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# Students' changing perceptions of programming skills in Materials Science and Engineering

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## Introduction

Programming skills are vital for workers involved in materials science and engineering (MSE). Advanced materials design requires computational materials science and engineering (CMSE) because simulation tools can be utilized to investigate phase changes, materials properties, and microstructural evolution [1]. An initial 2009 survey identified an increased need for computer modeling in MSE and noted that employers highly sought CMSE skills [2]. Over the following decade, academia pushed to integrate more CMSE into the undergraduate curriculum. A follow-up study published in 2018 found that 84% of MSE departments offered at least one CMSE course for undergraduate students, although the specific topics differed by institutions [3]. Furthermore, all surveyed faculty and department chairs agreed that CMSE should be included in the core MSE curriculum.

Although faculty and senior industry representatives agree on the importance of CMSE, this does not necessarily translate to undergraduate students' enthusiasm about the topic. Prior work compared students' motivations toward programming and homework assignments [4] using expectancy-value theory [5]. Surprisingly, the results in Ref. [4] were inconsistent across the two published survey cohorts. One cohort surveyed at the end of an academic term had a lower task value on programming assignments than homework, whereas there was no statistically significant difference of a second cohort surveyed at the beginning of the quarter. It was hypothesized that students' fluctuating perceptions might be attributed to the challenges of mastering a new topic, similar to observations by Galloway and Bretz [6]. Alternatively, Ref. [4] suggested that changing attitudes may also have been affected by the growing interest in the computer science industry. This work highlighted the need for longitudinal studies of students' perceptions of CMSE and programming.

Unfortunately, new investigations of CMSE motivation are confounded by the COVID-19 pandemic. Over the past two years since the pandemic began, many have recognized its long-lasting effects and its universal impacts on everyday life. During the first year of the pandemic, studies already noted the psychological effects on students, including worsening depression and anxiety [7] and more severe impacts among women and students of low socioeconomic status [8]. The pandemic also limited the engineering curriculum for many students. Often the curriculum was adjusted to align with the COVID-19 pandemic or to emphasize computation, programming, and simulations rather than in-person labs [9]. For instance, a survey of MSE faculty found that some instructors adapted lab sessions by utilizing digital simulations and at-home experiments [10]. Educational curriculum and job roles shifted rapidly during the pandemic, so this paper must consider these factors.

## Study Overview

This study explored the evolving perceptions of materials science and engineering students towards computer simulations and programming skills as they completed their degrees and began

their post-graduate careers. Specifically, we sought to answer the following research questions (RQs):

(1) Do students' perceptions of computer programming change over time, particularly as they leave the university and begin their careers?
(2) What was the effect of the pandemic on students' perceptions of programming and computer simulations?

RQ (1) builds on prior work [4], which found students had mixed perceptions about the value of programming skills, as described in the introduction. RQ (2) reflects the reality of the state of affairs: the study was conducted during the COVID-19 pandemic, which would inescapably affect these perceptions.

This study surveyed MSE students at the University of California, Davis (UC Davis). These students utilized computational tools in several required classes, including a lower-division mathematics lab and a required computational methods course. In students' third year, upper-division MSE courses integrated these tools, such as MATLAB and other simulation tools (e.g., ThermoCalc), to supplement course material and expand on core MSE concepts. Students completed many of the programming assignments in MATLAB, although other languages such as Python were also permitted. Students could utilize programming skills in later courses, such as the capstone design project, but these were not required to complete assignments before the pandemic. Unfortunately, a portion of the study cohort had their undergraduate educational plans disrupted by the COVID-19 pandemic. Students enrolled in the two-quarter capstone design project in Spring 2020 were not permitted to access laboratory equipment on campus or travel to sponsor companies. Thus, they relied on computational tools to complete their projects.

**Methods**

This study surveyed students enrolled in a Materials Kinetics course in either Winter 2018 or 2019. The new survey was distributed to the cohort in Spring 2021, nine to twenty-one months following the expected graduation date (based on course timing). However, some students may not have graduated before completing the survey.

The 2021 survey had three sections:

1) *Background information:* Year of enrollment in the Materials Kinetics and Senior Design courses and frequency of programming usage in classes;
2) *Motivation questions:* Task value of programming skills, perceptions of the programming tasks in the curriculum, and the relationship between programming skills and general problem solving; and
3) *Short answer questions*: Effect of the COVID-19 pandemic on perceptions of programming assignments.

Appendix A contains the complete survey from this 2021 study. Eight of the ten multiple-choice questions, Questions 1, 2, and 5-10, were adapted from a survey of MSE simulation modules at a different institution [11, 12]. The new survey was distributed to the cohort on April 1, 2021, and was open until April 16, 2021, with approval from the campus Institutional Research Board (IRB). Responses were collected anonymously, and $5 Amazon gift cards were provided to participants. Descriptive and in vivo coding were used for short answer questions [13].

The survey was distributed to 83 people and completed by 13 respondents; seven were from the 2018 study cohort and six from the 2019 study cohort. The survey did not collect demographic data from the survey respondents. For reference, Fall 2018 campus data for the MSE major indicated the student population was 26% Female, 3.5% African American, 17.7% Chicano-Latino, and 24.8% Under-Represented Minority.

**Results and Discussion: Student Experience**

Respondents completed background questions to indicate their skill level and use of computer programming as undergraduate students. As shown in Figure 1, 69% of students were required to use programming in three or more classes during their undergraduate career. This result aligns with the curriculum, which requires an introductory programming class (using either MATLAB or Python), and several MSE courses require students to use computer programming in assignments, projects, or lab reports. Interestingly, two students noted *fewer* (zero or one) courses requiring programming than required by the MSE curriculum. Additionally, many students used programming skills to complete assignments in other classes where it was not required: 93% used programming in at least one additional course, with 38% of respondents using it three or more times.

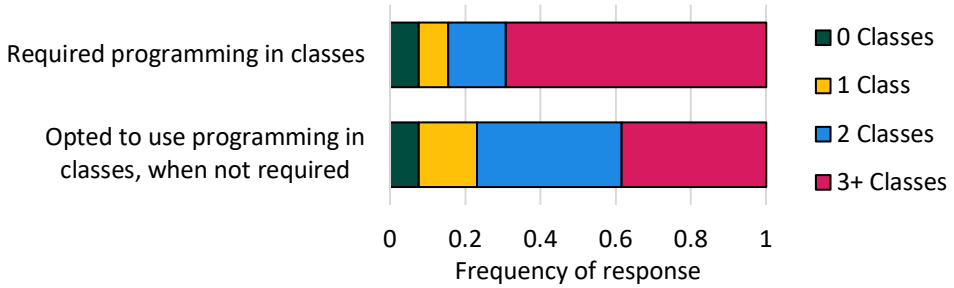


Figure 1. Frequency of usage of computer programming through the students' undergraduate careers.

When reflecting on their undergraduate career, most respondents noted favorably that their MSE courses' programming experiences were beneficial to them (summarized in Figure 2). They agreed that programming assignments helped them understand course content, were relevant to the courses, and had clear objectives. Interestingly, although 62% of respondents strongly agreed that programming helped them understand MSE content, fewer respondents (31%) strongly agreed that programming experiences were beneficial to them.

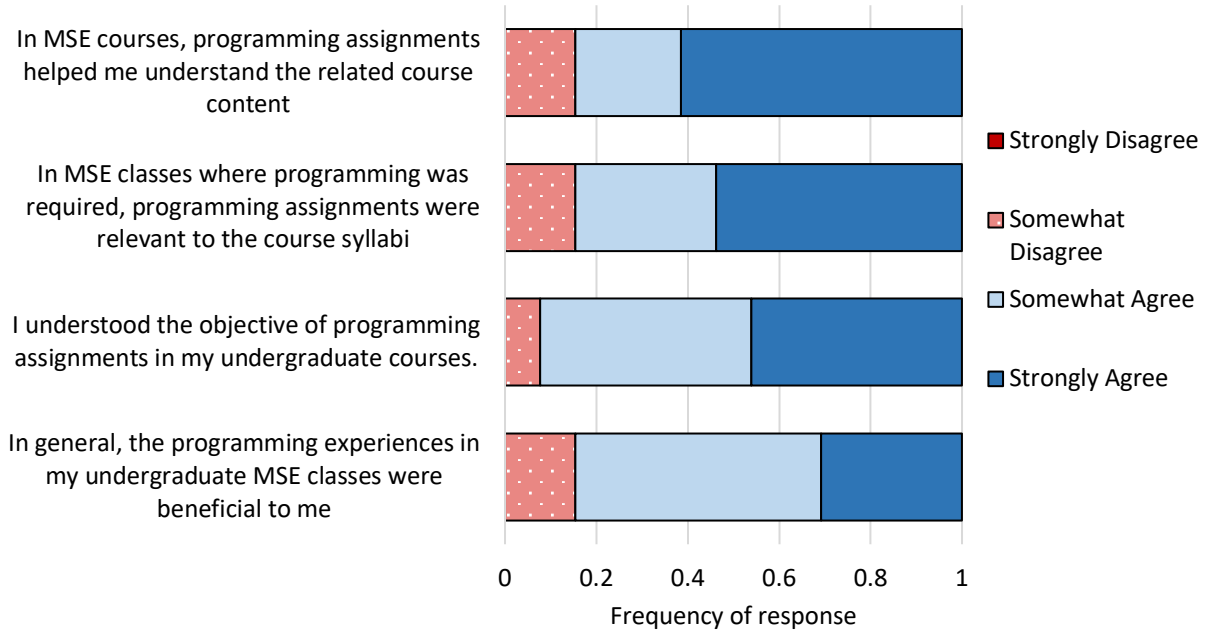


Figure 2. Summary of student perceptions of computer programming assignments in undergraduate MSE courses.

The authors were also interested in whether students would note the benefits of programming assignments on general problem-solving skills. For instance, writing code requires a methodical approach to defining a problem and identifying the steps needed for the analysis and troubleshooting (debugging) issues that may arise. The respondents favorably noted the relationship between problem-solving skills and programming assignments (Figure 3). All agreed that these helped their overall problem-solving skills, and 85% agreed with both prompts about these assignments helping them methodically approach similar complex problems and think systematically. They also agreed that programming assignments improved their ability to troubleshoot problems.

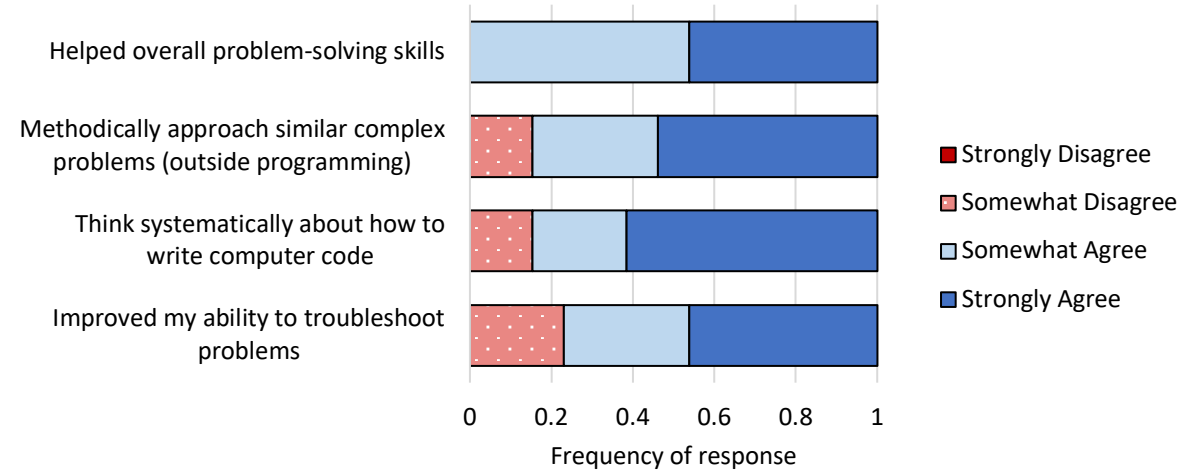


Figure 3. Students' perceptions of gains in problem-solving skills from programming assignments.

Finally, all respondents noted that programming tasks should be increased in the undergraduate curriculum. As shown in Figure 4, 85% of undergraduate students agreed that more programming should be in MSE courses. Furthermore, all students agreed, with 77% strongly agreeing, that the program should introduce programming skills earlier in the MSE curriculum.

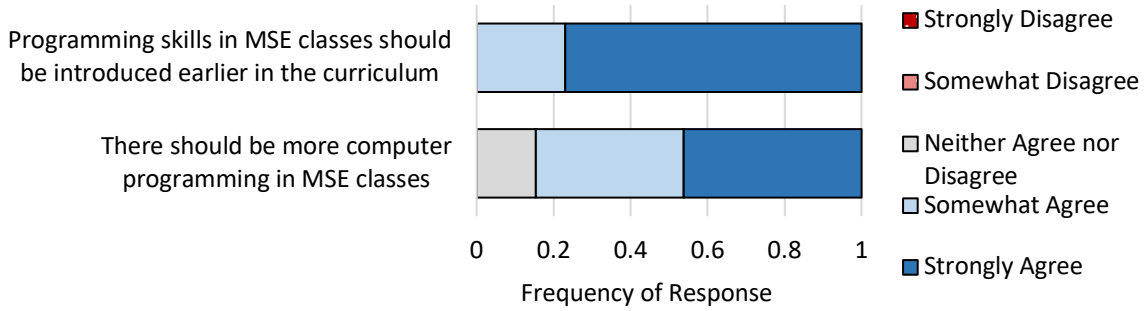


Figure 4. Student responses about the quantity and timing of computer programming in the MSE curriculum at UC Davis.

Respondents also reflected on their time as students by answering the survey question, "Prior to the COVID-19 pandemic, what were your perceptions of computer programming skills during your undergraduate education?" Figure 5 shows in vivo coding of the 11 responses. Of these responses, 55% noted that programming is an "important skill," while 27% specifically noted it is "important … for future career." The other themes identified in the responses were that programming was "helpful … to learn about" and "not taught enough," which were noted by 36% and 27% of respondents, respectively. These answers support the Likert-scale results shown in Figure 4, which indicated that students valued programming skills during their undergraduate careers and instruction should have been enhanced.

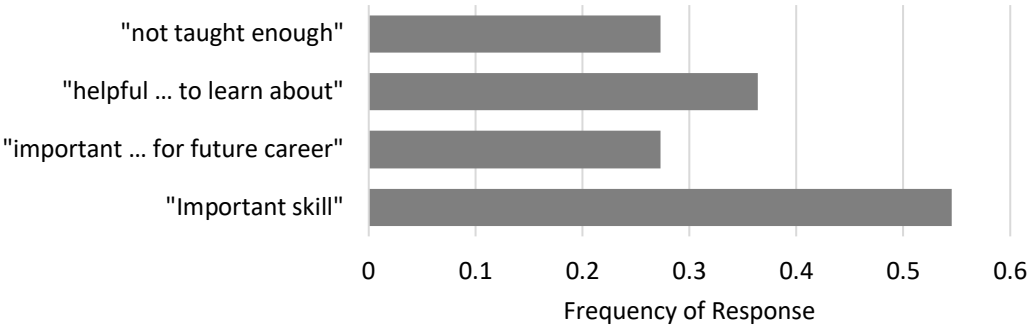


Figure 5. Students noted four common themes regarding their perceptions of programming skills during their undergraduate careers.

In summary, when reflecting on their undergraduate experience, respondents felt that these experiences were beneficial and should be expanded in the undergraduate curriculum. Students' requests for more programming experience are particularly noteworthy since faculty already teach these skills in lower- and upper-division courses. At UC Davis, sophomore students take an introductory programming course in addition to their preparatory basic math and science courses. Then, they utilize these skills in their junior year. Other institutions have also noted students'

requests for more programming experiences. Work published in 2017 by Zhang et al. found that students at the University of Illinois at Urbana-Champaign wanted more computational content in the MSE curriculum than was currently offered [12]. Furthermore, Zhang et al. found that students' opinions of when they should begin programming assignments shifted earlier as students completed more of their MSE coursework. These results indicate that students and alumni have high perceptions of programming skills.

**Results and Discussion: Post-Graduate Perspective**

The authors were also interested in respondents' perspectives after graduation. Within nine to twenty-one months of their expected graduation date, 62% of respondents had already used programming skills in their careers. Respondents had favorable perceptions of the importance of programming skills, as shown in Figure 6. All agreed that programming skills are important for MSE, and 76% agreed that these skills are important for their careers. These results reflect the varied individual career paths of MSE graduates, which may not need computational skills, and the relative importance of these skills within the broader discipline. Furthermore, respondents noted their increased value of programming assignments post-graduation compared to when they completed their coursework (Figure 6). This supports the research question that students' perceptions of programming skills change over time as students leave school and enter the workforce.

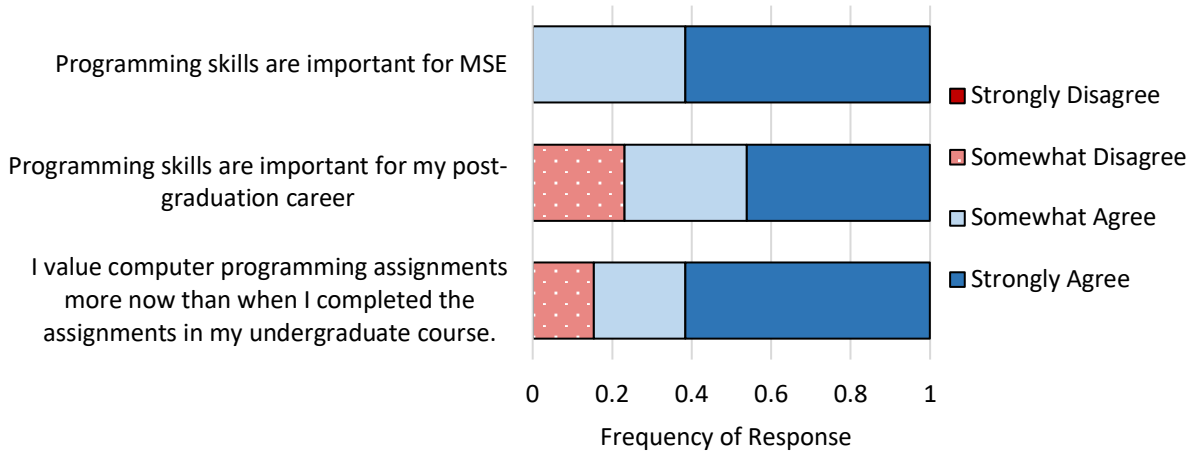


Figure 6. Reflections on the importance of programming skills for the field of MSE and graduates' careers.

**Results and Discussion: Effects of COVID-19**

The second research question asked respondents to reflect on the question, "What has been the effect of the COVID-19 pandemic on your perception of computer programming skills?". The 11 responses were coded twice to identify whether respondents felt that programming skills were more or less important due to the pandemic (Figure 7a) and then to identify topics addressed in these answers (Figure 7b). A large fraction (45%) commented that programming skills were more critical due to the pandemic, while 18% noted no change in their perception. One respondent felt that their perceptions had decreased, and the remainder did not comment on whether these skills were more or less important. As shown in Figure 7b, respondents nearly

equally commented on four themes: programming as a supplement for in-person work, relevance to their career, inadequate levels of knowledge, and relevance to senior design. Comments about insufficient knowledge are supported by participants' perceptions of undergraduate education, shown in Figure 5. As expected, some respondents commented specifically on their Senior Design experience, which could not run experiments in 2020. Similarly, it was not surprising to see the comments that programming skills were a supplement for experiments and "research estimation during the pandemic when less physical contacts are suggested."

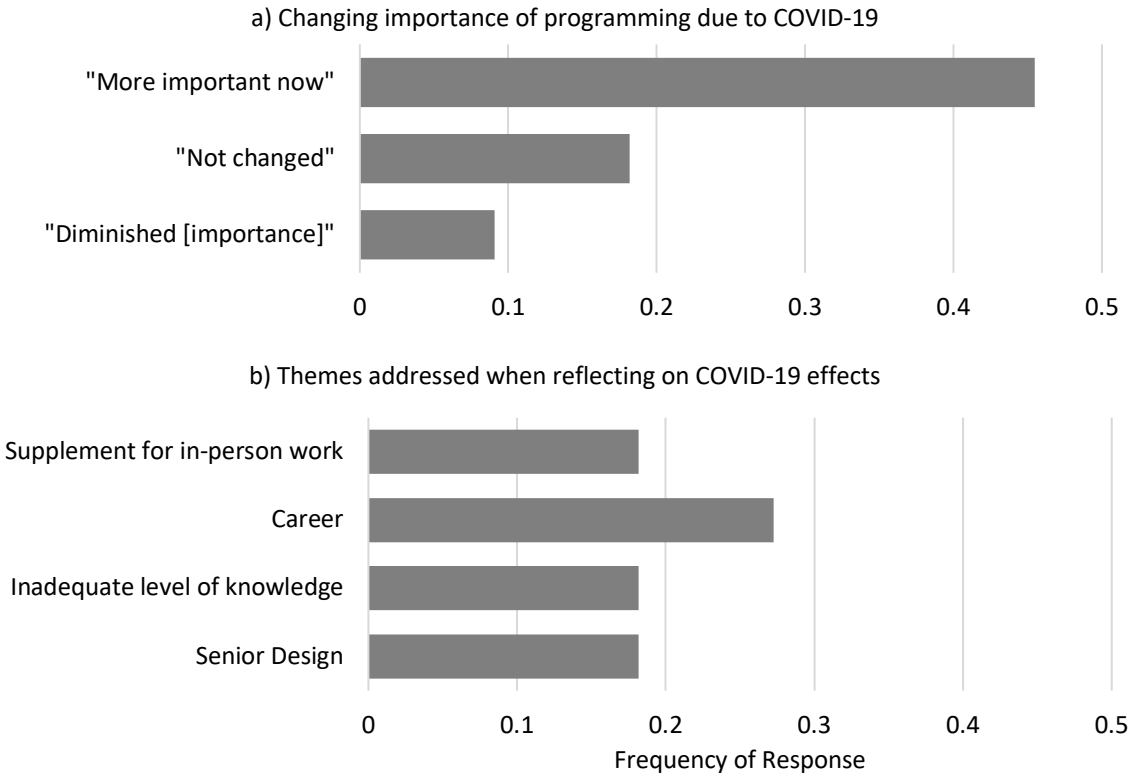


Figure 7. Effect of the COVID-19 pandemic on perceptions of computer programming skills. (a) Reflections on the relative importance of programming and (b) descriptive coding of the topics referred to in responses.

Finally, comments on the importance of programming skills for MSE careers provide helpful feedback, although none were directly related to the COVID-19 pandemic. Three surveys discussed career issues on the question, "What has been the effect of the COVID-19 pandemic on your perceptions of computer programming skills?". After completing the survey, a respondent sent a fourth comment that is included anonymously and with permission. These responses are shared below.

- "I feel as though they have diminished somewhat -- While in my mind the previous statement still stands, the difficulty I found in my job search is that there is limited opportunity for computational materials science in industry (with a B.S.)…."
- "N/A, COVID did not affect my college experience, and I have not used [programming skills] in my post graduate life due to career path."
- "Computer programming skills are a necessity to find a job."

- "I am working at a small company and because of my software and coding experience, I am an asset to the company in the lab, the field, and at a desk programming apps in C# to improve 10 year old software engineers have used at the company for years." [Comment submitted via e-mail, included anonymously with permission]

As reflected by the breadth of these comments, alumni of MSE programs often pursue various career paths, which may or may not utilize programming skillsets. This diversity is also supported by quantitative survey data, which found that 62% of respondents had used these skills in their careers. However, the first and fourth quotes show contrasting perspectives. One graduate was expecting to find career opportunities in computational MSE but was disappointed to discover these were not generally available for graduates with only a bachelor's degree. In contrast, another student working in industry was able to leverage their programming skills to improve software tools for their company, even though it was not a required part of the job. These reflections about careers were illustrative of individuals' varied experiences and career paths rather than the effect of the pandemic.

## Conclusions

As students completed their degrees and entered the workforce, they became more favorable of programming skills in support of RQ1. During their undergraduate careers, all MSE students were initially taught these skills, and most utilized these skills in other courses, even when not explicitly required. Survey respondents reflected on programming assignments as supporting their learning of MSE concepts. Many also requested more computational skills in MSE courses, with several reflecting on the inadequacy of their programming skills. As graduates entered the engineering workforce, their utilization of these skills varied depending on their specific career path. An unexpected finding was the disparity in attitudes regarding career opportunities and expectations for MSE students with bachelor's degrees.

The survey had several limitations, primarily the COVID-19 pandemic confounding the results. As addressed by RQ2, respondents generally noted that the pandemic caused them to value programming skills more highly, but some respondents noted no or negative change. Individuals' perspectives were affected by their senior design course, career path, or the general value of simulations as a substitute for in-person work. A second challenge was the limited number (thirteen) of survey responses, particularly when coding qualitative responses. Sample sizes are challenging when conducting engineering education research in small academic programs, so researchers may wish to coordinate surveys with similar institutions to obtain a larger pool of representative responses. This work provides a snapshot of alumni perspectives during a pandemic, but future work can more thoroughly evaluate their attitudes.

Lastly, we have several suggestions and considerations for MSE departments. Students at multiple universities have requested more CMSE instruction, so departments should strongly consider including programming and simulation tools at multiple academic levels (freshman through senior). Additionally, MSE departments are encouraged to consider the goals of their CMSE curriculum, such as whether learning activities are designed for career preparation or to teach advanced CMSE tools used by researchers. Programs can also support students' extrinsic motivation and career journeys by highlighting how undergraduate alumni use CMSE skills in their jobs. Finally, further surveys of how graduates utilize programming skills in their careers

may help align learning activities with program educational outcomes. Topics such as data science have rapidly grown since the first CMSE education survey was conducted in 2009 by Thornton et al.[2], so new surveys could guide programs in the directions of their CMSE curriculum.

**Acknowledgments**

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**Appendix A: Survey Instrument**

*(Lengthy Consent Statement)*
____ I have read this consent form, and I consent to participate in this study.
____ I have read this consent form, and I do not consent to participate in this study. I understand that selecting this option will close the survey.

**Part 1: Student Background**

To be eligible for this survey, you must have been enrolled in EMS 164 at UC Davis during Winter Quarter 2018 or 2019.

Were you enrolled in EMS 164 at UC Davis during Winter Quarter 2018 or 2019?
____ Yes, enrolled during Winter Quarter 2018. (This will continue on to the survey.)
____ Yes, enrolled during Winter Quarter 2019. (This will continue on to the survey.)
____ No. (This will exit the survey, as the study is only for students enrolled in the course.)

When were you enrolled in EMS 188A/B [Senior Design] at the University of California, Davis?
____ EMS 188A/B in Winter/Spring 2020.
____ EMS 188A/B in a year other than Winter/Spring 2020.
____ Enrolled in a different senior design course (e.g., EME 185A) or did not take a senior design course at UC Davis. OR Decline to answer.

*This survey investigates the use and perceptions of programming skills by students and recent alumni. This survey uses the term "programming skills" to refer to writing code that performs a given task, such as analyzing data using a script file for MATLAB or Python.*
*Below, reflect on your usage of programming skills both in the classes you took as an undergraduate student at UC Davis and in your career.*

1. How many classes **required** programming assignments or projects, as specified in the syllabus?
   0 1 2 3+
2. How many classes did you choose to utilize computer programming for your assignments, (e.g., homework, projects) that **did not require** programming?
   0 1 2 3+
3. I have used computer programming skills in my post-graduation career.
   Yes No

**Part 2: Motivation Questions**
*The next set of questions ask you to consider your motivation and perceived value of programming skills and assignments throughout your undergraduate career. These questions discuss skills that may be necessary for your post-graduate career.*
*For these questions, please indicate how representative each statement is of yourself from "Strongly Agree" to "Strongly Disagree". For each question, you may also select "Decline to answer".*

*[Answers (4 point Likert scale): Strongly Disagree, Somewhat Disagree, Somewhat Agree, Strongly Agree, Decline to answer]*

1. Programming skills are important for Materials Science and Engineering.
2. Programming skills are important for my post-graduation career.
3. I value computer programming assignments more now than when I completed the assignments in my undergraduate course.
4. I see more value in computer programming assignments now as compared to when I completed the assignments in my undergraduate courses.
5. I understood the objective of programming assignments in my undergraduate courses.
6. In general, the programming experiences in my undergraduate Materials Science and Engineering classes were beneficial to me.
7. In Materials Science and Engineering classes where programming was required, programming assignments were relevant to the course syllabi.
8. In Materials Science and Engineering courses, programming assignments helped me understand the related course content.

*Consider the classes you took as an undergraduate student at UC Davis.*
*Please indicate how representative each statement is of yourself from "Strongly Agree" to "Strongly Disagree". For each question, you may also select "Decline to answer".*
*[Answers (5 point Likert scale): Strongly Disagree, Somewhat Disagree, Neither Agree nor Disagree, Somewhat Agree, Strongly Agree, Decline to answer]*

9. There should be more computer programming in Materials Science and Engineering classes.
10. Programming skills in Materials Science and Engineering classes should be introduced earlier in the curriculum.

*The final set of multiple choice questions ask you to consider the relationship between programming assignments and problem-solving skills.*
*Please indicate how representative each statement is of yourself from "Strongly Agree" to "Strongly Disagree". For each question, you may also select "Decline to answer".*
*[Answers (4 point Likert scale): Strongly Disagree, Somewhat Disagree, Somewhat Agree, Strongly Agree, Decline to answer]*

11. Completing programming assignments has improved my ability to troubleshoot problems, even if these problems don't require computer programming.
12. Completing programming assignments made me think systematically about how to write computer code so that it would answer a particular problem.
13. Completing computer programming assignments helped me methodically approach similar complex problems outside of computer programming.
14. Completing programming assignments helped my overall problem-solving skills in general.

**Part 3: Short Answer Questions**
*For the last set of questions, consider how the COVID-19 pandemic has changed your perception of programming skills, specifically in regard to Senior Design (if applicable) and your post-graduation plans.*

1. Prior to the COVID-19 pandemic, what were your perceptions of computer programming skills during your undergraduate education?
2. What has been the effect of the COVID-19 pandemic on your perceptions of computer programming skills? (Short answer)

**End of Survey**
*Thank you for completing the survey. Clicking the "Next" button will submit your response.*

*You will be redirected to a Google Form, where you will have the option of entering your e-mail address to receive a $5 amazon.com gift card. Gift cards will be distributed at the close of the survey.*