of academic and socioeconomic privilege that ease student transitions into engineering, usually by hearing from students who lacked the privilege [24], [25]. Examples of academic privileges we found include the availability of AP courses in high school, prior computer programming experience through structured high school classes, and prior programming experience through extracurricular activities. Examples of socioeconomic privilege include the ability to afford to live on campus instead of commuting, not having childcare responsibilities for siblings, and being able to limit work hours to avoid interfering with academic goals. These results show a pattern of how integrating computer programming into introductory engineering classes can exacerbate existing inequities.

Additional analysis highlighted some institutional policies that may be exacerbating inequities in engineering. One institution has restricted access to many engineering majors primarily by GPA, resulting in greatly increased grade stress among students. This increased stress landed especially hard on the students who lacked academic and socio-economic privileges [25].

Third Major Result

A third major result from the past year is the unexpected racial/ethnic imbalances in participant demographics. White and Asian students self-selected to be participants in the study at much higher rates than members of other racial/ethnic groups, and far beyond their representation in the institutional demographics. This pattern was especially strong in the interviews, which are a bigger social risk although also a greater financial reward. Two of our three interviewers identify as white, although the students would not have been aware of this when they were scheduling interviews. In short, members of many systemically marginalized racial/ethnic groups were more reluctant to tell their story to researchers. We have not yet correlated reluctance to participate with lack of success in computational thinking courses.

Fourth Major Result

The fourth major result from the past year is that we have found that data collected from position-of-stress surveys do not show significant correlation to other indicators of success in computational thinking.

Fifth Major Result

The fifth major result from the past year occurred through added survey questions administered with the ECTD instrument. These questions asked students to reflect on artificial intelligence and its impact on their career prospects. Students found to be more confident through position-of-stress surveys administered later in the academic term were found to be more positive about their future in a world more influenced by artificial intelligence. The figures below show this result.

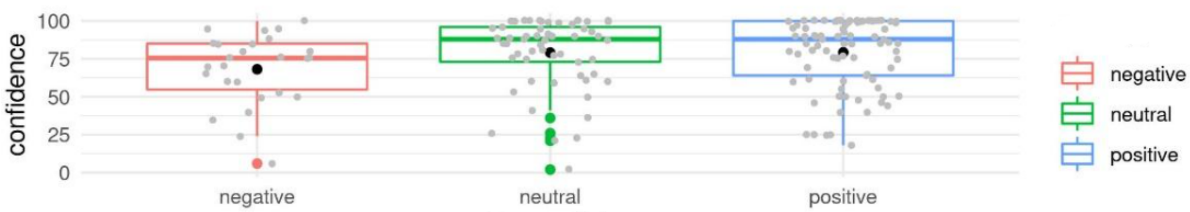

Figure 1. Boxplots for the confidence levels.

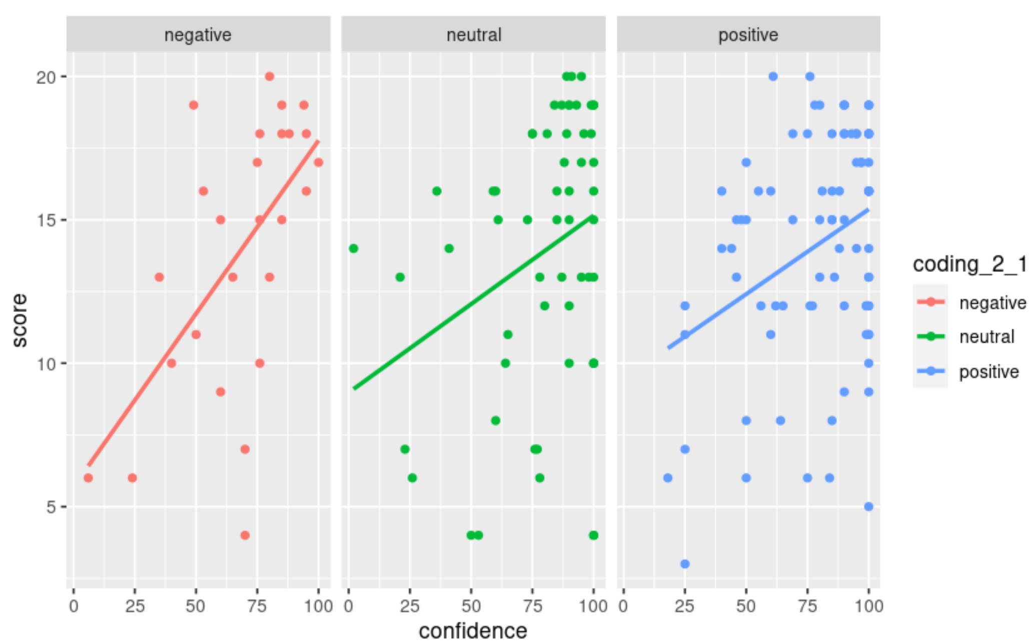

Figure 2. Three groups of confidence levels and their associated ECTD scores (Y axis) and confidence levels (X axis).

In short, students who lack confidence see themselves as being impacted and possibly even controlled by artificial intelligence. Students who are more confident see themselves controlling artificial intelligence and are therefore more positively inclined towards it.

Future Work and Broader Impact

Our challenges in recruiting students from systemically marginalized racial and ethnic groups lead us to examine other ways in which our participant sampling was not representative. We found, not unexpectedly, that students who appeared to be struggling in introductory engineering courses were not willing to be interviewed. This pattern mirrors that found in previous work where only four students who had left engineering were willing to be interviewed about the experience [14]. We will next reach out to students who did not pass the introductory courses where the ECTD was given and ask them for interviews about their experiences in introductory engineering courses. It is likely that a substantial financial incentive will have to be provided. Balancing the need for a financial incentive with the necessity of avoiding coercion of participants will have to be negotiated with our Institutional Review Board.

In year three, we accomplished a major goal of this NSF funded project by validating a diagnostic instrument that can be used to assess entry level computational thinking skills. Over the next year, we will begin disseminating this diagnostic through a publicly visible website (https://ectd.engr.tamu.edu/) and invite institutions to utilize it. We plan to maintain and update our diagnostic items according to national and international dissemination results, so this instrument becomes a long-lasting resource to engineering trainers.

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