Full Paper: Integration of Digital Tools and Technologies in First-Year Engineering Courses

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Abstract:

In a 15-week semester at Wentworth Institute of Technology, the utilization of digital tools and technologies in first-year engineering courses has proven to be quite beneficial in response to the demanding requirements of higher-level classes, the engineering profession, and the broader technological landscape. This paper aims to highlight the importance of integrating digital tools and technologies into the curriculum for first-year engineering students. Digital tools such as CAD, simulation and modeling software, virtual laboratories, interactive learning modules, SharePoint, data analysis and visualization tools, and programming environments offer diverse opportunities to enhance the learning experience, engage students, and prepare them for the challenges of engineering practice, particularly in the higher-level classes. These tools enable students to visualize and experiment with complex engineering concepts, conduct experiments remotely, access interactive learning materials, collaborate with peers, analyze and interpret data, and develop programming skills. Through the integration of digital tools and technologies, first-year engineering students can benefit from hands-on learning experiences, gain opportunities for collaborative learning and communication, and prepare themselves for the digitally focused modern engineering industrial world.

1. Introduction:

Over the past decade, there has been a significant evolution in technology, engineering textbooks, examples, and practice problems. This transformation has fundamentally altered our approach to thinking, analyzing, and solving problems within the field. Driven by various key factors, this shift underscores the stark disparity between today's technological landscape and that of just a decade ago. Engineering is a domain in perpetual motion, spurred onward by rapid technological advancements [1]. For first-year engineering students, this dynamic environment presents a mixture of potential and complexity as they embark on their educational journey. However, one notable absence in current undergraduate engineering curricula is the encouragement for students to leverage available technology in analyzing and interpreting results. In this paper, we propose methods to introduce and motivate first-year engineering students to utilize technological tools such as Microsoft Excel, MATLAB, and SOLIDWORKS, among others, to transition from traditional calculator-based approaches to problem-solving. Incorporating these tools into coursework or through self-learning initiatives could yield immense benefits, enabling students to tackle complex problems in significantly shorter timeframes compared to traditional pencil-and-paper methods [2], [3]. This paper primarily consists of three components: Microsoft Excel, MATLAB, and the integration of MATLAB with SOLIDWORKS. Each component is evaluated with an example, enabling students to tackle similar problems with efficiency and within a shorter timeframe. By exploring the opportunities and challenges associated with the incorporation of technology in engineering curricula, this paper offers insights for educators seeking to enhance the effectiveness of their teaching methods and prepare students for the demands of a rapidly evolving technological landscape [4], [5].

Through several Industry Professionals Advisory Council (IPAC) gatherings at our institute and multiple discussions with the Cooperative Education (co-op) and Career Office, we have identified three key skills that are highly sought after by employers:

- Proficient knowledge of Microsoft Excel
- Familiarity with at least one CAD software
- Proficiency in at least one programming language

While integrating these skills into the curriculum is important, mastering them to deliver results with accuracy and repeatability is crucial. We believe that through demonstrated examples and the proposed curriculum, we can equip our students to think critically and utilize the right tools to deliver accurate results in a timely manner. Several colleges require students to take certification exams in CAD classes, but proficiency in Microsoft Excel and any programming language is not easily determined. While it is impossible to include all the related and relevant examples from Microsoft Excel, MATLAB, or SOLIDWORKS, we have included specific examples to demonstrate how students can begin to approach problem-solving using these tools.

We are drawing upon a robust body of research on active and project-based learning. Studies such as [6], [7] provide a foundation for our approach, demonstrating the effectiveness of these methods in improving student engagement and learning outcomes. Our materials and course plans are informed by these prior works, and we aim to build on their findings by incorporating innovative assessment techniques and leveraging technology to enhance student learning experiences. Future research endeavors will focus on CAD/CAM and further examine the competence, engagement, and retention of students as they progress into higher-level engineering courses in subsequent years.

2. Results:

Over the past three semesters, we have observed that a significant number of Sophomores, Juniors, and Senior students encounter challenges when tackling a variety of problems, spanning from solving 3rd or 4th degree polynomials to basic cross products and determining unit vectors in specific directions. Additionally, they face difficulties in simple programming tasks, such as plotting shear force or bending moment diagrams. Based on our experience, the common problems are summarized in the table below.

Table 1: Common deficiencies among engineering students

Term	Course	Cohort	Concepts	Success Rate
Fall 2023	Manufacturing Processes	Seniors and Juniors	3rd or 4th degree polynomials, Integration of MATLAB and SOLIDWORKS	<10%
Fall 2023	Engineering Statics	Sophomores	Cross Product, Unit Vectors, Solving a system of equation	<25%
Spring 2024	Strength of Materials	Juniors and Sophomores	3rd or 4th degree polynomials, Conditional system of equations	<20%
Spring 2024	Strength of Materials	Juniors and Sophomores	Simple programming with for and if statements	Almost none

These findings raise significant concerns that warrant addressing through a thoughtful solution without resorting to spoon-feeding students. The groundwork for such solutions can effectively be established within the First Year Engineering (FYE) Courses. In many colleges, FYE students undertake a set number of courses mandated by the school curriculum, irrespective of their chosen major. While these students are embarking on their engineering journey, it is crucial to recognize the necessity for them to acquire advanced calculation skills that go beyond what traditional calculators can handle. With the ever-growing prevalence of artificial intelligence (AI), it becomes imperative for instructors to adequately prepare FYE students for the challenges ahead.

3. Discussion and Solutions:

The following discussion aims not only to identify instances of struggling students but also to explore potential solutions that could better equip these students to tackle challenges more effectively and efficiently, with efficiency being of paramount importance.

3.1 Instance 1:

In Fall 2023 in the Manufacturing Processes [8] class one of the topics related to metal casting is to determine the solidification time for a given part using the Chvorinov's rule.

$$T_s = C_m \left(\frac{V}{A}\right)^2$$

In the above equation, T_s is the solidification time, C_m is the mold constant, V and A are the volume and surface area of the casting. One of the problems that was given to the students was as follows:

"If a hypothetical wobbler had two stepped holes in it in the rectangular casting (Figure 1). What is the permissible Diameter (D in inches; please see the drawing) if the riser of diameter 3 inches, and length 1 inch takes 25% longer to solidify? Assume $n = 2$ in Chvorinov's rule. All dimensions shown in Figure 1 are in inches."

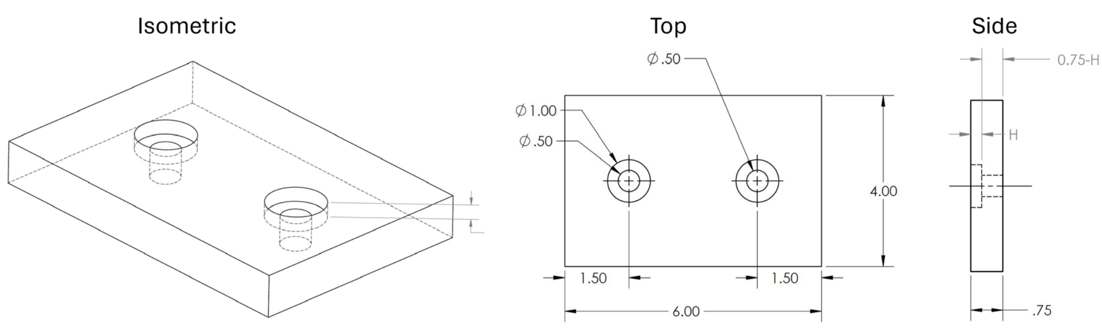

Figure 1:Problem Statement for Analyzing Metal Casting and Solidification Time with Various Perspectives.

During the Fall 2023 semester, in a class of about 11 students (consisting of Junior and Senior), Regardless of what the method was used, only one student was able to provide a correct answer.

This problem in essence requires solving a 4th degree polynomial under the assumption that the solution is real ($\mathfrak{R}$) (not complex, $\mathfrak{C}$).

3.1.1 Instance 1 Solution: MATLAB and vpasolve

Given the students' familiarity with the formulas for surface area and volume of simple shapes, writing these equations in MATLAB becomes significantly easier. Utilizing common commands such as "vpasolve" enables the determination of real ($\mathfrak{R}$) solutions to the aforementioned problems.

3.2 Instance 2:

During the Fall 2023 semester, in Manufacturing Processes class, 11 students were tasked with solving a problem concerning metal solidification time using the same Chvorinov's rule. The problem presented was as follows:

"Assuming the wobbler base is a regular hexagonal base with equal edges and angles, and with a thickness of 1/5th of the edge length. A cylindrical riser with equal diameter and length (equal to half of the edge length of the hexagon) is used in the casting. How much longer (in %) would it take for the riser to solidify compared to the casting? Assume $n = 2$ in Chvorinov's rule."

Only approximately 50% of the students in the class successfully arrived at the correct answer.

3.2.1 Instance 2 Solution: MATLAB and SOLIDWORKS

A potential solution discussed in multiple department meetings involves mandating CAD classes for all engineering students, irrespective of their chosen majors. Through the utilization of tools such as MATLAB with SOLIDWORKS or Excel with SOLIDWORKS, FYE students not only possess the capability to find accurate solutions but also to validate them in conjunction with precise CAD designs.

3.3 Instance 3:

Students in Strength of Materials classes are often presented with 3rd or 4th degree polynomials to find a solution. A typical example of such polynomials often occurs where students are trying to find the diameter of a shaft for a given value of shear strength (τ) or angle of twist (ϕ) [9].

$$\tau = \frac{Tc}{J}; \mathit{Here\ T\ is\ the\ torque, c\ is\ the\ radius\ of\ shaft, and\ J\ is\ the\ polar\ moment\ of\ inertia}$$

$$J = \frac{\pi c^4}{2}$$

And angle of twist, $\phi = \frac{TL}{GJ}; \mathit{where\ L\ is\ the\ lenght\ of\ the\ shaft\ and\ G\ is\ the\ Shear\ Modulus}$

- Case 1: If T and τ is given, students are often given a task to find the value of c.
- Case 2: If T, ϕ, G, and L are given, students are often given a task to find the value of c.
- Case 3: If τ and ϕ are both given with a limiting value, students are often given a task to find the value of c.

One of the problems that was given to the students in Spring 2024 was as follows:

"The engine of a helicopter is delivering 2000 kW to the rotor shaft when the blade is rotating at 2100 rev/min. Determine the permissible diameter of the shaft if the allowable shear stress is $\tau_{allow} = 80$ MPa and the angle of twist of the shaft is limited to 0.3° (degree). The shaft is 120 mm long and made from a steel with $E = 200$ GPa and $\nu = 0.5$."

During the Spring 2024 semester, in a class of about 23 students (consisting of sophomore and junior students), approximately <20% of the students were able to find the right value of c along with the proper interpretation, and all the students had access to Microsoft Excel or MATLAB.

3.3.1 Instance 3 Solution: Microsoft Excel GoalSeek and Solver and MATLAB

Initially, the problem appears relatively straightforward, as students attempt to solve equations of the form $x^3 = a$ or $x^4 = b$. However, to our surprise, fewer than 20% of students were able to arrive at the correct answers with appropriate units (mm or $inches$). One potential solution is to introduce FYE students to simple iterative methods using tools like GoalSeek and Solver (a condition-based iterative solver) and proper unit systems. This exposure would aid in their comprehension of when and how to utilize these tools effectively and efficiently to solve various problems.

3.4 Instance 4:

In the Fall of 2023, during the Engineering Statics [10] class, a significant percentage of students (in a cohort of 25) encountered substantial difficulties in determining unit vectors and cross products of two vectors necessary for calculating the moment of a given force about a point or axis. Although more than 75% of students successfully obtained the accurate coordinates, the majority struggled with discerning the vector's direction and performing additional preliminary calculations required to arrive at the final solution, often involving systems of equations with more than three variables.

3.4.1 Instance 4 Solution: Microsoft Excel and MATLAB

One possible solution is to motivate FYE students to create their own Excel calculation spreadsheets and permit them to use these spreadsheets during exams to accurately compute unit vectors and cross products of any two given vectors, and solutions for a system of equations. It is crucial for students to cultivate the skills to develop their own spreadsheets and MATLAB scripts for effectively, efficiently, and swiftly calculating unit vectors, cross products and solutions of system of equations.

3.5 Instance 5:

During the Fall of 2023 and Spring of 2024, in the Engineering Statics and Strength of Materials classes respectively, nearly no one (in a cohort of about 48 students) managed to accurately plot the equations of Shear Force (**V**) and Bending Moment (**M**) using Excel, MATLAB, or any programming language of their preference. While this trend is highly concerning, there are proactive steps that can be taken early on to address this issue.

3.5.1 Instance 5 Solution: MATLAB or Basic Programming

We propose that, akin to mandating a CAD class, integrating a programming class would be an invaluable step in preparing FYE students for their upcoming coursework. "Introduction to Computing 1st Edition" by David Joyner [11] emerges as a feasible and cost-effective solution for FYE students to engage with at their own pace and convenience.

4. Conclusions:

As of now, there is currently limited information on how leveraging tools like GoalSeek, Solver, MATLAB, Python, and SOLIDWORKS would enhance class outcomes. Majority of the students are well equipped with the concepts and the logic behind the given problems, however, as shown in Table 1, given the current success rates for the five instances without these tools—approximately averaging 15-20%—we anticipate that integrating these tools early in the engineering curriculum could significantly improve overall results. Furthermore, as technology continues to advance, we envision integrating these tools within the context of various engineering disciplines, leveraging advancements in AI and Machine Learning, the proliferation of mobile technology, the expansion of the Internet of Things (IoT), the rise of Big Data and Analytics, and the emergence of Blockchain Technology. By doing so, we can create educational opportunities that foster specialized focus, hands-on experience, adaptability, lifelong learning, and considerations of ethical and societal implications.

5. Future Work:

Currently, in one of the First Year Engineering classes at Wentworth Institute of Technology, ENGR14XX, Applied Engineering Analysis [8], students are introduced to the fundamentals of MATLAB, focusing primarily on mathematical operators, as well as Excel, covering mathematical operators, basic formulas, and introductory statistical analysis. We believe that augmenting this curriculum with the inclusion of advanced features such as GoalSeek, Solver, vpasolve, and introducing basic programming skills in languages like MATLAB, Python, or any other language of student interest, would better equip these first-year engineering students for their upcoming coursework [12]. The proposed curriculum aims to build a strong foundational knowledge through hands-on learning and real-world applications, featuring interactive lectures, weekly lab sessions, and problem-solving workshops. It includes diverse problems that are not easily solved with a calculator but require iterative methods and engineering judgment, prompting students to verify and justify their choices for interdependent variables [13]. These problems are designed to lead to data-driven case studies, statistical analyses, and simulations, ensuring students can effectively apply their learning [6], [7]. Upon successful implementation, we aim to document and share our findings in future publications. These findings can also be extrapolated to encompass students' GPA, Co-op opportunities, job availability during Co-ops, and post-graduation salaries. To achieve this, we plan to conduct a survey of junior and senior students to understand how the proposed curriculum has impacted their ability to think creatively and provide solutions that are verified and justified to the best of their engineering judgment.

6. Work Cited:

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