Enhancing Engineering Learning through MathCAD

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Abstract:

Engineering courses often require students to handle complex equations, symbolic derivations, and large matrices, which can be overwhelming and detract from the primary learning objectives. Repetitive transcription of equations and calculations becomes time-consuming, limiting understanding of the material. This paper explores the impact of MathCAD, a computational software, in alleviating these challenges by automating calculations, improving organization, and enabling students to focus on conceptual understanding. Survey results from students in the Mechanics of Composite Structures (MCS) course provide insights into the benefits of MathCAD in enhancing student engagement, reducing cognitive load, and improving overall learning outcomes.

Introduction

Engineering education frequently involves using complex mathematical equations, symbolic derivations, and large matrices, particularly in courses such as Mechanics of Composite Structures (MCS) and Machine Design (MD). These equations can be intimidating for students, especially when they must repeatedly write them out. The process of transcribing long formulas consumes valuable time and shifts students' focus away from understanding the physical meaning behind the equations. This cognitive load can lead to frustration, disengagement, and, in some cases, incomplete assignments.

One potential solution to this problem is to integrate software tools like MathCAD. MathCAD provides an interactive notebook interface that allows users to perform symbolic and numeric calculations, validate equations, and ensure unit consistency. This study explores the impact of MathCAD on engineering students' learning experiences, specifically in courses that require extensive use of mathematical formulas.

Cognitive Load Theory (CLT) suggests that a person's working memory is limited and that their learning is hampered by overload. It posits that schemas help with learning, so instructional methods should be designed to reduce the working memory load. Applying CLT to teaching suggests breaking down new topics into smaller parts and using various techniques to help learners reduce cognitive load [1]. Many educators have applied CLT in their classrooms to enhance students' learning [2] [3] [4]. Research has shown that students perform better when their cognitive resources focus on understanding concepts rather than peripheral tasks, such as copying equations during lectures. Studies have demonstrated that traditional equation solving methods can be tedious and mentally exhausting for students, leading to disengagement and poor retention of material [5]. MathCAD, as a computational tool, promises to mitigate these issues by automating calculations and providing a clear, structured format for problem-solving [6]. Previous studies suggest that MathCAD improves efficiency, enhances comprehension, and allows students to focus on understanding the physical meaning of equations rather than engaging in repetitive tasks [5]. Das [7] also noted that "the integration of MathCAD in his structural analysis class enhanced students' problem-solving skills as it allowed them to focus on the analysis while the software performed routine calculations." Mueller and Pritchard [8] used MathCAD as a computational tool

to de-emphasize mathematical analysis, enabling students to focus on understanding the definitions of engineering problems. This study aims to investigate these claims within the context of the Mechanics of Composite Structures (MCS) course.

Methodology

Mechanics of Composite Structures (MCS) is a senior-level mechanical engineering course that includes complex matrix manipulations and symbolic calculations. The traditional teaching method, with instructors lecturing and students taking notes, is not an efficient learning approach because students tire from copying large numbers of matrices and formulas. Many students opt not to take notes to avoid the distraction of writing for extended periods. Completing homework becomes a time-consuming challenge due to the repetitive nature of writing matrices and matrix calculations.

To alleviate the barrier of learning caused by the anxiety of writing matrices and performing manual calculations, MathCAD was introduced as part of the coursework. Students used MathCAD to manage complex matrices, perform symbolic derivations, and carry out calculations. Below are the strategies the instructor used to incorporate MathCAD in teaching this course:

1. A series of MathCAD tutorial videos were provided to students, who were assigned to follow the tutorials to learn MathCAD during the first two weeks of the semester.
2. Class lecture PowerPoint slides were given to students before each lecture, so students did not need to take notes.
3. The 90-minute class was divided into two parts: a one-hour lecture and thirty minutes of MathCAD calculations for class examples. Students had the opportunity to practice MathCAD with lecture examples, whose solutions were provided in class. This practice not only allowed students to check their MathCAD calculations but also required them to input the necessary equations into MathCAD.
4. Weekly homework problems were required to be completed using MathCAD.
5. All projects and exams were required to be completed using MathCAD.

To assess the effect of MathCAD on students' learning experience, a survey was distributed to 25 students enrolled in the course. A total of 20 students completed the survey. The survey included both quantitative and qualitative questions, focusing on various aspects of student learning, such as time saved, ease of use, and improvements in conceptual understanding. Specific questions explored the following areas:

- Familiarity with MathCAD prior to the course
- The perceived difficulty of learning MathCAD
- The impact of MathCAD on reducing repetitive tasks
- The software's role in enhancing conceptual understanding
- The overall effect of MathCAD on their academic performance and learning experience

The quantitative portion used 5-point Likert scales to assess students' agreement with statements, and the qualitative section allowed for open-ended responses.

Results

A total of 19 out of 25 students completed the survey. Figure 1 summarizes the results of the survey. The results indicated significant positive impacts of MathCAD on student learning:

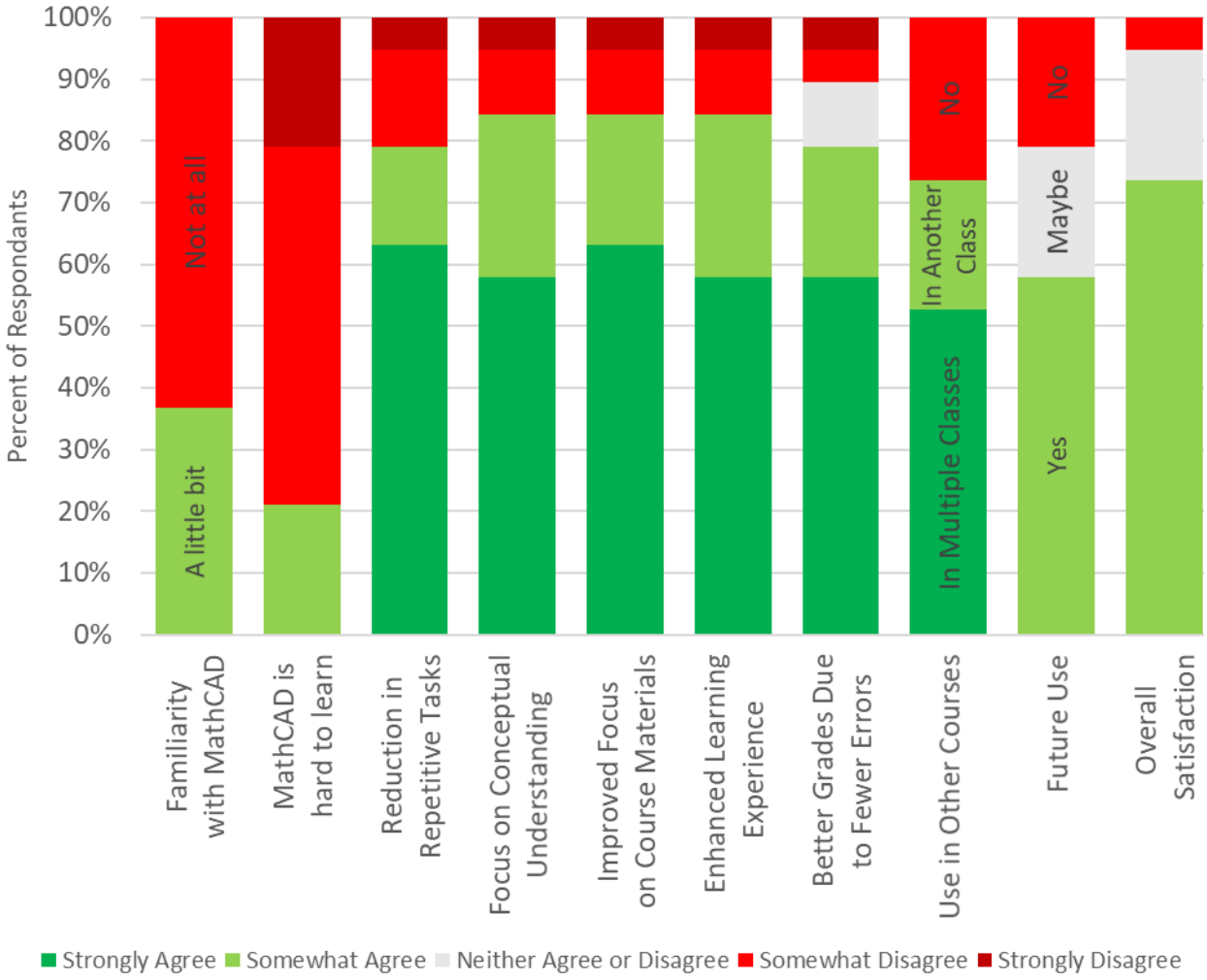

Figure 1, Student Responses to the Survey

- **Familiarity with MathCAD:**
  - 63% of students reported being unfamiliar with MathCAD before the course, while 37% had limited knowledge. This suggests that MathCAD was a new tool for most students in the course.
- **Ease of Learning MathCAD:**
  - 79% of students "somewhat disagreed" or "strongly disagreed" that MathCAD was difficult to learn, indicating that the software is relatively easy for students to grasp after an introductory session.
  - 21% "somewhat agreed" that MathCAD was difficult to learn, but no students "strongly agreed" with this statement.
  - This result shows that MathCAD is not hard to learn. Students can quickly grasp

how to use the tool in their studies.

- **Reduction in Repetitive Tasks:**
  - 79% of students agreed or strongly agreed that MathCAD alleviated the labor of writing down equations repeatedly. This indicates that students found significant value in MathCAD's ability to automate repetitive calculations and reuse equations, saving time on homework assignments.
- **Focus on Conceptual Understanding:**
  - 84% of students agreed (58% strongly) that MathCAD helped them focus more on understanding the course concepts instead of spending too much effort on manual calculations. Students also mentioned that the feature of calculating with units helped them understand units better and avoid errors caused by unit conversion. This suggests that the software allowed students to shift their focus toward learning the material more deeply.
- **Improved Focus on Course Materials:**
  - 79% of students reported that MathCAD helped them stay focused on understanding the physical meanings of equations and their applications because the use of MathCAD relieved them of the anxiety associated with equations involving matrices.
- **Enhanced Learning Experience:**
  - 79% of students agreed that MathCAD enhanced their learning experience in the course, reinforcing the notion that MathCAD positively impacted their academic performance.
- **Better Grades Due to Fewer Errors:**
  - 58% of students strongly believed, and 16% believed that using MathCAD helped them avoid calculation errors and improve their grades.
- **Use in Other Courses:**
  - After learning MathCAD in the MCS course, 74% of students used it in other classes (either multiple or individual courses).
- **Future Use:**
  - 79% of students planned to use MathCAD in future studies or work, demonstrating a high level of satisfaction with the software and a desire to continue using it in professional practice.
- **Overall Satisfaction:**
  - 74% of students liked the application of MathCAD in the class, while only 5% disliked it.

Students were also asked how they used MathCAD in other classes. Figure 2 shows the results of the survey. Over 50 percent of the students used MathCAD on homework and projects, while many fewer used it on tests. In the free response portion of the survey, students indicated that they were using MathCAD in their Machine Design and Capstone courses. In the machine design course, the instructor noted that a few students use MathCAD for the take-home exams each year.

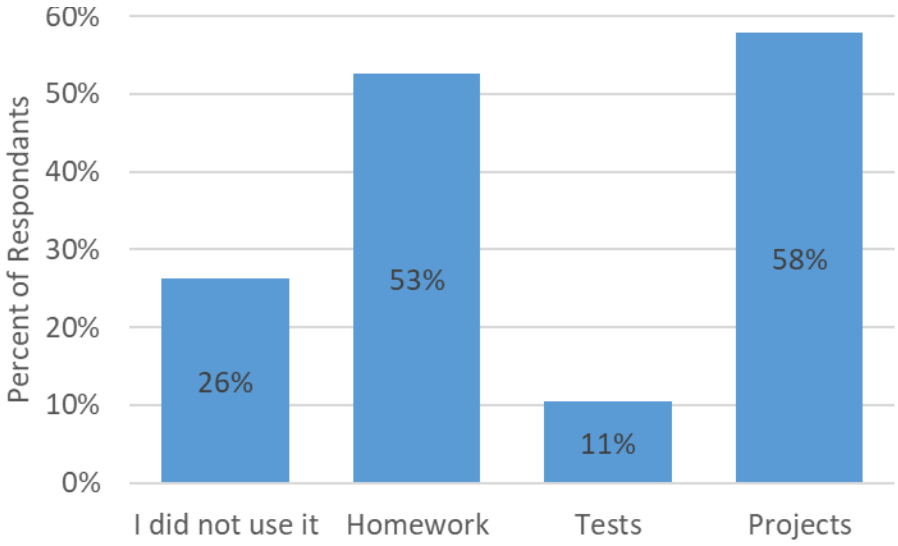

Figure 2, Use of MathCAD in other classes

Discussion

The survey results suggest that MathCAD significantly enhances student engagement and understanding in engineering courses. MathCAD alleviates repetitive tasks that often detract from deeper learning by automating equation solving and ensuring unit consistency. The reduced cognitive load allows students to focus more on the physical interpretation of engineering concepts and less on the mechanical task of transcribing and recalculating equations.

Additionally, the positive feedback regarding the software's ease of use and its impact on academic performance reinforces the idea that computational tools like MathCAD are valuable in engineering education. The fact that students continued to use MathCAD in other courses and plan to use it in the future further supports its effectiveness as a learning aid.

Conclusion

MathCAD has proven to be an effective tool for enhancing student learning in engineering courses. The survey results demonstrate that it significantly reduces repetitive tasks, improves organization, and allows students to focus on understanding the conceptual aspects of the material. By automating calculations and providing a straightforward, structured interface, MathCAD helps students engage more deeply with the course content and improve their academic performance. Given the positive feedback and the continued use of MathCAD by students in other courses, it is clear that the software plays a crucial role in modern engineering education. Future research should explore the long-term impact of MathCAD on student outcomes and its potential integration into other engineering disciplines.

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