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Impact of Transitions between Online and Offline Learning During COVID-19 on Computational Curricular Reform: Student Perspective

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Abstract

Computational methods have gained importance and popularity in both academia and industry for materials research and development in recent years. Since 2014, our team at University of Illinois at Urbana-Champaign has consistently worked on reforming our Materials Science and Engineering curriculum by incorporating computational modules into all mandatory undergraduate courses. The outbreak of the COVID-19 pandemic disrupted education as on-campus resources and activities became highly restricted. Here we seek to investigate the impact of the university moving online in Spring 2020 and resuming in-person instructions in Fall 2021 on the effectiveness of our computational curricular reform from the students' perspective. We track and compare feedback from students in a representative course MSE 182 for their computational learning experience before, during and after the pandemic lockdown from 2019 to 2021. Besides, we survey all undergraduate students, for their online learning experiences during the pandemic. We find that online learning enhances the students' belief in the importance and benefits of computation in materials science and engineering, while making them less comfortable and confident to acquire skills that are relatively difficult. In addition, early computational learners are likely to experience more difficulties with online learning compared to students at late stages of their undergraduate education, regardless of the computational workload. Multiple reasons are found to limit the students' online computational learning, such as insufficient support from instructors and TAs, limited chances of peer communication and harder access to computational resources. Therefore, it is advised to guarantee more resources to students with novice computational skills regarding such limiting reasons in the future when online learning is applied.

Introduction

The outbreak of the COVID-19 pandemic and the public efforts to control its spread have brought about profound impacts on higher education worldwide, mostly with challenges. In a study covering over 400 unique higher education institutions in over 100 countries and regions, the International Association of Universities (IAU) reported that, by April 17, 2020, almost 100% of the institutions have been impacted by the pandemic, with 59% of them stopping all campus activities; as to teaching and learning, two-thirds of the institutions claim to have replaced classroom learning with distance learning, facing major challenges such as technical infrastructure, competences and pedagogies for distance learning and study requirements, while gaining some benefits of more opportunities for flexible learning possibilities[1]. Other challenges regarding affordability, life-long learning, education policy, and students with special needs are well summarized in a 2021 literature review[2]. Till 2022, an abundance of researches have focused on the general impact of campus closure and classes moving online[3,4,5,6,7,8,9,10,11,12]. Studies focusing on specific areas or needs of education, however, are gaining popularity recently as an effort to assess the unique challenges in these areas caused by the pandemic, and to explore possible opportunities of teaching-learning innovation for the post-pandemic future[13,14,15,16,17,18].

The education of computational tools and skills in science and engineering programs face mixed impacts in the pandemic lockdown. In an investigation of distance learning for undergraduate chemistry lab researches and activities, Qiang *et al.* report that simulation and computational tools benefit a portion of the students by providing versatile and flexible opportunities during remote learning, while challenge other students due to their complexity and steep learning curves[19]. As an interdisciplinary subject, materials science and engineering share similarities with chemistry. Computational tools are becoming important for research and development of new materials both in industry and academia. Decade-long efforts have been taken by our team at the Department of Materials Science and Engineering (MatSE), University of Illinois at Urbana-Champaign, to provide ideal amount of computational training with high quality at undergraduate level. Given the large size of the affected student population, it is important to evaluate the pandemic effect on the computational training with scrutiny.

The University of Illinois moved completely online in late March, 2020 as a measurement to protect people from the novel COVID-19 virus. Lectures were delivered over Zoom or prior recordings, homework and exams were done using online platforms and/or other virtual resources, while discussions and office hours relied heavily on emails, video chats, and online forums. In our department, the computer labs in which students used to do their computational assignments or other explorations regarding materials simulation were shut down, making remote access the only viable way to use computational resources. Students were located at different time zones across the United States or even in other countries, making synchronized teaching, learning and communication difficult. The university campus reopened in Fall 2021, resuming face-to-face activities while retaining part of the online resources and practices applied during the pandemic shutdown, again changing the pattern of our computational training. We hereby would like to investigate the influence of the rapid-changing situations on the consistency of the quality of our computational curricula, and prepare for further improvements in the post-pandemic times. Specifically, we focus on the perspective of our students and compare their perception of the computational training they received before, during and after the pandemic lockdown.

Computational Modules and Curriculum Reform

Our team has consistently worked on incorporating computational modules into all mandatory undergraduate courses since 2014. Till 2022, these computational modules have covered all required courses and several semi-required/elective courses in the undergraduate curriculum, with each course having at least two computational modules. These computational modules are closely related to the content covered in class, with a focus on one of the computational applications listed as follows

- OVITO[20], for visualization of atomic structures;
- Materials Project[21], for searching materials information in materials databases commonly used in academia and industry;
- OOF2[22], for finite element methods (FEM);
- MATLAB[23] and Python[24,25], for scientific computing, such as data fitting, solving differential equations numerically;
- LAMMPS[26], for molecular dynamics (MD);
- Thermo-Calc[27] (CALPHAD), for phase diagram calculations;
- Quantum Espresso[28], for density functional theory (DFT) calculations.

For example, diffusion is an important topic covered in course Kinetic Processes in Materials (MSE 402). Here, a module of MD simulation of diffusion processes is designed, in which the students are instructed to run LAMMPS simulations with the help of example input scripts, and analyze the output data for diffusion coefficients. By running the simulations with different particles and at different temperatures, the students are able to check their results against the quantitative relations taught in class, such as the Stokes-Einstein Equation, Arrhenius Equation, etc. In this way, the students get hands-on experience of observing atomic diffusion in a "computer experiment", which hopefully aids their understanding of the in-class knowledge.

Generally, a computational module requires the students to go through the course materials covering computational contents and complete the assigned computational tasks individually or in groups, based on specific requirements from the course. To help the students in this process, a computational teaching assistant (TA) is appointed each year, who explains and demonstrates the computational modules by giving lectures, and holds regular office hours. Computer labs with Engineering Workstations (EWS) are provided with the necessary software for the computational modules and can be accessed by the students in person or remotely. Feedback is collected from the students after completion of these modules, usually at the end of the semester, to help improve existing modules and develop new modules. The curriculum has stayed generally stable with detailed descriptions in our previous works[29,30,31], and new modules are introduced as needed[31,32].

The introduction of computational modules has shown obvious positive effects on the undergraduate curriculum in our previous studies. Not long after the inception of these computational curricula, A. Kononov *et al.* finds that students show increased interest and confidence in computations, and higher perception of competency in computation after certain amount of computational training[29]. This is followed by the work of X. Zhang *et al.*, which shows increased familiarity with simulation tools and awareness of their importance in computational materials science among students, and also revealing the desire for early and more exposure to computations in MatSE classes[30]. The proceeding work by G. M. Lu *et al.*[31] and K. Kang[32] investigates the impact of new modules in MatSE courses as the computational curriculum reform deepens, both showing continued increase in students' interest, perception and satisfaction. In addition, C. Lee *et al.* suggest that computational curriculum reform has impact on non-participating courses as well[33]. Most of the researches were done before COVID-19 except the work of K. Kang *et al.*, which focuses on a freshman course MSE 182 that was delivered online in 2020 during the outbreak of the pandemic. Although the generally positive feedback revealed in the work by K. Kang *et al.* suggests possible limited pandemic influence on the computational courses, more investigation is needed to analyze the perception of students in detail.

In addition, before the COVID-19 pandemic, our team has endeavored to apply computer-based teaching techniques to the MatSE undergraduate courses since early 2014, including iClicker, lecture recording and online homework/exam. These techniques were proved to be useful for better teaching experience as revealed by C. Lee, *et al.*[33] in 2018. For example, lecture recording is reported to have the benefits of helping students review the course content, provide flexibility, substitute lectures and provide supplementary lectures. Online homework and exam help speed up the grading process, provide flexibility and track student performance. During the pandemic, the computer-based techniques became an essential way of teaching and learning as the university moved completely online, and were used at much higher frequencies. Along with other techniques like Zoom, the teaching and learning experiences were reshaped as the university moved online or hybrid, as resources like office hours, computers/workstations were accessed remotely, while laboratory experience became limited. Although the work of C. Lee *et al.* shows positive impact of computer-based techniques on teaching experience from the perspective of the professors, perception of students over these techniques and online learning experiences remains unknown, calling for research from the students' perspective.

Survey on MSE 182 from 2019 to 2021

We begin our research by surveying freshman students from the MSE 182 course, which is an introductory course to materials science and engineering. This course is designed to give new MSE undergraduate students a general sense of materials science and engineering, with a broad range of topics and knowledge covered at basic level. Among them, crystal structure and crystallography of materials is a key subject on which our computational modules are focused. Starting from 2019, students in MSE 182 were asked to visualize different atomic structures, such as diamond cubic structure of Si and body-centered cubic structure of Fe, using a visualization software OVITO[20]. In 2020, Material Project[21] was introduced into this course, and students were guided to explore the materials database, download a crystallographic file and open it in OVITO for visualization[32]. Downloading crystallographic files from Materials Project and their visualization in OVITO serve as two closely related computational modules in this course, which are associated with the content of crystal structures and crystallography covered in the lectures. Through practice in these two modules, students are trained to have better understanding of how materials are constructed from atoms, and their connection with materials properties.

We focus on surveying MSE 182 students for three reasons. First, MSE 182 students do not have previous experience with computational modules, which helps categorizing them into in-person learners and online learners of computational modules. They do not have mixed learning experience of both in-person and online, so their perception of computational learning well reflects the impact of the shift between in-person and online learning. Secondly, as 100%

freshman students who start their first undergraduate semester, MSE 182 students are more similar in university learning experiences and less diverse in professional skill sets in MSE than students taking higher level courses, which is good for controlling irrelevant variables that might influence our conclusion in unexpected ways. Thirdly, surveys on MSE 182 students were done in 2019[31] and 2020[32], and detailed data are available for comparison.

In 2021, we reuse the same questionnaire as those in 2019 and 2020 that focuses on the general perspective of the students on the computational modules, so that we are able to compare survey data across these three years. This part of questionnaire consists of 9 questions and are listed as below. Most of the questions ask the students to rate their perception of computational learning on a scale from 1 to 5, after their completion of the computational modules.

- Q1: Do you think computational tools are important for materials science and engineering? (Very Unimportant 1 — Very Important 5)
- Q2: Do you think computational materials science skills are important for your post-graduation career? (Very Unimportant 1 — Very Important 5)
- Q3: Should there be more or less computational material in MatSE classes? (Much Less 1 — Much More 5)
- Q4: In general, do you think the computational experiences you have had in MatSE classes are beneficial to you? (Not Beneficial At All 1 — Very Beneficial 5)
- Q5: What do you think is the best time to start learning computational skills in MatSE classes? (Freshman 1, Sophomore 2, Junior 3, Senior 4)
- Q6: Do you think the computational modules help you understand the related course materials in class? (Strongly Disagree 1 — Strongly Agree 5)
- Q7: Do you understand the objective of the computational modules? (Don't Understand Very Well 1 — Understand Very Well 5)
- Q8: If you were asked to visualize and compare different crystal structures, how comfortable would you be using: drawing with pencil and paper? (Very Uncomfortable 1 — Very Comfortable 5)
- Q9: If you were asked to visualize and compare different crystal structures, how comfortable would you be using: drawing with OVITO (or similar software)? (Very Uncomfortable 1 — Very Comfortable 5)

In 2020, additional questions about the updated computational modules were included to evaluate the effectiveness of the updates. These questions ask about the task difficulties, quality of the instruction, utilization of the computational tools (Materials Project and OVITO), and amount of exercise. In 2021, we continue to use these questions for comparison between 2020 and 2021. These questions are listed as below.

- Q10: How difficult is it to find the target information through web interface of the Materials Project? (Very Difficult 1 — Very Easy 5)

- Q11: How difficult is it to download the structure from Materials Project and open the crystallographic file on the OVITO program? (Very Difficult 1 — Very Easy 5)
- Q12: How difficult is it to analyze the structure through the OVITO program? (Very Difficult 1 — Very Easy 5)
- Q13: How would you rate the instructions for computational modules in MatSE 182? (Too Short 1 — Too Long 5)
- Q14: How would you rate the instructions for computational modules in MatSE 182? (Very Vague 1 — Very Clear 5)
- Q15: How comfortable would you use OVITO or any visualization programs to solve the problems? (Very Uncomfortable 1 — Very Comfortable 5)
- Q16: How comfortable would you use Materials Project or any materials database to solve the problems? (Very Uncomfortable 1 — Very Comfortable 5)
- Q17: If you were asked to find a material with specific properties in another class, would you use Materials Project or similar databases? (Not Likely 1 — Very Likely 5)
- Q18: If you were asked to analyze a material's crystal structure in another class, would you use OVITO or similar visualization programs? (Not Likely 1 — Very Likely 5)
- Q19: Do you think MatSE 182 needs more/less exercises for different materials to study atomic structures with computational modules? (Much Less 1 — Much More 5)

We conducted the surveys at the end of the semesters. The surveys results are included in the supplementary materials in Figures S1, S2, S3 and S4. We collected 58 valid responses out of the 68-people in-person class in 2021. The numbers of valid responses in 2019 and 2020 are 82 and 47, respectively. The first seven questions (Q1-Q7) assess the general perspective of students regarding computational modules and are not limited to MSE 182. These questions are also included in another 2021 survey targeted at all MatSE undergraduate students currently enrolled, and the results are shown in Figures S5 and S6. 26 valid responses are collected, and are presented in the figures based on the students' year of class (expected year of graduation), with 4, 6, 6 and 10 samples from Classes of 2025, 2024, 2023 and 2022, respectively.

Survey on Online Learning Experience

In order to assess the students' general perspective on the online learning experience of the computational modules during the COVID-19 pandemic, a survey targeted at all undergraduate students in the Department of MatSE was conducted in December, 2021. The lockdown on campus and the move from offline to online instructions have brought about major changes and challenges to the teaching and learning of the computational modules, and we developed the questionnaire to evaluate the situation of the students from different aspects. Six questions cover the availability of resources related to computational learning, including the computational resources, reading materials, help and support from the teachers and teaching assistants, chances for discussion among students, and lecture recordings. The last question asks the students' general feelings of difficulty for online computational learning experience. The questions are listed as below.

We would like to know more of your online learning experiences of the computational modules, specifically, your experience with learning and doing assignments using computational tools like OVITO, OOF2, MATLAB, LAMMPS, Thermo-Calc (CALPHAD) and Quantum Espresso (DFT), etc.

- Q(a): I had easy access to computational resources (e.g. engineering workstation, Ceramics Computer Lab machines) for learning computational modules and doing the computational assignments, when the courses were delivered online. (Strongly Disagree 1 – Strongly Agree 5)
- Q(b): I had easy access to reading materials (e.g. in-class materials and any other materials that help understanding) for learning computational modules and doing the computational assignments, when the courses were delivered online. (Strongly Disagree 1 – Strongly Agree 5)
- Q(c): I got sufficient help/support from the instructor(s) on learning computational modules and doing the computational assignments, when the courses were delivered online. (Strongly Disagree 1 – Strongly Agree 5)
- Q(d): I got sufficient help/support from the TA(s) on learning computational modules and doing the computational assignments, when the course were delivered online. (Strongly Disagree 1 – Strongly Agree 5)
- Q(e): I got sufficient chances for discussion/communication/group-working with my peer classmates (e.g. class forums, emails, social apps, in-person...), on learning computational modules and doing the computational assignments, when the course were delivered online. (Strongly Disagree 1 – Strongly Agree 5)
- Q(f): I think lecture recordings are necessary for learning computational modules and doing the computational assignments, when the course were delivered online. (Strongly Disagree 1 – Strongly Agree 5)
- Q(g): In general, I found learning computational modules and doing the computational assignments in online courses is as easy as doing so in regular in-person courses. (Strongly Disagree 1 – Strongly Agree 5)

The survey was carried out from December 2021 to early 2022, and we collected 27 valid responses from the undergraduate students, and 21 stated that they have online experiences of computational learning. The survey results are included in Figure 5. We present the results based on the students' year of class (expected year of graduation): Classes of 2024, 2023 and 2022, each having 6, 6 and 9 samples, respectively. No students from Class of 2025 appear in this survey because the university moved back to in-person instructions before their enrollment in the university in Fall 2021.

Results and Discussion

In the MSE 182 surveys, the majority of students show positive opinions steady over time from 2019 to 2021 on the importance of computational materials science skills in general, regardless of learning online or in person. By giving an answer of 4 (Important) or 5 (Very Important), 90.2%, 95.6% and 89.7% students believe that computational tools are important as found by Question 1 in 2019, 2020 and 2021, respectively, while 81.7%, 88.9% and 81.0% believe that computational skills are important for their post-graduation career in Question 2. The result of Question 3 indicates that students have moderate desire for more computational contents in MSE classes at the current level. 45.12%, 44.44% and 41.82% students want some more computational training from 2019 to 2021, respectively; 17.07%, 11.11% and 16.36% want much more computational training, while 36.6%, 40.0% and 32.7% think they like the current amount of computational modules across the years. In Question 5, the percentage of students who would like to learn computational skills early stays above 95%, with 75.9% want it in the first year and 20.4% want it in the second year in the 2021 survey, while those percentages are 77.8% and 22.2% in 2020, and 67.1% and 31.7% in 2019. This indicates generally limited negative effect from the COVID-19 pandemic on the students' perception of importance and desire for computational modules in general.

Figure 1 sees some improvement in MSE 182 students' satisfaction with module contents in 2021 compared to 2020, especially with module length and number of exercises, while their opinions are more polarized regarding the clarification of instructions. For best quality and teaching effectiveness, the computational modules are updated each year based on feedback from students in the previous year. It is important to take the factor of module updates into consideration when comparing across the years for change in the students' perception related to online or in-person learning. Question 13 checks how the students like the length of module instructions, and the percentage of students who like the current length increases from 58% in 2020 to 67% in 2021. For exercises in the modules, 40% students like the current number in 2021, which doubles from 2020, as found in Question 19. In Question 14, while the percentage of answers which believe that instructions are very clear increases from 9% in 2020 to 16% in 2021, answers giving "Vague" ratings of 1 and 2 also increase by a similar amount. The average rating is 3.489 in 2020 and 3.456 in 2021, which indicates that the students think the instructions are almost as clear in 2021 as in 2020 on average.

Comparing across the years, Figure 2 shows that increased online learning experiences in 2020 enhance the students' belief in the importance and benefits of computational tools, skills and experiences, as compared to in-person learning before and after the pandemic lockdown in 2019 and 2021. The percentage of students giving positive answers (4 or 5) to Questions 1, 2, 4 and 6 are greater in total for year 2020 than 2019 and 2021. This increase is mainly contributed by the surge of population giving the answer of 4, which indicates that a non-negligible portion of students who were originally neutral or negative towards computational modules switch to somewhat positive under online learning. This might be because more exposure to computer facilities and related technologies, computer-based academic tasks, trainings and solutions also helps build a better impression on computations in materials science for freshman students. The percentage that shows strong favor over importance and benefits of computations with answer 5 sees major increase from 2019 to 2021 for Questions 1, 4 and 6, indicating steady improvement in

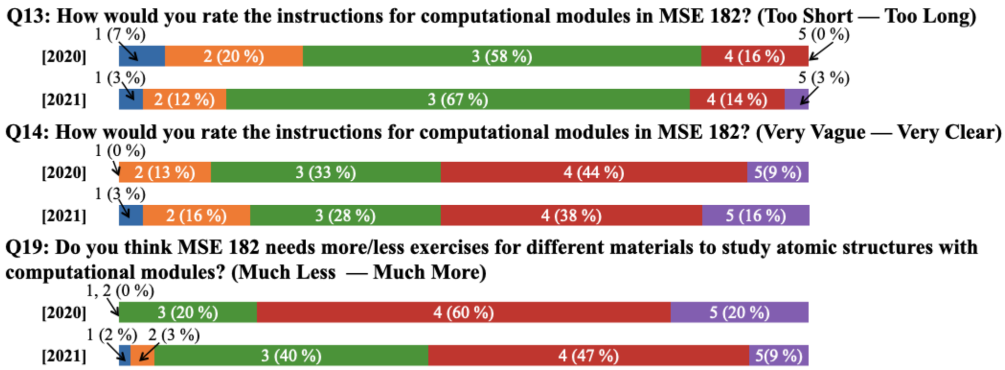

Figure 1: Feedback from students in the MSE 182 course in Questions 13, 14 and 19, which reflect their change of perception regarding the course content (instructions and exercises) from 2020 to 2021. Answers are scaled from 1 to 5. he total valid responses in 2019, 2020 and 2021 are 82, 47 and 58, respectively.

the quality and effectiveness of the computational modules and the students' satisfaction, regardless of online or in-person teaching. While there is no significant increase in the percentage of rating 5 in Question 2, it stays steady at a high level around 50%.

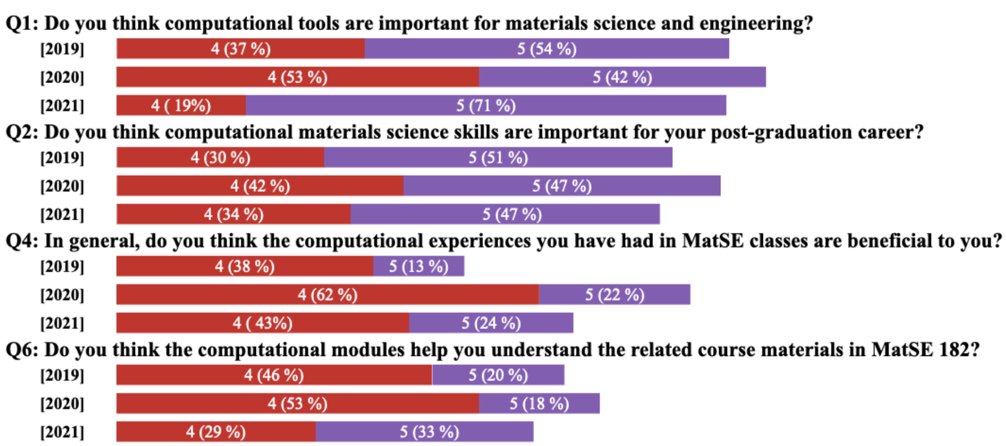

Figure 2: Positive answers from students in the MSE 182 course in Questions 1, 2, 4 and 6, which reflect general attitude towards computational modules. Answers are scaled from 1 (most negative, such as most unimportant, unbeneficial or unhelpful) to 5 (most positive, such as most important, beneficial or helpful). The total valid responses in 2019, 2020 and 2021 are 82, 47 and 58, respectively.

Figure 3 shows that in-person learning helps increase students' comfort and confidence in using OVITO to solve problems. Questions 11, 12, 15 and 18 show improvement in the easiness and comfort level of the students regarding OVITO usage from 2020 to 2021. This improvement can be partly explained by enhancement in the quality of the computational modules per se in 2021, based on the course feedback from 2020 and confirmed by results of Questions 13 and 14 in Figure S3. However, Question 9 sees obviously lower percentage of students who feel very comfortable using OVITO for visualizing and comparing crystal structures in 2020 (4%), compared to 12% in 2019 and 19% in 2021, which suggests a likely negative effect of online learning. Because students generally feel difficult with OVITO tasks in the MSE 182 class as discovered by Kang *et al.*[32], this might suggest that in-person learning is currently better than online learning at mastering difficult skills for students.

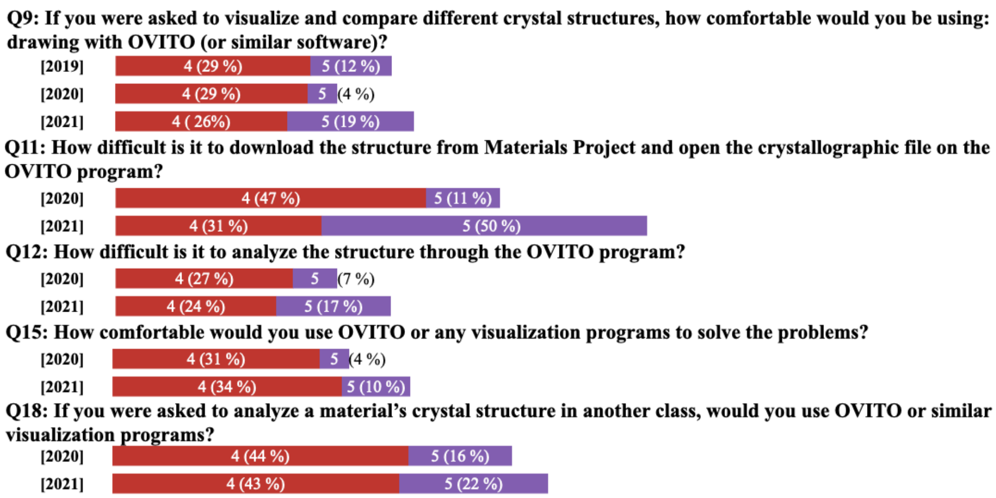

Figure 3: Positive answers from students in the MSE 182 course in questions 9, 11, 12, 15 and 18, which reflect perception to learning experience with OVITO. Answers are scaled from 1 (most negative, such as most uncomfortable, difficult or unlikely) to 5 (most positive, such as most comfortable, easiest or most likely). The total valid responses in 2019, 2020 and 2021 are 82, 47 and 58, respectively.

The feedback regarding Materials Project in Figure 4 shows improvement in the students' perception with the database in 2021 compared to the previous year, which is likely a combined result of improved instructional quality and switch from online to offline learning. Similar to the case of OVITO, the percentage of students who show the most positiveness to the database with answer 5 increases in 2021 for all the questions we asked, indicating the effectiveness of our endeavor to refine the computational modules as well as the merit of face-to-face instruction. The combined percentage of students who give answers 4 or 5 increase for Questions 10 and 11, indicating that students feel easier with in-class activities related to Materials Project in MSE 182, while this ratio remains constant for Question 16 which asks about their comfortableness, and slightly decreases in Question 17 which asks about their likelihood of using the database in the future. There are two reasons seen by us regarding the results of Questions 16 and 17. First, unlike OVITO, the use of Materials Project is a relatively easy task, which is perceived by the MSE 182 instructors during the instruction, and can be seen by higher positive ratings of Materials Project in Questions 10 and 16, compared to their OVITO correspondent Questions 12 and 15, respectively. The inconvenience of online learning is possibly a less concerning barrier for students to try applying this database for problem-solving. Secondly, the fact that students see slightly less value in Materials Project in 2021, as suggested in Question 17, might be another indication of the correlation between online learning experiences and students' belief in the importance and benefits of computational tools, a conclusion we reached earlier in this paper.

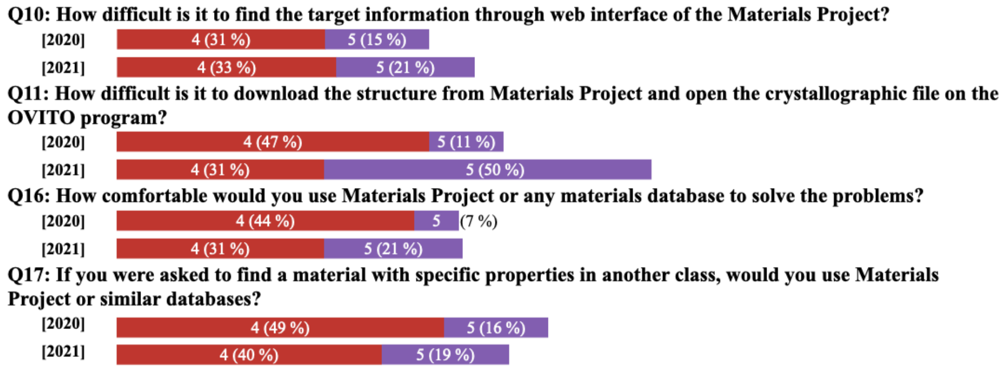

Figure 4: Positive answers from students in the MSE 182 course in questions 10, 11, 16 and 17, which reflect perception to learning experience with Materials Project. Answers are scaled from 1 (most negative) to 5 (most positive). The total valid responses in 2019, 2020 and 2021 are 82, 47 and 58, respectively.

Figure 5 summarizes the result of the online learning experience survey targeted at all undergraduate students from Department of MatSE, indicating that students from Class of 2023 faced the most difficulty working on computational modules online. By giving answers of either 4 or 5 to Question (g), 16.67% of students from Class of 2023 agree that online learning is as easy as face-to-face learning, lower than 33.33% for Class of 2024 and 77.78% for Class of 2022. The average rating given by Class of 2023 in Question (g) is 2.50, while Class of 2024 gives 2.67 and Class of 2022 gives 4.11, suggesting that students at early stages of undergraduate education find online computational learning difficult, while those at late stages feel less difference. Similar trend can also be seen in other questions in the same survey, in which ratings from Class of 2023 are significantly lower than the other two groups. This might be an indication that sophomore students are the most vulnerable to the negative impacts of online computational learning, since the pandemic lockdown policy on campus lasted from the second semester in their first year to the end of their second year, and they took MSE 182, the only freshman course with computational modules, before this policy in fall 2019. We also find that workload of computational modules is a less relevant factor that contributes negatively to the students' perception of online learning. Currently, our department has 1 required/semi-required course at freshman level with computational modules (MSE 182), while the number is 2 at sophomore level (MSE 201, 206), 4 at junior level (MSE 304, 401, 402, 406) and 1 at senior level (MSE 404), along with two elective courses at junior/senior level (MSE 422, 440)[31]. Junior level classes have the most computational workload, while students from Class of 2022, who took their entire junior year online during the pandemic, give more positive responses in Question (g) than Class of 2023. A possible explanation is that students who have had more computational training are better equipped with the skills to handle the computational tasks with online support only. Sophomore students gain complexity in their computational training during their second year, yet they have not fully developed such skills. As a result, they are the group that finds most difficulty.

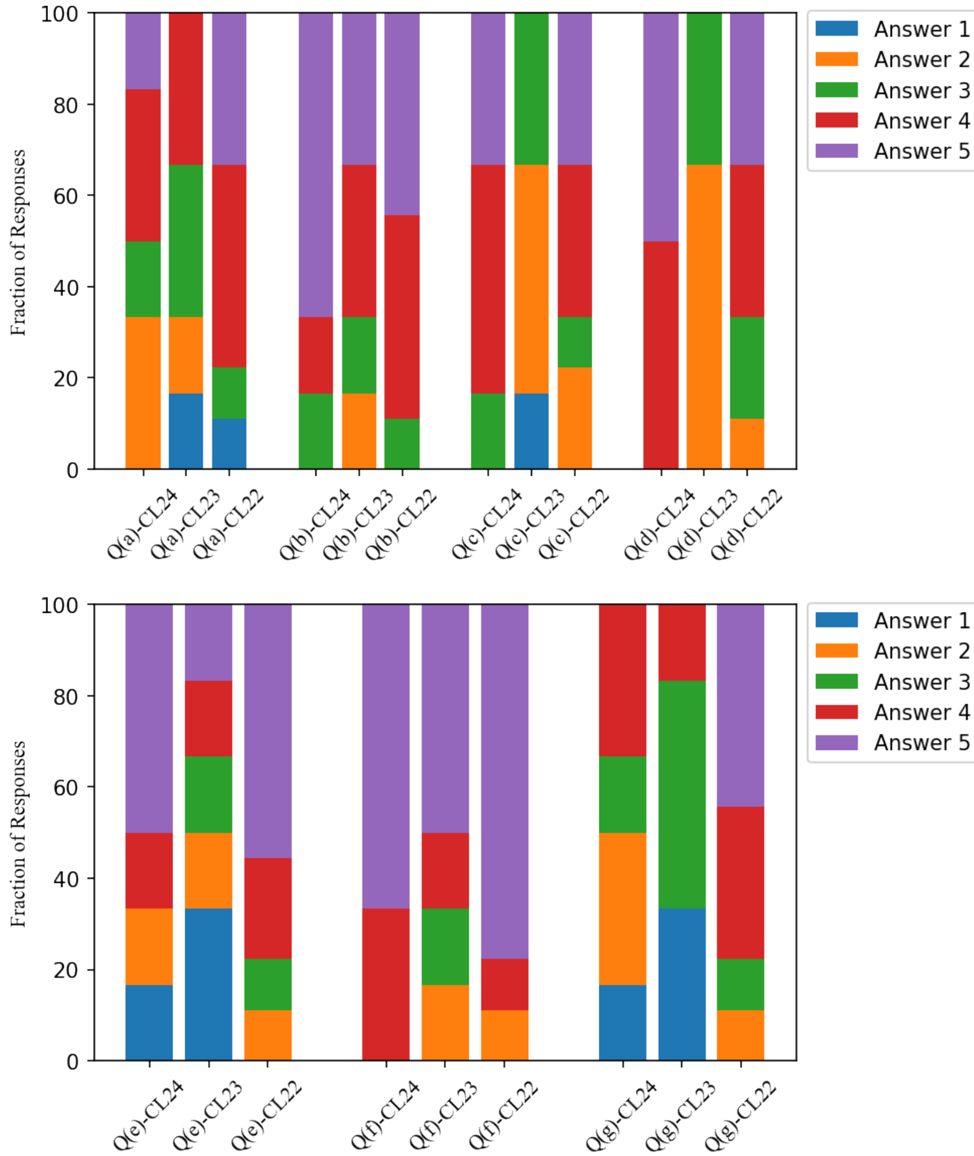

Figure 5: Distribution of answers to the survey of online computational learning experience conducted in 2021, collected from undergraduate students who studied at least one computational module online and classified by their year of class (expected graduation year). The number of valid responses is 21, with 6 from Class of 2024, 6 from Class of 2023 and 9 from Class of 2022.

Results of Questions (a) to (f) in the online learning experience survey suggest that different student groups face different major obstacles in their online computational learning. The main problem faced by Class of 2023 is the lack in help/support from instructors (average rating 2.17) and TAs (average rating 2.33), followed by limited chances of peer discussions (average rating 2.67) and access to computational resources (average rating 2.83). Specifically, no student from Class of 2023 agrees that they have got sufficient help or support from their instructors and TAs in Questions (c) and (d). We believe that this result is consistent with our previous explanation, since if students are in need of computational skills for problem solving, they are likely to have more demand for communication with other people, preferably those better in skills such as instructors and TAs. Class of 2024 thinks that lacking computational resources is the biggest problem (average rating 3.33), followed by limited chances of peer discussions (average rating 3.67), while they find help/support from instructors (average rating 4.17) and TAs (average rating 4.50) sufficient. The bottleneck for Class of 2022, if any, is help/support from instructors (average rating 3.78) and TAs (average rating 3.89) along with access to computational resources (average rating 3.89). Access to reading materials seems not an issue to all student groups, and they all agree on the necessity of lecture recordings. Therefore, we conclude that multiple factors constrain the students' perception of online computational learning in practice. Seeking possible ways to increase support from instructors and TAs, granting easier access to computational resources, and help creating more chances of communication among peer students will likely improve the overall online computational learning experience of students.

Conclusion

As a result of the COVID-19 pandemic lockdown on campus, the training of computational modules in undergraduate MatSE courses, which is a key part in our computational curricular reform at Department of Materials Science and Engineering, was moved online in spring 2020 and back to offline in fall 2021. The impact of the online-offline transition on the students' perception was studied in two surveys, one targeted at a freshman course MSE 182, and another targeted at all MatSE undergraduate students. The MSE 182 survey finds that online learning helps enhance the students' belief in the importance and benefits of computational tools, skills and experiences in MatSE, while making them less comfortable and confident in the use of OVITO, a relatively difficult task in the module. For Materials Project, an easier computational task in MSE 182, we see less improvement from 2020 to 2021 in the students' comfortableness regarding its usage and likelihood of its future usage, compared to the corresponding data of OVITO. This might suggest that offline learning is currently more effective than online learning for students to acquire relatively difficult skills. The second survey targeted at all MatSE undergraduate students suggests that sophomore students (Class of 2023) feel the most difficult with learning computational modules online, followed by freshman students (Class of 2024), while students at higher levels (Class of 2022) are the least negatively impacted. With more facts, we believe that students at early stages of developing computational skills feel more difficult in online computational learning, while the workload of computational modules plays a tangential role. Multiple reasons are found to limit the students' online learning experience, such as insufficient support from instructors and TAs, limited chances of peer communication and harder access to computational resources. Therefore, it is advised to guarantee more resources to students with beginning computational skills and alleviate the limiting factors aforementioned, if online learning is to be applied under similar unusual circumstances in the future, as alternative educational resources, or if it is to be further explored in the post-pandemic teaching and learning schemes.

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Supplementary Materials

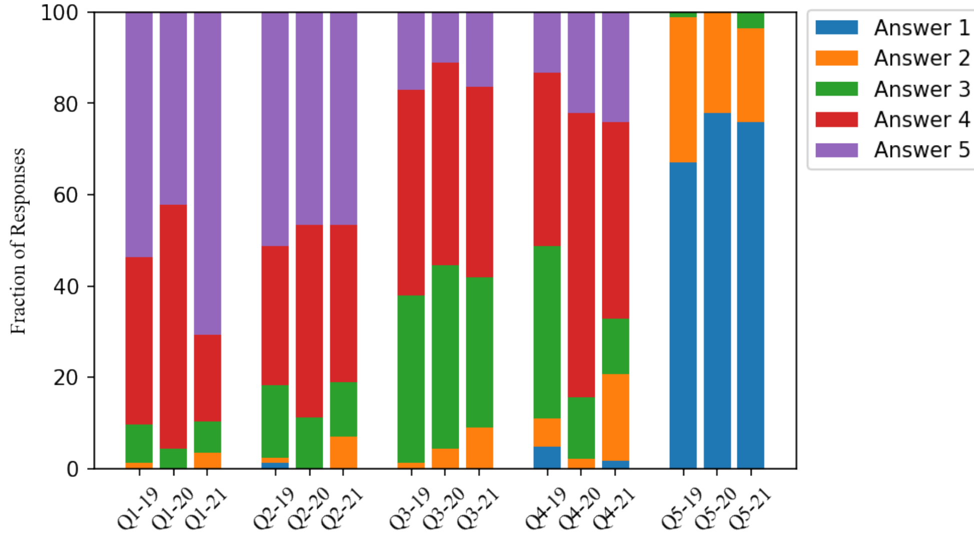

Figure S1: Distribution of answers from students to questions 1 to 5 in the MSE 182 course surveys, conducted in 2019, 2020 and 2021. The numbers of valid responses in 2019, 2020 and 2021 are 82, 47 and 58, respectively.

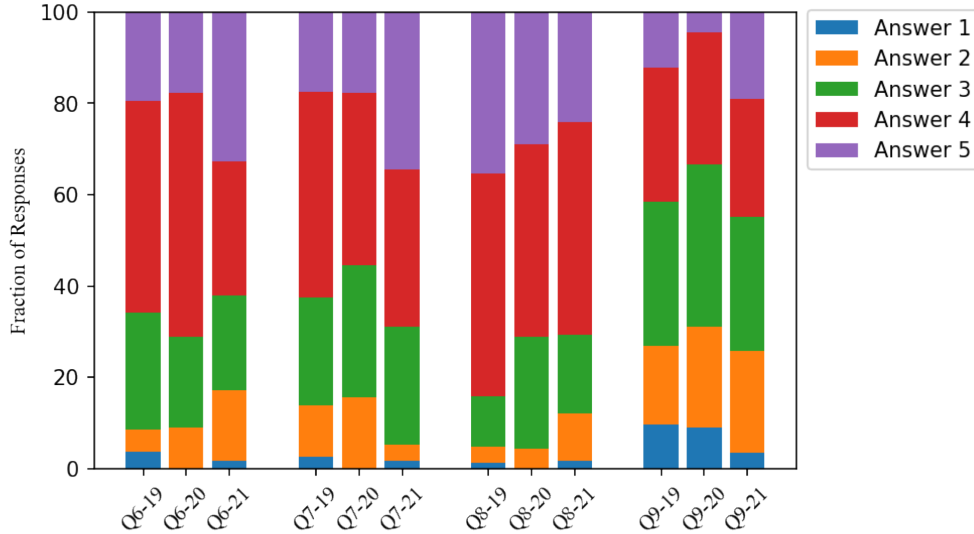

Figure S2: Distribution of answers from students to questions 6 to 9 in the MSE 182 course surveys, conducted in 2019, 2020 and 2021. The numbers of valid responses in 2019, 2020 and 2021 are 82, 47 and 58, respectively.

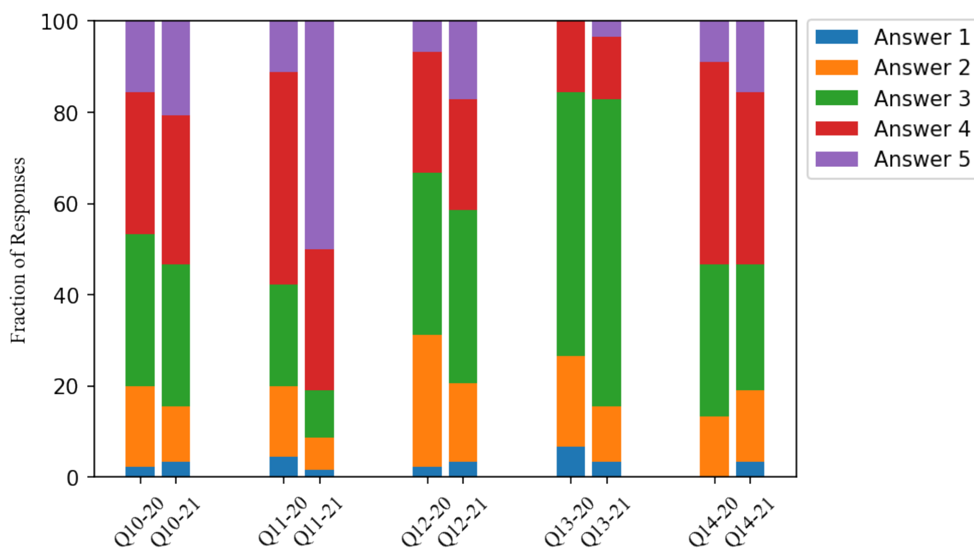

Figure S3: Distribution of answers from students to questions 10 to 14 in the MSE 182 course surveys, conducted in 2020 and 2021. The numbers of valid responses in 2020 and 2021 are 47 and 58, respectively.

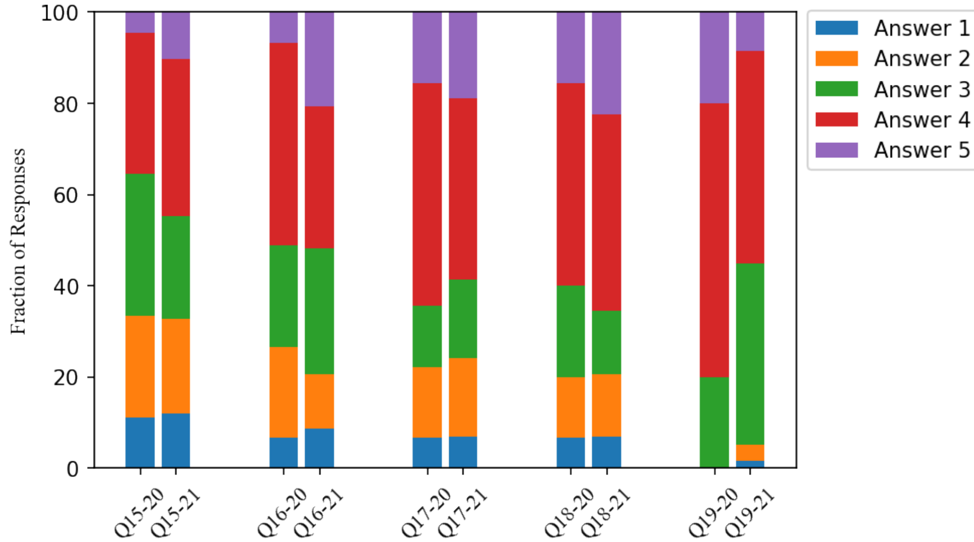

Figure S4: Distribution of answers from students to questions 15 to 19 in the MSE 182 course surveys, conducted in 2020 and 2021. The numbers of valid responses in 2020 and 2021 are 47 and 58, respectively.

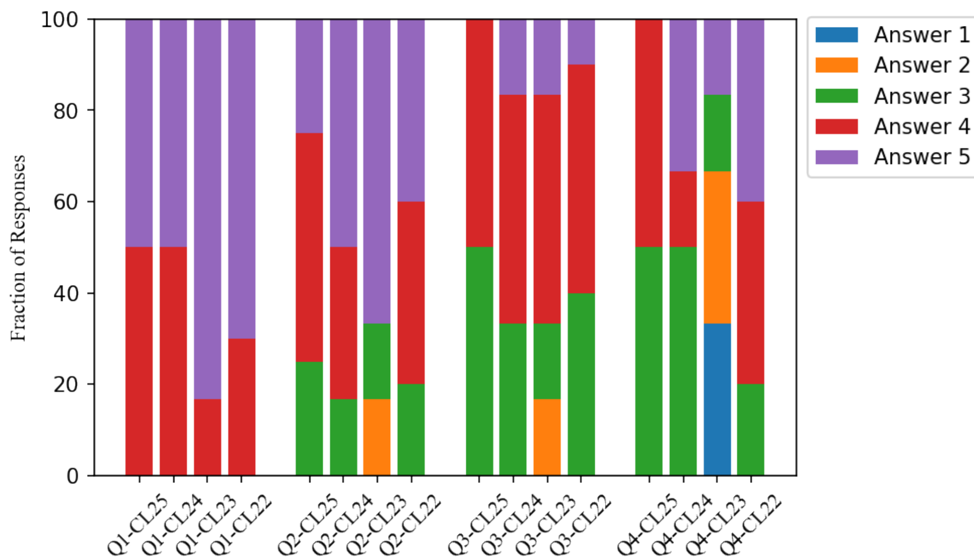

Figure S5: Distribution of answers from undergraduate students at all levels (from Class of 2025 to Class of 2022), to questions 1 to 4 in the MSE 182 survey regarding general perception of computational modules. The survey was conducted in 2021, receiving 26 valid responses. The numbers valid of responses from Classes of 2025, 2024, 2023 and 2022 are 4, 6, 6 and 10,respectively.

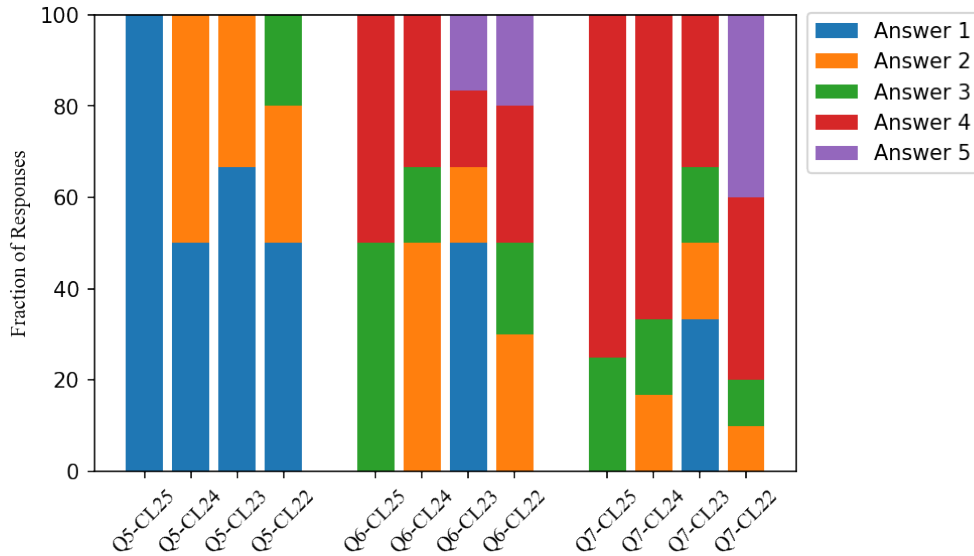

Figure S6: Distribution of answers from undergraduate students at all levels (from Class of 2025 to Class of 2022), to questions 5 to 7 in the MSE 182 survey regarding general perception of computational modules. The survey was conducted in 2021, receiving 26 valid responses. The numbers valid of responses from Classes of 2025, 2024, 2023 and 2022 are 4, 6, 6 and 10,respectively.