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The Impact of Prior Programming Experience on Computational Thinking in
First-Year Engineering Experience.

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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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Introduction

Computational thinking is a critical skill set that must be developed by engineers and other computing professionals. Computational thinking allows people to apply computers and technology to systematically solve problems. The ABET student outcomes and the educational outcomes section of the Taxonomy of Engineering Education acknowledge the importance of this skill set for engineers [1] [2] [3]. Moreover, many introductory engineering courses have a component of programming or computational thinking. Earlier work has shown that computational thinking is important to successfully achieving an engineering identity [4].

First year engineering students matriculate with varying levels of computational thinking. Some arrive adequately prepared for engineering computation because of early academic access to computing courses but most arrive with only pre-university mathematics and science training [5]. In addition, inequities in course quality, self-confidence, and technology access disadvantage women, African American, and Latinx students [5].

Our multi-institutional team of researchers has been investigating how academic preparation and disparities affect computational thinking skills development, professional enculturation, and educational trajectories of first-year engineering students that are required to take introductory courses in engineering computation. With funding from the National Science Foundation, we are working to answer a broad set of research questions. In this paper, we specifically address this subset:

1. How does the integration of computational thinking into the foundational engineering courses affect the formation of engineers?
2. In what ways does prior experience with computer programming impact the engineering student experience with computational thinking and engineering enculturation?

We begin this paper with a review of relevant research literature. Following a discussion of the researcher's positionalities, the research methodology is discussed. Results and discussion are presented as well as comments on the limitations of the study. The final section discusses conclusions, recommendations, and future work.

Literature Review

Computational thinking is a complex set of skills including applied mathematics, data manipulation, logical decision making, and computer science to solve problems. It combines creativity with the systematic use of programming or scripting languages to assist design and analysis in many fields of study. Its importance for early childhood development has been explored for many decades and national frameworks exist to support the introduction of computational thinking into pre-university curricula [6] [7] [8] [9] [10]. These frameworks help pre-university students gain a general degree of computer literacy and computational thinking before entering professional career training at the university level. A lack of consistency among frameworks is evident as computational thinking is defined in the literature using different topic sets. We support the assertion made in the literature that computational thinking is much more than simple programming skill [11] [12] [13]. In our framework, engineering students mastering computational thinking have mature skills in computational abstraction, solution decomposition, algorithm development and implementation, data representation and analysis, and a respect for how computers impact society [14].

First-year engineering courses vary widely. Some institutions have common first-year experiences where all engineering students are introduced to computer programming and the basics of engineering computational thinking [15] [16] [17]. Other institutions use a direct-to-major admission strategy and vary in how much computing is introduced in the first year. Regardless of admission type, white males continue to receive most of the engineering degrees in the United States [18]. Factors including technology access, pre-university course access, classroom dynamics, societal stereotypes, social support, cultural relevancy, academic advising, and self-efficacy affect how women and underrepresented minorities prepare for and experience the first-year engineering classroom [5] [19] [20] [21] [22] [23] [24]. Computational thinking interacts with these existing factors.

The participants that we discuss in detail in the Results and Discussion section are Asian American, as our sample population was biased towards this group. Racial and ethnic groups can have unique processes for racial identity development [25]. The process of Asian American identity development is quite different than that for other racial/ethnic groups. Asian Americans typically go through five stages: ethnic awareness, white identification (either active or passive), awakening to social political consciousness, redirection to an Asian American consciousness, and incorporation [26]. We will focus on two stages. White identification begins with racial harassment (e.g., mockery) and leads to Asian Americans trying to fit into white society (passive white identification) or claiming a white identity (active white identification). Awakening to social political consciousness occurs when Asian Americans come to recognize that racism is white society's responsibility, not their fault. During this stage of identity development, white society moves from being the referent group to the anti-referent group and the realities of racism and oppression are exposed.

Research Team Positionality

As a multiracial Latina immigrant and based on her lived experiences in the United States, Dr. Mendoza Diaz identifies with the sector of the population that is marginalized based on gender, ethnicity, race, accent, and their intersection. She, however, recognizes her hidden privilege as the daughter of a physician and an architect (not a first generation in college student) which gives her a 'meritorious' viewpoint. This in turn provides her with a different perspective from those in the lower socio-economic status spectrum. Her interests, however, rely on all these identities.

Dr. Trytten is a white, cisgender female and came from a middle-class family with two generations of experience and attainment in higher education. She is appointed in both the School of Computer Science and Department of Women's and Gender Studies. She has engaged in research on the interplay between many social identities in engineering and computing education, however her lived experience as a woman who has spent decades in the computing field could direct her attention to gender related issues at the expense of other dimensions of social identity. She teaches introductory programming classes to an audience of computing and engineering students and therefore is well attuned to the challenges of first-year college students learning this material, although also at risk of projecting challenges her students face onto participants.

Dr. Meier grew up on a farm on a Native American reservation. He descends from Western European immigrants and nearby towns were mostly white European descendants. Native Sioux and Ponca Americans attended school, played sports, and socialized within the communities. He grew up appreciating Native American culture but saw inequities limiting education and career potential, and intersectionality resulting in cultural bias and discrimination. As a cisgender white male high school student, he was recognized in academic conversations, received college scholarships, pursued music, bought a home computer, and taught himself programming – setting the stage for a computer engineering career. His lived identity reveals hidden privilege that can conceal other people's opportunity loss. As a first-generation college student, he lacked parental advice about academics and work-life balance. Today, he focuses teaching and research activities on the first-year experience but recognizes he projects the white male viewpoint onto participants rather than a cohesive one inclusive of all genders, racial, and ethnic identities.

The team overcomes our inevitable biases by working collaboratively to discuss sensitive issues. We check and question each other's assumptions and interpretations. The differences between our backgrounds are a primary strength of this group.

Methodology

In phase one of our research, we developed an Engineering Computational Thinking Diagnostic (ECTD) that can be used to measure development of computational thinking factors such as the social impact of computing, computational abstraction, data representation, task decomposition, and algorithmic thinking. Pre-validation use of the instrument showed its ability to measure skills growth [27].

A second phase of our research progressed while the ECTD underwent formal validation attempts through multi-term large population sampling and factor analysis. In this second phase, we added a three-question instrument administered at the end of each ECTD administration. We called these moments "Position of Stress" because they represent times during the term where student career confidence may be changing. The ECTD and Position of Stress instruments were administered together to students taking a course that we will refer to as Intro, at a large public southwestern institution at the beginning of the Spring 2021 semester and after the midterm exam. The Intro course is followed by another course mentioned by some participants that we will refer to as Physics.

> **Intro:** This is an introductory engineering course that involves (1) the design and development of computer applications for engineers; (2) computation to enhance problem solving abilities; (3) basic concepts of software design through the implementation and debugging of student-written programs; (4) introduction to engineering majors, career

exploration, engineering practice within realistic constraints such as economic, environmental, ethical, health and safety, and sustainability.

Physics: This is the second course in the first-year engineering experience and has Intro as a pre-requisite. Many of the experiments involve rely on Python code to interact with sensors and actuators. Therefore, a solid foundation in the skills from Intro is necessary.

From the population of position-of-stress participants, a stratified sampling technique was used to choose interview candidates in three categories of decreasing, same, and increasing career confidence. Stratified subpopulations were identified by confidence level and race, confidence level and sex, confidence level and first-generation status, confidence level and identification as academically talented, as well as subpopulations that saw the most drastic changes in confidence.

Using our research questions to guide us, and to capture as many diverse perspectives as possible, the research team focused on different social identities. We originally selected 32 students of non-majority race and ethnic background (Hispanic, Black, and multi-racial) and conducted 13 interviews. The second cohort targeted 20 first-generation students and students not identified as gifted and resulted in ten interviews. The last and third cohort targeted 18 students with decreased confidence level between post- and pretests, providing only four students who agreed to be interviewed.

During Summer 2021, semi-structured interviews were conducted to gain qualitative insight into the computing background of participants, the entry path to engineering, how the participant felt about engineering while progressing through the course, the likelihood of enculturation as an engineer, and social identify factors that may be impacting success. Most of these interviews were conducted by a faculty researcher from a different institution who would be unknown to the participants. Two interviews were conducted by a faculty researcher at the same institution, but who is appointed in a different College and therefore likely to be unfamiliar to the students.

Interviews were initially transcribed by software and then manually edited to ensure correctness. We found this process saved substantial research time over manual transcription. Transcripts were coded using an iterative and inductive methodology from an initial codebook that was modified by multiple coders [28]. Coding was done by five researchers working collaboratively using NVivo. Interrater reliability was not calculated because a small group of codes that were straightforward to identify were used for this research and counts of code within categories are not given. The codebook served to direct researchers to the relevant parts of the interview.

The coded interviews were summarized and categorized by one researcher based on observed similarities that provided insight to the research questions. The categorization of participants into these groups was analyzed by a second researcher working independently.

Within each category, we examined the participant experiences and have presented a single participant's pathway in depth to represent an experience within that category. As students had widely disparate experiences there was no way to select one experience to be representative. Instead, we selected participants that represented the range of student experiences. These experiences therefore provide boundaries to the data set. They can be thought of as four case studies that span a range of participant experiences and provide insight into the hills and valleys that students experienced as computational thinking intersected with their formation as engineers. Category counts are not given because these counts might falsely imply a population distribution that cannot be determined from a sample of the size, especially given the challenges we experienced recruiting participants with decreased confidence in their ability to succeed in engineering. These difficulties will be discussed in the limitations section of this paper.

We use the following conventions in quoting participants. Square brackets are used to indicate that information was removed that might identify the participant. Words in square brackets were inserted by the researchers to indicate the type of information being removed, for example [sport] when a participant says "football". Ellipses (...) are used when part of a participant's response is removed because it is excessively wordy, reveals irrelevant personal information, or is not interesting in the context of the research questions. Parentheses are used when the research team was not sure that the transcription was correct. Interviewer questions, when given, are preceded by I:. When both the interviewer and the participant are quoted, the participant's response is preceded by a P:. Quotes without an I: or P: come from the participant. Verbal ticks (e.g., ah, um, yeah) and are removed to increase readability of quotes without changing meaning. Curly braces are used to specify the context for words that might be unclear without it. This context comes from parts of the interview that were not quoted.

Names that are used in the paper are fictitious and selected by a researcher from a table of 2025 Atlantic ocean tropical cyclone names [29]. Selected names are matched to gender with the gendered pronouns that the participants used in reference to themselves. These names should not be used to infer race/ethnicity.

Results and Discussion

The racial/ethnic breakdown of the pool of students who had completed the ECTD and the Position of Stress survey is given in Table 1, below. The racial/ethnic categorization used follows U.S. government practice with its many known shortcomings. This group contains more Asian students than would be expected, given the demographics of the institution’s College of Engineering (13% Asian) [30].

The self-described racial/ethnic identity of interview participants is given in Table 2. Three of the Asian students were international students. This distribution is weighted more toward Asian students than the college demographics and the pool of interview participants. It is unclear why Asian students were more willing to complete the survey and participate in interviews than students of other races/ethnicities. This imbalance is a known limitation of the research, which will be discussed in detail later. Table 3 shows interview participant’s self-described sex. Participants were offered wider options for sex, including the option of selecting their own term.

Table 1: The self-described racial/ethnic identification of the pool of potential interview participants.

Racial/Ethnic Group	Count
Asian	27
Black or African American	4
Hispanic	21
Multi-Racial	11
White	71

Table 2: The self-described racial/ethnic identification of interview participants.

Racial/Ethnic Group	Count
Hispanic	2
Asian	8
White	4

Table 3: The self-described sex of interview participants.

Sex	Count
Female	5
Male	9

Participants came from a wide variety of majors: computer science, computer engineering, industrial distribution, engineering technology, mechanical engineering, electrical engineering, aerospace engineering, civil engineering, chemical engineering, and biomedical engineering. Some students changed majors between the position of stress survey and the interview. Other students indicated that there were several majors they were still considering.

While our research questions focus on computational thinking, this term is likely to be unfamiliar and hence confusing to participants. As a result, the interviewer used the term "programming" as one that was more accessible to participants.

In the next subsection we will discuss participants who increased their confidence in succeeding in engineering during Intro. In the following subsection, will discuss participants whose confidence in succeeding in engineering decreased during Intro. In each subsection we will analyze the experiences of two students in depth: one with prior programming success and another without. All four of the participants whose experiences are discussed in detail are Asian, although their ethnicities vary and are not given to help conceal student identities.

Increased Confidence With and Without Prior Programming Success

Many participants reported that their confidence about pursuing engineering increased during Intro. Of these participants, many had significant experience programming computers in high school or before.

Barry started programming in grade school. He took programming classes the first two years of high school, including taking the Advanced Placement Computer Science A course (AP CSA). This course provides a full year of experience programming computers in Java and equates to a single introductory Java course at many colleges. There were other participants that have more programming experience than Barry, and more recent experience. Barry has engineers in his family, including his father and a brother. He was encouraged to start programming early by a female family member who was a software engineer.

He began his college career by doing poorly on a chemistry examination, which shook his confidence. However, he improved his studying techniques and understanding of the material and ultimately had a 4.0 GPA at the end of his first semester. When asked how having prior programming experience contributed to his increase in confidence, he responded:

> *P: It wasn't too hard for me because it is stuff I have done before. So, I guess at first, I just thought it was hard and as it goes on it was like, I've done this before in high school and just other personal projects I have done...*
>
> *I: ...How about the other courses that you took at [University]? … Do you think those helped your confidence or hurt it?*
>
> *P: Actually, in the spring semester, I took [a second computer science course]. The class was just a C++ programming class and there was a lot of problems in there that I have never done before. It was really fun to work on those problems. One of them was a string calculator. I think it might be a common problem that y'all give but C++ doesn't have the memory to take integer, so you would make a calculator using string to be able to do large calculations like multiplication, subtraction, and addition. I didn't do division, I don't know why I didn't do division, maybe because it was too hard. It might have been a bonus problem. It was really fun figuring out how to approach the problem and getting to solve it was a lot of fun. I think that increased my confidence. Programming in general is like "oh I can figure out this problem."*

There were many participants interviewed that had a substantial programming background. These students generally saw Intro as an easy course, and many suggested or acknowledged that the course would be harder for students without programming experience.

Some students who did not have prior programming experience still gained confidence in Intro.

Andrea had never programmed before college, although she had engineers in her family and her father was a software engineer. Her Dad had tried to teach her to programming but was not successful.

> *P: He {my father} did {try to teach me programming}, but what he was doing was just so in depth and required so much prior knowledge to me, I was just like, okay, I don't really follow, but okay … But I had no prior experience and honestly intimidated me beforehand….*
>
> *I: So, when you found out the programming was going to be part of your Intro to Engineering class. How did that make you feel?*
>
> *P: I was very nervous because I felt that I needed some sort of experience beforehand. And I was just really worried that I wasn't going to perform well in the class because they had no idea what I was doing. So, and I had wished that I had picked some sort of coding*

camp or something like that in high school that could have prepared me better. But looking back, it wasn't entirely necessary. But I do wish I had a little bit more experience walking in.

When Andrea started Intro, she found programming challenging.

> *It {computer programming} was definitely a curve ball at first because I definitely thought it was very challenging. I do believe that my professor adequately explained what she could. And then the students I worked with in my group in that class, really helped me to understand it as well and also just a lot of online research of my own on different forms and things like that really helped me to understand, gain the understanding that I currently have.*

Her class did group projects, and she was placed into a supportive group of knowledgeable peers where mutual respect was developed. She believed that groups were selected randomly.

> *I: What was your group like?*
>
> *P: It was me, and three other guys and I believe two out of the three guys had had prior experience with computing and coding and things like that. And so, they were very knowledgeable, and they were also very understanding and willing to help me as I was asking all these sorts of questions. But were also very helpful and just kind of making it very clear what it was we were supposed to be doing.*
>
> *I: Did you ever feel intimidated?*
>
> *P: I did feel intimidated at first being the only girl. But overall, I think I found my place in the group. I usually did a lot of the going back and editing and following up on catching any mistake that they had made in the code and things like that. And that seemed to work for our group dynamic and overall, I think the way we learned how to have a mutual respect for one another.*

Andrea recognizes that the members of her group who had prior programming experience had an advantage.

> *I: Do you think the members of your group who had prior programming experience had an advantage?*
>
> *P: I do believe that they did. I think they were a little bit more knowledgeable on the things that we were required to do. And so, some topics, they had that foundation of prior knowledge, which help them to better understand and faster dive into the project that we were supposed to do.*

But, at the end of the semester she is ultimately confident in her decision to remain in engineering.

> *I: ...How has your confidence in your ability to be an engineer changed over the semester?*

P: I definitely struggled with the thought of me being an engineer both my fall semester and my spring semester because I really felt like I wasn't competent enough to be an engineer and that I wasn't going to understand the things that were going to be taught. And I just didn't want to waste my college education if I didn't think that I was going to make it. But I think my confidence in being an engineer just came from the fact that I know that I'm going to [this university] which has an excellent engineering program and that I have the resources available to me to help me succeed and do my best and to understand the way they seem difficult. ... But I made up my mind and I'm going to stick with engineering. And just because it's a motivation knowing that this degree has many possibilities to provide me with a good career in the future. And I know that this is something that can be applied in so many diverse ways and it's a very much needed career right now. And so, I think with all those things and knowing that I can apply my passion, creativity into the engineering field, it gives me a hope and a motivation that I can continue moving forward with it, despite my previous doubts.

Andrea's placement in a group of male peers that were both experienced in programming and welcoming to a woman was fortunate. Isolated females are not always respected in male majority groups [31]. In addition, the presence of respectful group members with programming experience made the process of completing challenging projects easier. As a result, Andrea's initially shaky confidence grew.

Decreased Confidence, With and Without Programming Success

Some students experienced decreases in confidence during Intro despite having significant experience and success in programming previously.

Dexter was initially interested in becoming a chemical engineering major, although he switched to another engineering major during his first year because of difficulty in his chemistry courses (his new major was withheld to protect confidentiality). Dexter attended a well-resourced high school with lots of opportunities.

I went to [a prestigious high school], which is a very good. I think it's probably the second or third best high school in the [urban location]. A lot of students, tons of AP classes, lots of help from teachers, faculty, stuff like that.

Dexter took three years of programming in high school, including two Advanced Placement classes (AP CS A and AP CS Principles). He described himself as average in programming. He, like several other participants, recognized that the pandemic had disrupted his learning. He also repeatedly recognized that his privileged background made it possible for him to attain success during the learning challenges of the pandemic.

... {In the Intro class} a lot of people would be struggling. I was okay. I would finish everything on time, do okay. But I do know a lot of people struggled because they hadn't taken {programming} classes prior. So, I do think the online aspect that we had to take on last year impacted a lot of students because they would listen to a lecture, but they

wouldn't really understand anything, myself included. If I hadn't taken those classes in high school, I probably would not have understood what to do and the courses last year.

Dexter later reinforced that his high school background had helped him learn enough to succeed during the pandemic in science and mathematics courses too.

I: I noticed from the survey responses that as the [Intro] class went along, that your confidence had been dropping, your confidence in being an engineer. Do you know why that happened?

P: ... I feel like since all the classes are online, all the classes I at least took. Yes, the teachers, they would see responses from students needing help, but they couldn't really do anything more. They could stay an extra five or 10 minutes on the online zoom. But I'm going to be honest that I don't think that would really help any students.

So, then a lot of people relied on their friends to teach them. But even then, learning from a friend can be quite difficult. So, um, I just I struggled by. I did okay, because, you know, I tried my hardest. But I feel like students who didn't have any prior knowledge would crumble a lot faster than I did.

Like many of the participants, Dexter thinks he doesn't see color or gender [32]. He neither experiences nor thinks he expresses racism or sexism. He then, with some hesitation, puts forth the disproven and sexist notion that women aren't interested in engineering to the female engineering professor conducting the interview. [33]

I: Ok, how about your race and ethnicity? Does that play any role in this?

P: ...I basically lived my entire life in [a state with a relatively small Asian population]. Yeah. And I mean, I don't I never consider my race to be a factor in anything. You know, I feel like I'm treated the same. I treat everyone else the same. I haven't seen any issues in that regard, that aspect. I do know it's out there, but I haven't experienced it myself.

I: I would think in the last year you might have seen some things. {At the time this interview was being done, rumors that the COVID virus had escaped from a Chinese laboratory were circulating online, and several Asian people in the US had been attacked.}

P: Yeah, not in person, but you see it online. You know...

I: ...What about your gender?... Do you think that had any influence?

P: Um, I do know that there's a lot more men in engineering and I don't think that's {pause} like a sexist type of issue. I think that just {pause} women don't necessarily gravitate towards engineering as much.

I feel like whenever I talk to girls and I ask them what they're going into college for, it's more med stuff, more business oriented. And even if they go to [this university], they'll probably go to like a med type thing or a business thing. Whenever there's other schools *out there that are more specified for those types of degrees. But they still chose [this institution]. So, I was a little confused about that.*

Dexter lost some confidence in his ability to be successful in engineering because of science courses and the pivot of classes to virtual learning caused by a pandemic, not because Intro had programming as a learning outcome. This interview serves as another reminder that just because the challenges of programming can be overcome, the other challenges to becoming enculturated into engineering have not disappeared.

Chartal is a student who lost confidence during Intro, although her confidence was later improved by some second semester successes and being accepted into the computer science major at this institution on the morning of the interview. Unlike many other participants, who expressed a lack of color and gender recognition, Chartal is more racially and ethnically aware. Our protocols were not specific to Asian American students, and hence we did not ask the kinds of questions that would make it possible to definitively state participant's levels of Asian American identity development. However, Chartal's responses would be typical of someone who is awakening to social political consciousness. From the information in the interviews, Barry, Andrea, and Dexter appear to be in the White Identification phase of Asian American identity development. As a result, Chartal sees dynamics that the other participants whose experiences we have analyzed in detail did not.

Chartal was forced to major in STEM, and selected computer science because of an intense dislike for other engineering fields.

I: …You said there was some pressure from them {your parents} for you to stay in STEM?

P: Yeah. There was no other option. To them {my parents}, any degree that is not within STEM is kind of obsolete.

I: Did they sort of imply that they wouldn't help fund your education?

P: 100%, Yeah. You can choose to do that, we are just not going to help you. I was like well I guess I don't have a choice.

Her high school experiences in computer science were not successful. She took the AP CSA course as a high school freshman, instead of the more welcoming AP CS Principles course that was available at her high school. She did not take any other computer science in high school.

P: … Freshman year {of high school} I took a comp sci {computer science} class {AP CSA} and I actually failed it and dropped it with a [D]. …

I: You had a lot of opportunities to experience computer science in high school?

P: I just felt so discouraged after the first time that I was like, I am not meant for this, I'm never going to do it again.

Chartal's family was skeptical of her opportunities for success in computer science, given her high school failure.

It was kind of funny when I decided senior year to shoot to major in comp sci because my parents were like "Are you sure you are going to be able to do that"? Going into [Intro] I was super nervous because I didn't have a robust background in programming like a lot of other engineering students do.

Chartal's anxieties about her programming background were exacerbated by having peers with programming knowledge.

I: We noticed from your survey responses that as [Intro] went on your confidence dropped a little bit, your confidence in being able to continue engineering. Can you explain how that happened and how you feel now about that?

P: A big part of it was I felt like everyone else knew what they were doing. My group members would meet up to talk and would be like "have you done this iteration and what is on this one?" I'm sitting there like I have no idea what anybody is talking about. I have no idea what is going on….

...After the first couple of weeks and the labs started getting harder, I think it was lab three or four I was so confused. I don't know what is going on. I don't understand any of this. I don't know what an iteration is. I decided to reach out to one of my friends and I was like please help me. Teach me how to code. They would sit with me every day for an hour after classes and explain stuff to me over and over until I finally got it.

Chartal's Intro instructor exacerbated her insecurities about programming by using inequitable classroom practices.

I: …You said that everybody in your class had already programmed before. Why did you think that?

P: Because in class, our teacher would go super-fast and would say "Hey, does anyone need us to slow down?" And all the guys in the back would go "No! This is so easy." We were learning Python and I guess a lot of people think Python is super introductory. So, in my mind I was already behind…Everyone seemed like they knew what was going on and I had one girl in my group who was completely honest about it, she was "Like man, I have no idea what is going on, I am so confused."

Asking students about class pacing in a public way allows students with confidence to get their wants and needs met at the expense of students with less background, who fear being exposed as academically unprepared. It is possible that these male students were also participating in grandstanding, where students openly display their superior knowledge to impress the professor and intimidate other students. Chartal's education was diminished by this, not only because it increased the pace of a class that was already challenging for her, but because the comparison to her peers eroded her confidence.

One of Chartal's peers took it upon himself to offer demoralizing unsolicited academic advice, further diminishing her confidence.

P: …There was a guy helping me study for [Intro]. He was like "I know you will need my help because you have never done coding before." I was like "Yes, I will. Thanks for helping me." He stopped me once when we were studying probably mid semester and said, "If you can't do this now, you shouldn't be majoring in comp sci. Genuinely I'm trying to be nice and trying to help you, I just don't think you will be able to do it."... He was an experienced coder too; he had been working in coding since he was a freshman in high school. I was so bummed out. When I said my confidence dropped, I think a big part of it was because of that. I dress a certain way and I definitely have got some comments from other male engineers because I go to in person classes where they are like "You don't look like an engineer; you don't look like a comp sci major."

Chartal links these experiences both to her gender and being a person of color. Linkages of this sort to race can be hard for some to accept, especially those who are members of the dominant social categories in many dimensions (i.e., cisgendered, male, white, middle class or above, Christian, without disability, etc.). People of color are the experts on racism, thanks to daily experiences with racism [32]. The assessments of people of color of what is and is not racist must be accepted. The use of "us" (for the class), "they" (for the White students), and "I had" (in reference to the other person of color in the class) speaks volumes about her feelings of exclusion.

{Due to a unique and identifiable academic situation} The same 20 people were in all my classes. There were 30 of us, actually, but they were all white. I don't think there was another Asian person. I had one [different racial group] student and he was my friend. It was kind of hard, I feel out of place at [this university] all the time.

Chartal's experiences are intersecting with the model minority stereotype [34].

Part of me feels like I need to meet this stereotype where Asians are supposed to be smart and [people of her ethnicity] are supposed to know what computer science is like. They are supposed to be good at [a skill related to computing] and all of this stuff. Part of me doesn't just want to be a stereotype and another part of me is also really afraid that I won't be seen as a real Asian if I am not fitting the stereotype.

In parallel, Chartel was having a difficult experience with a mathematics instructor she felt was being unreasonable.

I: How about the other courses you were taking other than [Intro] like your math and science courses? How did they contribute to your confidence?

P: First semester math destroyed me. My math teacher, even though I had already taken Calc 1, I already understood everything in that class, he really graded aggressively to the point where he was taking off points for the way that I drew arrows. I was super depressed because I absolutely tanked that class. The semester after I had a different teacher, and I was taking a much harder calculus class, but I still did better than that class because of the way she was teaching and instructing. Even though I had already taken Calc 1 in high school and done very well in it.

This institution not only has integrated programming into Intro, they have also integrated it into Physics. This integration allows Chartal's experience with programming to be repeated the next semester when the physics professor assumed that all students automatically knew statistics, even though it wasn't a published prerequisite in her view.

> *I: Is there anything else you want to tell me about this experience?*
>
> *P: The only thing is, I wish we did a secondary class to [Intro]. Directly after we did [Intro], we did [Physics]... I took physics at the community college and then they tell us we have {to take} this lab statistics coding class {called Physics in this work}. That class was awful for me. I was so lost. My confidence went out the window. I don't know what is going on. Just for reference, I got a [High A] in my physics class and I scored a [mid range F] on my [Physics] final. That definitely hurt to get a [High A] on your physics final and then here is this physics final that I got a [mid range F] on because I don't understand statistics at all. I never took statistics in high school; I never got the chance too, if even.*

Chartal had not taken the expected mathematics courses because she had chosen high school electives that had more people of color in them.

Chartal was academically rescued during the semester after Intro by joining an ethnic student association. This reinforces the need for organizations that support minoritized students on college campuses.

> *I really struggled just being there first semester. Even second semester too. I was like, I hate this school, there is nobody here who is like me, especially with COVID it was so hard to meet people. Then I joined [an ethnic student association] like halfway through the semester... They were so welcoming and so comforting about computer science and they were always helping me with assignments and showing me stuff. After that I had a much stronger community. It was very nice to have other Asian people who I can relate to with my family stuff, who were also doing the same stuff that I was and going through the same stuff that I was. It was a nice feeling that I wasn't super alone.*

Despite these experiences with gender and racial discrimination, Chartal remains committed to majoring in computer science. It is important to remember, however, that her back is against the wall due to her family's willingness to fund her education being predicated on a STEM major.

> *I: ...In the face of all this, why are you deciding to stay?*
>
> *P: I have always been so stubborn and I am in comp-sci because I want to prove to my parents that I can still do art and coding and still be successful in life and to the same point I can definitely excel in a field that I am quote un-quote not supposed to excel in, or not meant to be in, or don't look like I am supposed to be in. To that point I would rather die than let a man tell me what I can and can't do. … I think a lot of female engineers feel the same way. You can either choose to submit and let them talk to you like that or you can prove them otherwise.*
>
> *I: It is still a lot to carry on your shoulders.*

P: For sure, it is definitely there, I think in my weak moments when I struggle, it's like wow I feel like every girl that is in comp-sci, I'm feeling every mixed person in comp-sci, it feels like it is your community, so you need to work for them. I think that might be an individual POC {person of color} thing, I don't know if white people feel the same where they have a community to prove their worth to in the same way.

Chartal's comments point to the potential for stereotype threat [35]. Stereotype threat occurs when task performance is diminished as the result of intense pressure to disprove stereotypes about a social identity group that you identify with. Even though Chartel is aware of the model minority stereotype for Asians, she identifies as a person of color too. Thus, her gender and racial identity marginalize her in engineering.

From the four student interviews, we can see that programming helps to increase student confidence for some engineering students and diminishes it for others. We see the extremes in comparing Chartal's experience to Andrea's. Both are women who had little or no prior programming experience. Andrea found a supportive group of male peers to boost her confidence. Chartal encountered peers who wouldn't or couldn't help her learn to program, a professor that allowed grandstanding by other students to go unchecked in the classroom, and privileged peers who told her that she wasn't good enough to be one of them.

Limitations of the Study

The study was mainly limited by the fact that during the 2020-2021, the COVID-19 pandemic was affecting participants and students, disrupting their activities and lives. Participation was low and groups that have traditionally being underrepresented remain underrepresented in our sample. The Asian population, overrepresented in engineering, was even more overrepresented in our sample. Another aspect the research team noticed was the self-selection aspect of the ECTD and position of stress, that is, by virtue of the voluntary participation in the study (as required by the IRB), students who might have bad experiences and who might have left engineering did not provide their insights. The time between the post-test and the time interviews were conducted exacerbated this issue.

Conclusions

Programming is an important skill for an engineer to develop. However, programming assignments in Intro can add to the already excessive list of challenges that engineering students face early in their college careers during their formation as engineers. Potential engineers get the message clearly that you need to excel in mathematics and science to consider engineering. Adding programming to the list does little to make engineering more accessible to people from minoritized groups, especially since programming is more accessible to students from privileged backgrounds and remains male dominated [5]. It should be remembered that computer science, the field that computational thinking represents, has one of the lowest levels of inclusion of minoritized people of any academic discipline. It also is the rare discipline that has periodically substantially decreased in diversity over time. The detailed analysis of the student interviews shows that integrating computer programming into Intro and Physics has not removed many of the traditional challenges that discourage beginning engineering students and has added new challenges.

Many participants acknowledged that knowing programming was an advantage in Intro and Physics, whether they had studied programming or not. By using programming in Intro and Physics, the institution rewarded students who came from high school backgrounds where computer programming was available and chosen by the students. Hence programming experience became another privilege. Like most privileges, it is hidden from most of those who have it.

Recommendations and Future Work

The computer science community has made considerable effort, although with noticeably limited long-term success, in making beginning programming more equitable. Engineering can follow their lead. One attempt at making computer science more equitable was implemented at the University of Oklahoma, following the inspiration of Jim Cohoon at the University of Virginia [36]. The introductory programming classes for computer science majors are broken into three sections: a four-credit class for students with little or no programming experience (with a two-hour laboratory weekly), a three-credit class for students with some programming experience, and a one credit class for students who are fluent programmers but need to learn Java. Students who are proficient in Java are directed to a prior knowledge examination to earn credit. These three classes have the same outcomes and prepare students to enter a single second programming class. Placing students in these classes is done from a short survey about prior programming experience. The logistics are complicated, especially at the start of the semester. This effort can be thought of as similar to how mathematics departments test students to place them in classes with students with similar knowledge.

If the overhead on separate sections is too great, Chartel's experience tells us that the culture of the existing sections needs to be made more equitable. This would be true whether the class features programming or not. Instructors need to pay careful attention to the classroom climate. Grandstanding can be interrupted. The rate at which material is presented can be governed by the needs of the average (or even below average) student, not the most privileged and vocal

If group work is desired, the composition of the groups and structure of the assignments becomes important. For groups with three or more students, the group could be intentionally structured to be diverse in their academic background. Tools such as CATME can be used to accomplish this task [37]. For example, in a three-person team one student with no programming success, another with some programming experience, and a third with substantial programming experience could be a good combination. Clustering people from minoritized groups together can also be done, although the practice is not without controversy. Another possibility is to use strategies like pair programming, borrowed from extreme programming, where a pair of students of similar background work together [38] [39]. Pair programming has been shown to increase success in minoritized students in introductory programming classes.

This work provided detailed analyses of four Asian students and could be transferable to other large, public institutions with computational thinking integrated into their introductory engineering classes, especially to Asian American students.

The work of understanding the impact of integrating computational thinking into introductory engineering classes on the enculturation of engineers is not finished. This work highlighted the experiences of Asian American students but given the small number of participants whose interviews were analyzed it should be viewed as providing the initial outline and data to support further investigations. Other minoritized groups need to be studied, such as other racial/ethnic groups, people with disabilities, and sexual orientation and gender identity minorities. Some of these investigations would need to be qualitative in nature, given the likelihood of a small participant population. Other investigations could use more quantitative methods to reach larger populations and attempt to generalize our conclusions.

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