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Pilot Study: Incorporating the study of engineering history into engineering courses.

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Abstract

Engineering students often question the relevance of humanities and social science courses in their curriculum, wondering whether a direct focus on technical subjects is more beneficial. However, a comprehensive education is crucial for addressing complex engineering challenges. Engineers need to be well-rounded professionals, equipped not only with technical competence but also critical thinking, ethical skills, cultural understanding, and awareness of the social impact of their work. We propose an approach that infuses historical figures (mathematician, scientists, engineers) and case studies into two junior level engineering courses to address this concern.

In this paper, we investigate the impact of introducing historical figures and unique case studies into engineering courses. Selected historical figures and case studies were presented in class, and student feedback was positive. Integrating historical context into engineering courses positively affected student engagement and retention of basic principles, as well as enhancing their interest in learning the topics. By doing so, we hope to enhance the students' understanding of the context and real-world relevance of the theories and principles they encounter in their engineering education.

Introduction and Background

When discussing the incorporation of history into engineering education, many students express a preference for dedicating that time to learning engineering courses. However, it's crucial to recognize that every technical principle we study today is built upon the groundbreaking work of mathematicians, scientists, and engineers. These pioneers have not only made significant discoveries but have also applied their findings in the STEM field. Exploring their work can serve as a role model for engineering students, potentially sparking their interest in technical disciplines.

Some universities offer technology history courses as part of their general education curriculum [1-4]. For example, Loendorf and Geyer [1] integrated historical technologies and their impact on society into their engineering curriculum, aiming to improve students' awareness of technology's historical heritage and foundation. Niemi [2] presented efforts to create a new course engaging STEM students by examining history courses through the lens of the history of technology. Barley [3] demonstrated how historical sensitivity could sharpen scholarship for management of technology students. Gaynor and Crebbin [4] showcased examples highlighting the potential roles of history in engineering education. In mathematics education, researchers have worked on incorporating the history of mathematics into mathematics education [5-6]. Bure [7], as a mechanical faculty member, created a "history of technology" course that integrated history into engineering. However, many engineering programs face constraints in terms of credits and resources, making it challenging to introduce such courses and assign faculty to teach them.

At Wentworth Institute of Technology, a history of technology course is offered as an elective, providing students with insights into the evolution of technology and its impact on society and historical developments. However, not every student takes this course and benefits from it. Another approach to integrating history into engineering is by teaching historical snapshots within the engineering curriculum [7]. Many textbooks claim to provide a historical context, often including brief histories and applications of engineering principles. Instructors can expand on this by providing a more in-depth introduction to historical snapshots.

With a sense of curiosity, we embarked on implementing the idea of introducing historical figures and related case studies into our two mechanical engineering core courses, Engineering Fluid Mechanics and Design of Machine Elements. This pilot study aims to explore the impact of incorporating historical context into the engineering curriculum, focusing on promoting interest in the subject matter, enhancing knowledge retention, and fostering stronger motivation for pursuing an engineering career. We believe that consistent implementation of this practice helps bridge the gap between the technical and human aspects of engineering. In this paper, we delve into the detailed implementation of the content, provide examples, discuss student feedback, and outline future work.

Motivation

While the theoretical underpinnings of engineering principles may sometimes be perceived as dry and uninteresting, we recognize that the practical applications of these principles hold immense fascination. Students often wonder about the origins of these theories and principles - who were the visionaries behind them, and why are they named after specific individuals? For instance, concepts like the Bernoulli equation and von Mises stress are widely known, but the individuals behind these names often remain shrouded in mystery.

The inspiration for our initiative was sparked by a simple yet powerful question posed by a student in a design of machine element class, "Who is von Mises?" This question led us to introduce historical figures into our engineering courses. While engineering education traditionally revolves around equations and derivations, historical engineering achievements can serve as a wellspring of inspiration and motivation. By studying the accomplishments of past engineers and their groundbreaking innovations, students are encouraged to think creatively and explore new horizons.

Case studies are a potent tool for teaching students about the history of human ingenuity and technological advancement, frequently employed in engineering design-related courses. For example, when introducing the engineering design process, instructors often cite the invention of the manned aircraft by the Wright brothers as a case study [8]. However, delving deeper into the principles underlying such inventions can further intrigue students.

We believe in the positive correlation between learning fundamental principles and incorporating historical figures and case studies into the context of their development. During numerous iterations of teaching Engineering Fluid Mechanics by one of the authors, a deliberate approach was taken to integrate historical perspectives alongside essential principles. We have observed that introducing the history of science and engineering, along with highlighting the contributions of pivotal figures, enhances student interest and engagement during lectures and laboratory activities. Additionally, this learning experience may lead to improved retention of learned materials. The objective of the current research is to formally gather students' responses about this approach at the conclusion of the courses. By doing so, we aim to collect empirical data to establish preliminary learning effectiveness and provide guidance for follow-up research on fundamental engineering education.

Implementation

The implementation of the idea took place in two junior-level mechanical engineering core courses: Engineering Fluid Mechanics and Design of Machine Elements. In the subsequent sections, we provide a detailed discussion of how this implementation was carried out.

- **Engineering Fluid Mechanics**

Engineering Fluid Mechanics serves as an introductory exploration into the behaviors of liquids and gases, whether they're at rest or in motion. This branch of engineering science proves highly versatile, finding application across various engineering domains including aerospace, chemical and petroleum, civil, and biomedical engineering.

A foundational understanding of fluid mechanics has played a pivotal role in the advancement of human civilization. Historical records demonstrate that early societies utilized fluid mechanics principles in the construction of irrigation and sewerage systems. Throughout the Middle Ages and into modern times, the development of this field continued to expand. The 16th and 17th centuries witnessed significant breakthroughs in fluid mechanics, with notable figures such as Evangelista Torricelli, Blaise Pascal, and Isaac Newton making groundbreaking discoveries. Torricelli's experimental demonstration of the existence of vacuum and the effect of atmospheric pressure with the invention of the barometer marked a turning point in our understanding of fluid behavior. Pascal's formulation of the law of hydrostatic pressure laid the groundwork for manometry, while Newton's law of viscosity provided insights into fluid resistance to flow. Although these historical contributions may not be included in traditional textbooks, we believe they are essential for students to recognize the profound historical lineage that underpins the evolution of physical science and engineering practice. By understanding the historical context of fluid mechanics, students can gain a deeper appreciation for the principles they study and their significance in shaping the world around us.

In this course, we focus on two historical figures and their significant contributions to fluid mechanics within the realms of hydrostatics and elementary fluid dynamics: Evangelista Torricelli (1608 – 1647) and Daniel Bernoulli (1700 – 1782).

Torricelli, an Italian mathematician and natural physicist, made pioneering advancements in understanding atmospheric pressure and the behavior of fluids [9]. He famously conducted experiments that led to the creation of a sustained vacuum and elucidated the effect of atmospheric pressure. Torricelli's groundbreaking work also gave rise to the invention of the first functional barometer. Additionally, his investigations into liquid discharge velocity through a small orifice in a large open tank resulted in the formulation of Torricelli's Law, which predates the Bernoulli Principle. In our class, rather than adopting a traditional biographical approach, we present Torricelli's life through engaging anecdotes intertwined with discussions on basic hydraulics topics. Students gain insight into Torricelli's formative years as a precocious teenager mentored by his uncle, a Camaldolese monk in Florence. Furthermore, they learn about Torricelli's correspondence with Galileo, highlighting his involvement in the intellectual circles of his time, even amidst the backdrop of Galileo's house arrest by the Catholic Church. Through these narratives, students not only grasp Torricelli's scientific contributions but also appreciate the historical context in which they were made.

Daniel Bernoulli, a Dutch-born member of a renowned Swiss mathematical family, made significant contributions to the understanding of fluid mechanics, particularly through his formulation of the Bernoulli Principle. His seminal work, encapsulated in the treatise "Hydrodynamica" (1738), delved into the fundamental properties of fluid flow, including variations in pressure, density, and velocity [9]. Similar to the presentation of Torricelli's life and work, Bernoulli's biography is enriched with captivating anecdotes. Despite being deeply passionate about mathematics, Bernoulli's father, Johann, guided him towards the study of philosophy and logic at Basel University in Switzerland at the tender age of 13. Remarkably, Bernoulli earned his doctorate in medicine by the age of 20. During his medical apprenticeship, his fascination with fluid mechanics was ignited while investigating the intricacies of blood flow and the respiratory system.

Collaborating with Leonard Euler, one of his father's esteemed students, Bernoulli made his most impactful contribution to modern fluid mechanics by establishing the Bernoulli principle. Rooted in the principle of energy conservation within a moving fluid, this principle revolutionized our understanding of fluid dynamics. In our class, we illustrate the immediate application of Bernoulli's principle through the proof of Torricelli's Law using the Bernoulli Equation. This demonstration not only reinforces foundational concepts but also underscores the interconnectedness of fluid mechanics principles across different phenomena.

Another practical application of the Bernoulli principle was highlighted through the use of measurement technology like the Pitot tube, a device widely employed in aviation to indicate flow velocity. To underscore the critical role of a properly functioning Pitot tube in ensuring aviation safety, we introduce two aviation disasters as case studies. One such disaster involves Birgenair Flight 301, a Boeing 757 that crashed into the ocean shortly after takeoff from Puerto Plata, Dominican Republic, on February 6, 1996. Investigation revealed that faulty airspeed data, caused by a blocked Pitot tube (due to a bird's nest obstruction), was fed to the onboard computer, contributing to the accident. Another tragic incident is that of Air France Flight 447, an Airbus 330 enroute from Rio de Janeiro to Paris on June 1, 2009. The aircraft stalled and crashed into the Atlantic Ocean after the pilots mishandled procedures to address the confusion caused by faulty airspeed data, resulting from an ice blockage inside one of the Pitot tubes while cruising at an altitude exceeding 30,000 feet.

By examining these dramatic events, closely tied to a commonplace device like the Pitot tube, as part of our discussion on fundamental principles, students gain a profound appreciation for the marvels and perils of engineering applications in real-life situations. This approach not only reinforces the importance of understanding and maintaining critical systems but also emphasizes the broader implications of engineering decisions in ensuring safety and reliability in complex systems like aviation.

- **Design of Machine Element**

Machine design involves designing structural components of a product to fulfill specific functions, with failure prevention being a crucial aspect. In this course, various failure theories in static and dynamic load scenarios were introduced, with the distortion energy theory proving to be highly accurate for ductile materials under most stress conditions. This theory, also known as the maximum shear stress theory or Von Mises theory, has become indispensable for analyzing fatigue failure in ductile materials. In response to students' curiosity about the origins of the theory, the exploration into historical figures and their contributions to the subject matter was expanded. Among the figures introduced in class, two examples are Dr. Richard von Mises (1883 - 1953) and Christian Otto Mohr (1835 ~ 1918).

Dr. von Mises, an Austrian scientist and mathematician, made significant contributions to various fields including solid mechanics, fluid mechanics, aerodynamics, aeronautics, statistics, and probability theory [10]. His work during World War I as a pilot and in aircraft design is noteworthy. In the realm of solid mechanics, Dr. von Mises formulated the von Mises yield criterion, a pivotal concept in plasticity theory. In 1913, he discovered that the combination of principal stresses, even if individually below the material's yield stress, could still lead to yielding. To address this, he proposed a formula for combining these stresses into an equivalent stress, known as the von Mises stress. This equivalent stress, named in honor of Dr. von Mises, serves as a crucial parameter for assessing whether elements will fail under given conditions.

Another notable figure is Christian Otto Mohr, after whom Mohr's circle is named. Mohr's circle serves as a graphical representation of the transformation equation for plane stress problems. Mohr, a German civil engineer, made significant contributions to structural engineering and stress analysis [11]. Mohr was a proponent of graphical tools and pioneered the method for visually representing stress in three dimensions, initially proposed by Carl Culmann. In 1882, he developed the graphical method for stress analysis known as Mohr's circle, which became widely used in engineering. He also proposed an early theory of strength based on shear stress using this method. Additionally, Mohr contributed to the field of structural engineering by developing the Williot-Mohr diagram for truss displacements and the Maxwell-Mohr method for analyzing statically indeterminate structures. Students interested in delving deeper into his life and contributions can explore more information at their leisure.

These historical figures served as guiding lights for students, influencing how they perceive and solve problems. Additionally, the historical development of certain phenomena, such as fatigue, was explored.

The term "fatigue" was first introduced in the 1840s and 1850s to describe failures resulting from repeated stresses [12]. Some of the earliest notable fatigue failures involved railroad axles in the mid-1800s, prompting investigations by Albert Wohler. Wohler deliberately studied and articulated basic principles of fatigue failures, along with design strategies to prevent them.

During the war period of 1920-1945, fatigue became a significant concern due to industrial development, leading to numerous reported accidents. This spurred investigations into fatigue in all industrialized nations, resulting in a surge in papers, meetings, and books on the subject. Failures in various structures, including automobile components, military equipment, and civil aircraft, further highlighted the importance of addressing fatigue. A notable case is the Comet jetliner crashes in 1952, where the fuselage failed due to fatigue after as few as 1,000 flights. This revelation was groundbreaking at the time and underscored the danger of metal fatigue. Since then, there have been over 18 aircraft crashes attributed to fatigue failure since 1968, highlighting its continued relevance [12].

Student Feedback

After the completion of the courses, a survey was distributed to students enrolled in two junior level required courses: (a) Engineering Fluid Mechanics, comprising three sections with a total of 65 students, and (b) Design of Machine Elements, consisting of one section with 18 students. Out of the 83 students enrolled in these two classes, 55 students responded to the survey questions, resulting in a combined response rate of 66.3%. Table 1 outlines the survey questions, with three open-ended inquiries (Q2, Q11, and Q12) and the remaining questions being multiple choice. The findings from the survey are presented in Fig. 1.

Table 1. Survey Questions

Q1. Have you been exposed to historical figures (scientists, mathematicians, or engineers) related to your courses?
Q2. If yes, please specify the individuals and the engineering principles associated with their work.
Q3: How do you feel learning about the contributions of historical figures impacts your understanding of engineering concepts?
Q4. In your opinion, how might knowing the stories of these historical figures impact your motivation to learn and apply engineering principles?
Q5. In your opinion, is it useful/impactful to introduce historical context in engineering lab experiments?
Q6. In your opinion, do the stories of historical figures make the learning of engineering principles more interesting for you?
Q7. Have you been exposed to engineering case studies in your courses?
Q8. How do you feel learning through engineering case studies impacts your understanding of real-world applications of engineering principles?
Q9. How do case studies contribute to your improved retention of learned engineering principles?
Q10. How do case studies contribute to making the learning of engineering principles more interesting or engaging for you?
Q11. How do you think incorporating the stories of these individuals could make learning and practicing engineering principles more interesting or relatable for you?
Q12. What suggestions do you have for improving the integration of historical content into engineering courses?

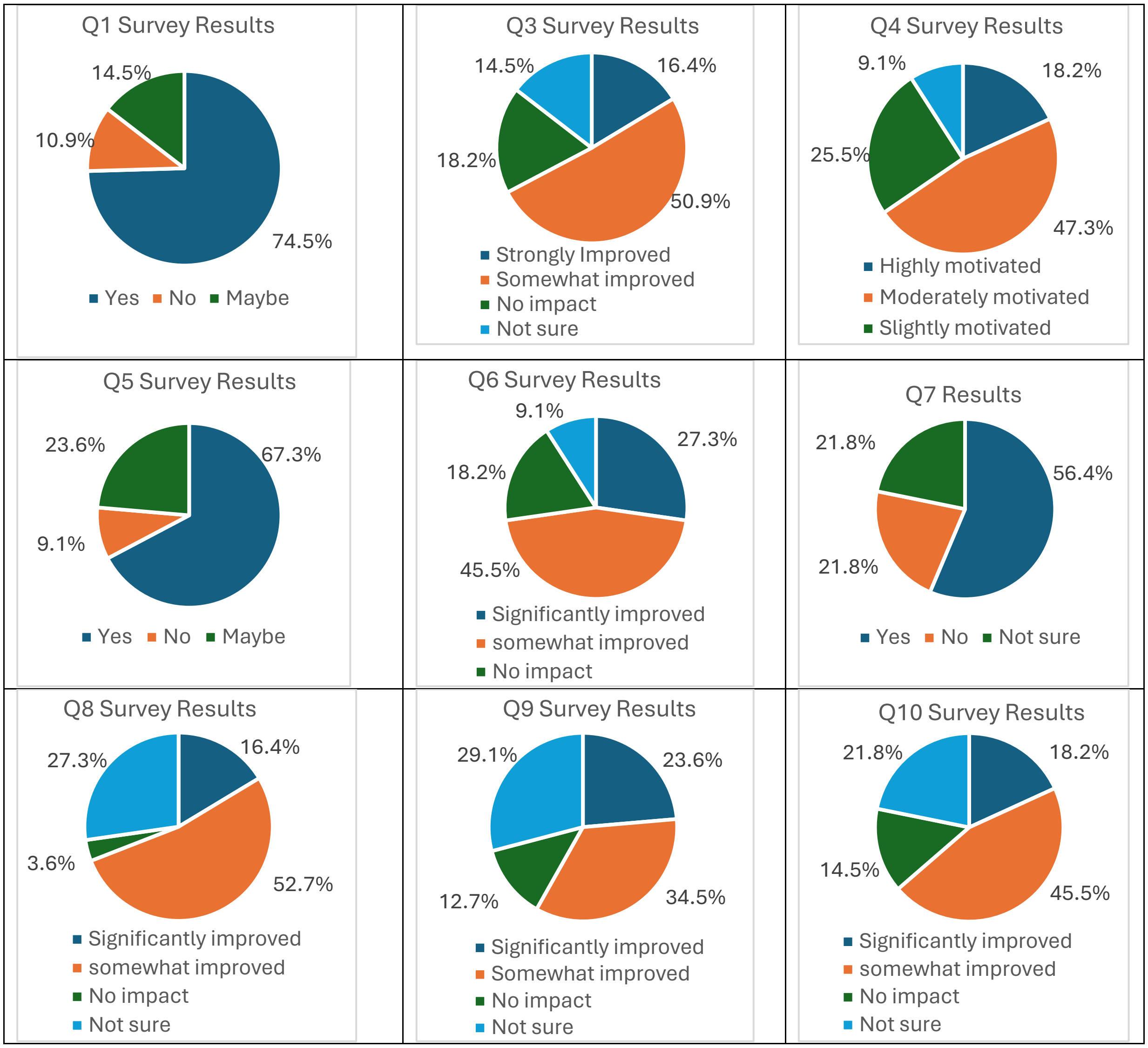

Figure 1. Survey Results

A significant portion of students (74.5%) reported being exposed to historical figures related to their engineering courses (Q1). When students were further prompted to specify the individuals and the engineering principles associated with their work (Q2), several notable names emerged, including Newton, Torricelli, Bernoulli, Tesla, Faraday, Mohr, Euler, Blasius, Ludwig Prandtl, Galileo, Reynolds, Pythagoras, and Maxwell. Many of these figures were associated with different principles and equations taught in their mechanical engineering courses. 67.3% expressed that the inclusion of historical figures somewhat or strongly improved their understanding of engineering principles (Q3). When students were asked about the potential impact of knowing the stories of historical figures (scientists, mathematicians, or engineers) on their motivation to learn and apply engineering principles (Q4), 65.5% of students indicated that they were moderately or highly motivated. This suggests a notable interest among students in integrating historical content into engineering education. Furthermore, when asked about the usefulness and impact of introducing historical context in engineering lab experiments (Q5), 67.3% of students responded affirmatively. This indicates that a majority of students perceive value in incorporating historical perspectives into practical laboratory experiences within engineering courses. Additionally, 72.5% of students believed that learning about the stories of historical figures strongly or somewhat enhanced their interest in studying engineering principles (Q6). These findings underscore the potential benefits of integrating historical content into engineering curricula to enrich students' learning experiences and foster greater engagement with the subject matter.

When students were asked about their exposure to engineering case studies (Q7), 56.4% indicated that they have encountered such studies. Among these students, 69.1% felt that the case studies significantly or somewhat improved their understanding of the real-world applications of engineering principles (Q8). Additionally, 63.7% of students reported that the case studies significantly or somewhat enhanced their interest in learning engineering principles (Q9). While the majority of students perceived improvements in their understanding and interest, 58.1% agreed that the case studies somewhat or significantly improved their retention of learned engineering principles (Q10), slightly above the average. Notably, 23.6% of students reported a significant improvement in retention, despite 43.6% indicating uncertainty about their exposure to case studies.

Furthermore, open-ended questions were posed to gather additional insights. Below are some selected comments from students regarding how incorporating the stories of historical individuals could make learning and practicing engineering principles more interesting or relatable (Q11):

- *Just add another layer to the course content. Often considers a perspective atypical to general engineering work.*
- *Hearing the context around the individual helps you memorize what they're known for and the equations associated.*
- *It could be more interesting because you get to learn how the experiments were conducted and what caused them to do these experiments.*
- *Learning the background and stories of notable historical figures that came up with the work makes it much easier to remember and recall because it's no longer just a string of numbers and letters but has depth meaning and context that isn't otherwise there when simply going over the material.*
- *It gives more societal worth as well as individual worth. If you reflect on event on a horrible tragedy of engineering done poorly, it gives you more worth and responsivity.*
- *incorporating the history and background of a engineering principal can create a good foothold/base for any student to start expanding their knowledge of a said principle*
- *I believe that being able to see the work of these individuals in front of me rather than in a textbook, as in through videos or interactive walkthroughs of their accomplishments in the field makes it much easier to visualize, therefore allowing me to be more interested as I see their work come to life rather than just be notes in a notepad.*

There are some suggestions regarding the incorporation of historical context into engineering courses (Q12).

- *I would like some information about who created the principles that could be sprinkled in to lectures just for some historical context.*

- *When Introducing subjects, mention who discovered and how, through what means and methods, when, what was the impact on the study going into the future.*
- *I am a fan of using stories about the figure behind a certain principle that is currently relevant in the course as a Segway into the theory behind their principles. I think this is the most effective spot to incorporate such content.*
- *I believe briefly going over the historical context is better than going deeply into it so that it doesn't take too much time from it. Giving an introduction to the historical figure and how he came about the equation is the best way to do it: short and interesting.*
- *attaching the content we learn to something with an interesting background can help us remember what we're learning better.*
- *When applying equations or theories, give the students a quick and brief history of the material and background of the founder.*
- *Relating it to more of what we're doing and going through case studies is a great way to keep students engaged and to see applications of these principles and the thought process behind them.*

Nevertheless, some students have voiced their concerns about the additional workload, as integrating another layer into the curriculum could consume significant class time.

- *for me, it takes away time from learning the equations and acquiring the skills to become proficient in solving engineering problems.*
- *I am worried it would waste time.*

Discussion

Overall, the feedback was positive, with students providing valuable insights into the importance of understanding historical figures and related case studies, as well as suggestions for implementing historical context into engineering courses, despite tight schedules. Here are some key takeaways:

- A significant majority (74.5%) affirms coming across historical figures in STEM courses taken so far. However, figures and the associated fundamental principles cited by the respondents may reflect some recency effect, since these surveys were given to students in the two junior classes.
- Most students are quite positive about introducing more historical context of fundamental principles in engineering lab experiments, conducted as part of a course components, deeming the practice useful and impactful (67% affirming).
- Students' responses are generally rather positive about being exposed to historical figures and related case studies having a positive effect on their staying engaged in learning basic principles, with improved retention of subject matter.
- There is a general sentiment/demand from respondents about having a more structured and purposeful component in the lecture lesson plan to introduce historical figures and case studies.
- One concern is balancing the time devoted to covering subject materials versus that on historical figures and related case studies. In some lectures, historical figures or case studies are only discussed for about 10 minutes. Additionally, we've reduced the number of in-class quizzes to make room in class periods for adoption of new materials.

- Several student ideas, such as integrating history into lab experiments, highlighting key figures in chapters, and using videos to spark curiosity, can inform recommendations for future course development.
- One student suggested creating an optional open discussion forum on Brightspace for sharing findings and thoughts.

Conclusion and Future Work

A study was conducted to gauge the effect on learning fundamental engineering with the integration of historical context into two junior-level courses within our mechanical engineering program. While engineering education typically emphasizes equations and derivations, incorporating historical engineering achievements adds depth to the technical curriculum, serving as a source of inspiration and motivation. By examining the successes of past engineers and their groundbreaking innovations, students are encouraged to think creatively and explore new perspectives. This pilot study also seeks to bridge the gap between the technical and human aspects of engineering.

In this paper, we examined the impact of introducing historical figures and unique case studies into engineering courses. Selected historical figures and case studies were presented in class, and student feedback was positive. Integrating historical context into engineering courses positively affected student engagement and retention of basic principles, as well as enhancing their interest in learning the topics.

However, there were concerns about the time allocated for historical context within the curriculum. The tight schedule of the subject presented challenges in balancing time for historical content. As a result, the frequency of quizzes had to be reduced to accommodate these changes. We are also exploring alternative methods to integrate historical context into the course, such as assigning homework tasks and facilitating discussion threads on the course management platform Brightspace. Moreover, limited information provided by textbooks required instructors to dedicate extra time to research historical figures. To address this challenge, the authors plan to collaborate with faculty who specialize in teaching history of technology to gather relevant information and resources. Additionally, we aim to incorporate more modern case studies and diverse role models into the curriculum.

Furthermore, it’s important to note that the data presented here represents a snapshot of the perceived impact from a relatively small sample size of students exposed to historical figures and case studies. Follow-up studies are needed to expand the sample size and include a broader range of courses. Moreover, future research should focus on assessing the delivery and effectiveness of the method discussed in the present work. It would be beneficial to determine whether this approach contributes to enhancing students' performance.

A longitudinal comparison over the same set of survey questions would provide better guidance in designing survey methodologies and evaluating the sustained impact of integrating historical perspectives into the curriculum. By conducting comprehensive studies over time, we can refine and optimize our approach to ensure that historical content enhances the learning experience without compromising the coverage of essential material.

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