Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #48381

BOARD # 219: WIP - Digital Engineering Notebooks to Support Technological and Engineering Literacy in Pre-College Engineering Education

Dr. Erik Schettig, North Carolina State University at Raleigh

Dr. Erik Schettig is a lecturer in the Technology, Engineering, and Design Education program area of the Department of STEM Education in the College of Education at NC State University. His research interests include developing open-access engaging STEM curricula for K-12 teachers and guiding students in technology, engineering, and design education teacher licensure.

Marissa Franzen, North Carolina State University at Raleigh

Title: WIP - Digital Engineering Notebooks to Support Technological and Engineering Literacy in Pre-College Engineering Education

Abstract

This work-in-progress aims to produce an open-access digital engineering notebook for pre-college engineering education applications. Grounded in the Standards for Technological and Engineering Literacy, the digital notebook template acts as a tool to provide students with practical and industry-related experience in documenting problem-solving and design processes. As education increasingly shifts toward digital solutions to match what is occurring in various STEM industries, this project explores how digital engineering notebooks compare to physical notebooks and how they can enhance student learning while preparing students for professional environments that rely on digital documentation. The initial phases of this project include observing how technology, engineering, and design education students at a large land-grant university in the southeastern United States utilize digital notebook tools compared to physical notebook tools during design challenges. Data will be gathered through de-identified submissions of digital notebooks and anonymous student feedback to assess the usability, benefits, and challenges of these tools. From there, a template will be constructed for use in pre-college engineering education environments.

Key areas of investigation include how the digital notebooks align with core standards, practices, and contexts of the Standards for Technological and Engineering Literacy, as well as how the digital notebooks support skills critical to both academic success and workforce preparedness. Expected outcomes include insights into best practices for integrating digital engineering notebooks into the classroom and potential recommendations for addressing challenges in their adoption, ultimately supporting educators in fostering technological and engineering literacy through innovative documentation methods.

This presentation will act as an opportunity to preview the open-access engineering notebook template that is freely accessible on Google software to middle and high schools and other pre-college engineering education environments throughout the United States of America. Discussion during this time will also be targeted toward gaining input on changes to the templates and avenues of distributing the template for pre-college engineering education applications.

Introduction

Pre-college engineering education prioritizes the engineering design process, emphasizing hands-on learning, critical thinking, and essential skills (such as communication and collaboration). Engineering notebooks and the design process on physical paper are crucial for student learning and mirror the professional practice of recording innovations. While these notebooks have historically been paper-based, driven by factors like cost, accessibility, and teacher familiarity, advancements in digital technology offer benefits that can enhance the capability of student documentation techniques. These improvements include enhanced collaboration, improved accessibility, and better alignment with the digital tools used in professional engineering settings.

Purpose and Significance of the Work-in-Progress

Developing pre-college engineering education students' technological and engineering literacy is crucial in today's digitally driven world. However, while many classrooms still rely on traditional paper-based engineering notebooks, professional engineering practices increasingly emphasize digital documentation to enhance project management and team communication. While handwritten information and drawings are valuable, they may not fully reflect the digital tools and practices used in industry today. This study aims to bridge this gap by investigating physical and digital engineering notebooks in a technology and engineering education course.

This research will examine the differences and similarities between physical and digital notebooks and evaluate their alignment with ITEEA Standards for Technological and Engineering Literacy. By investigating available resources, capabilities, and challenges of each format, this study seeks to inform effective practices for educators. Ultimately, this research will contribute to developing an open-access digital notebook template, providing valuable resources for educators to incorporate industry-aligned digital tools and practices into their classrooms to enhance student engagement and success.

Literature Review

History and Role of Engineering Notebooks

Engineering notebooks have evolved alongside advances in engineering practices and technology. Early notebooks documented key ideas and research that acted as foundational documentation for inventions, innovations, as well as scientific and mathematical progress that have had monumental influences on societies around the world. Notebooks have become an integral part of science and math education curricula from very early educational movements in the early 1900s and continue today. Over recent decades, digital platforms such as Computer-Aided Design (AutoCAD and SolidWorks), and collaborative cloud storage (Microsoft OneDrive and Google Drive) have transformed how engineers model and share their work [1, 2]. Digital tools offer enhanced capabilities, including 3D modeling, simulation, and real-time collaboration, which are now integrated into many professional workflows.

Research highlights the value of digital notebooks in education, emphasizing their ability to provide students with interactive, hands-on learning experiences that extend traditional documentation methods [3]. These tools also foster critical thinking and iterative design by allowing students to incorporate advanced features such as real-time feedback and collaborative editing [2].

Benefits and Limitations of Digital and Physical Notebooks

Both physical and digital engineering notebooks play vital roles in pre-college engineering education by enabling students to document their design processes and reflect on their progress. Physical notebooks have long been favored for their simplicity and ability to support cognitive engagement through writing and sketching, which research shows enhances memory retention and understanding [4]. They are also accessible and affordable, making them a practical option in schools with limited digital resources. Despite advancements in digital technology, many students and professionals still opt for the physical notebook format due to its ease of access and use without having to deal with the complexities of accessing expensive equipment (hardware and software) and learning about how to use digital tools [5]. The favoring of a physical notebook over a digital format continues to include the key element that physical notebooks favor a flow of creativity and intimacy to the work that digital notebooks unequally provide [5].

However, physical notebooks present challenges, including limited accessibility for collaborative work and difficulty integrating digital elements like photos, simulations, models, and data visualizations. Digital notebooks, on the other hand, excel in these areas by providing tools for extended collaboration and the integration of diverse multimedia elements [3]. They also support accessibility for students with disabilities and align closely with modern professional practices, making them a valuable resource for preparing for future careers.

Standards for Technological and Engineering Literacy (STEL)

Engineering notebooks, whether physical or digital, align with the Standards for Technological and Engineering Literacy (STEL), which is a set of nationally recognized educational standards that emphasize problem-solving, collaboration, and critical thinking [6]. Notebook tools provide students with a structured method for documenting the iterative design process, enabling them to meet STEL benchmarks for defining and solving engineering problems as well as utilizing tools. Engineering notebooks also foster communication and teamwork, as a notebook allows for the clear documentation and sharing of design choices, encouraging constructive feedback and collaborative refinement. The STEL practices prepare students for success in STEM careers, promoting resilience and adaptability in the face of evolving workplace technological demands. Educators can encourage students to develop skills essential for technological and engineering literacy, such as appropriate communication practices, critical thinking, effective collaboration, and the ability to adapt to challenges by integrating design notebooks into pre-college engineering education curricula.

Method

This work-in-progress qualitative study explores the use of physical and digital engineering notebooks through a convenience sample of 24 students enrolled in a technology, engineering, and design education course. The course focuses on incorporating technology through an engineering design process. The study was held at a large land-grant university in the southeastern United States with a particular focus on how students utilize digital notebook tools compared to physical notebook tools during course design challenges. Data has been gathered through de-identified submissions of digital notebooks and student feedback to assess the usability, benefits, and challenges of these tools. The proposed research questions, shown below, are the initial focus of this work-in-progress as the team evaluates survey questions and open-access resources that can lead to enhancements in pre-college engineering classroom practices and open-access tools.

Research questions:

1. What are the similarities and differences in student use of physical and digital engineering notebooks?
2. How do engineering notebooks align with the practices outlined in the Standards for Technological and Engineering Literacy?

Students in this sample first received lessons on the common elements typically required in an engineering notebook. These elements included: defining the problem, brainstorming solutions, selecting a solution, planning the solution, constructing and testing a model, using feedback to make improvements, and communicating the solution. In addition to these lessons, they also explored the practices associated with technological and engineering literacy as outlined in the Standards for Technological and Engineering Literacy (STELs). Following these lessons, students were tasked with a design challenge where they were required to document their design process using either a physical or digital engineering notebook. Both documentation formats required the same elements and necessary engineering design content. In previous course sections, students were required to use physical notebooks; however, in this study, the intervention of having a digital option allowed students to choose between physical and digital formats.

After submitting their engineering notebooks, students were provided with optional survey questions, as shown in Table 1. Twenty-four students submitted survey responses that provided input leading to a qualitative analysis of feedback on the use of engineering notebooks in a design project. A transcript of students' responses was analyzed using free, open-source software (Taquette), primarily used for qualitative data analysis, allowing users to upload documents and analyze feedback for elements supporting pre-established themes identified by the researchers.

Table 1: Optional Survey Questions for Student Feedback

Did you use a Physical or Digital Engineering Notebook? Please explain briefly why you chose your notebook format.
Describe how your digital or physical notebook integrates practices identified in the Standards for Technological and Engineering Literacy.
Describe briefly how using a physical or digital notebook influences your ability to express creativity and/or critical thinking in your designs.

The deductive coded themes for this qualitative analysis were established before data analysis based on the seven ITEEA Standards for Technological and Engineering Literacy Practices: Communication, Optimism, Critical Thinking, Making and Doing, Creativity, Systems Thinking, Attention to Ethics, and Collaboration as defined in Table 2 as these are elements of what engineering education encourages to possess and demonstrate[6]. In addition to the researcher's analysis of qualitative data, an AI-assisted qualitative analysis was conducted to assist in filling any potential gaps.

Table 2: Definition of Standard for Technological and Engineering Literacy Practices

Practice:	Definition:	Evidence in Responses/Notebooks:
Systems Thinking	Understanding how different parts of a system interact and influence one another.	Discussing inputs, outputs, constraints, and feedback loops related to the engineering design process.
Creativity	Applying imagination and innovation to develop new ideas, products, or solutions.	Discussion of flow of thought, sketches of multiple novel design ideas, and evidence of brainstorming with divergent thinking.
Making and Doing	Engaging hands-on with tools, materials, and processes to construct, prototype, or fabricate solutions.	Discussion of planning, construction, assembly, and/or testing, along with photographs or screenshots.
Critical Thinking	Evaluating problems, claims, and solutions through reasoning, analysis, and evidence-based decision-making.	Discussion of decision-making matrices or rationale for choosing one solution over others. Reflective questions or critiques of the initial assumptions.
Communication	Effectively conveying ideas, processes, and solutions using verbal, written, visual, and digital formats.	Evidence of peer feedback or teacher input, with responses. Use of text, diagrams, images, or hyperlinks to convey ideas.
Collaboration	Cooperatively working with others to achieve shared goals.	Discussion of teamwork or group dynamics, with an indication of team member roles and responsibilities.
Attention to Ethics	Recognizing the moral, environmental, and social implications of technology and engineering decisions.	Discussion on how the design considers user safety, accessibility, or sustainability. Identification of possible negative impacts or unintended consequences.
Optimism	Maintaining a positive, forward-thinking mindset toward solving problems and embracing challenges	Entries showing perseverance through failed tests or setbacks and the use of encouraging language to reframe challenges as opportunities.

Demographics of the 24 students in the sample include a mix of male (18 students) and female (6 students) students enrolled in a public university located in an urban setting. In the course, there were 15 juniors, 6 seniors, 2 sophomores, and 1 freshman, showing that this is primarily an audience of students who were upperclassmen. After analyzing students' responses, the engineering notebooks were analyzed for evidence supporting student responses and to provide visuals that show how the notebook formats are similar and different.

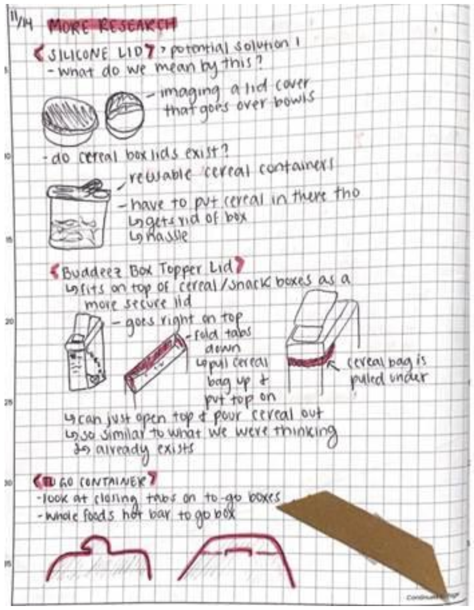
Results

This analysis explores student experiences with physical and digital notebooks. Both formats were valued for fostering effective documentation and practices associated with technological and engineering literacy, allowing students to track progress and organize their thoughts. However, key differences emerged. Physical notebooks were favored for hands-on, messy ideation, offering a more personal and intuitive sketching experience. The physical notebooks encouraged spontaneous creativity but were limited by physical space and lacked seamless integration with digital tools. In contrast, digital notebooks excelled in structure, flexibility, and collaborative potential, offering increased storage space, multimedia capabilities, and improved organization. However, some students found them less tactile, potentially reducing engagement, and their use required proficiency in digital tools, which could be a barrier for some. Ultimately, both formats offered valuable avenues for personal and team expression of ideas, and the choice of format likely depended on individual learning styles and the specific needs of the design process.

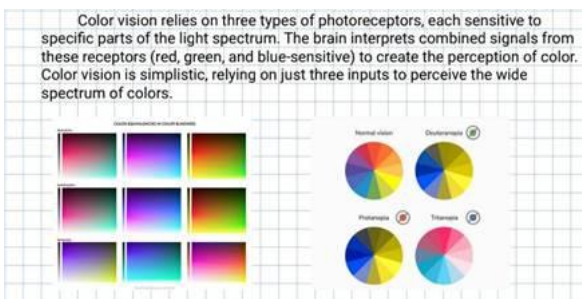
Students identify various practices from the Standards for Technological and Engineering Literacy in their responses, as summarized in Table 3, which includes quantitative data supporting the qualitative feedback. The following table demonstrates the common practices discussed in responses, the number of references made in student feedback, and visuals supporting student examples and feedback.

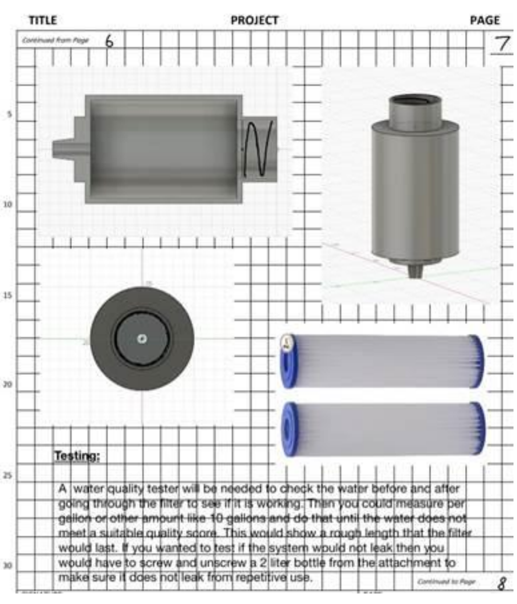
Table 3: STEL Practices From Student Responses and Supporting Evidence From Student Engineering Notebooks.

Communication (110 references made in student responses)
Students valued the ability to communicate their thoughts and ideas in both notebook formats. Physical notebooks were noted for their tangible clarity in expressing hand-drawn sketches and annotations. Below shows how there seems to be more free flow of ideation.



Digital notebooks facilitated communication through features like easy image inclusion, linking, and sharing for collaboration. Many images included in the digital notebooks are images that would not be as easily drawn in a physical notebook.





Critical Thinking (56 references in student responses)

Students emphasized how notebooks helped organize their thoughts, iterate designs, and refine problem-solving approaches. Digital notebooks, in particular, were praised for enabling edits and reorganizations to support critical thinking.

Progress Log(CARDBOARD CHAIR)

This is a straightforward log of my work. I add to this every meeting. But more detailed works and sketches are in the following pages:

8/29/2024: (Meet in class)

What we did: We started with an orthographic drawing, focusing on the side view of the chair. This gave us a good idea of how the chair would look and work. We talked through the main goals, like making sure it holds 120 pounds and can collapse.

Challenge: We worried about making the chair strong enough while still keeping it easy to take apart.

Solution: We decided to use interlocking pieces and add extra supports to make it sturdy. Next time, we'll finish a more detailed sketch to guide us through building.

9/3/2024: (Meet in class)

What we did: We took our design and made it bigger on paper to get a feel for how the chair would look in real life. We labeled the slots and made sure the measurements were accurate for when we cut the cardboard.

Challenge: We realized how important it was to be super precise when cutting, or the whole chair might not fit together well.

Solution: To avoid mistakes, we carefully labeled everything and double-checked the measurements before starting. This was important to make sure the structure stays strong.

9/10/2024: (Meet in Leazar)

What we did: Today, we built a ⅕ scale model to test the design. Afterwards, Elliot and Moayad worked on cutting brackets, and I cut the foundation. We made around 14 or so brackets to support the chair.

Challenge: The chair was wobbly and couldn't hold much weight, which was frustrating because we thought it would be sturdier.

Solution: We realized we needed more support in the base, so we decided to add extra reinforcements in our next session and rethink how we're distributing weight.

9/12/2024-9/19/2024 Remodel/Final Test: (Meet in Leazar)

What we did: We tackled the wobble problem by adding more brackets and glued extra cardboard pieces inside the chair to act like weights. This helped make it more stable.

Challenge: Even with the added support, the chair still eventually collapsed when we tested it with 120 pounds, so it wasn't quite there yet.

Solution: We'll need to rethink the base and maybe add even more support to handle the full 125 pounds. Our next step is to make those adjustments and test it again.

Research

https://www.youtube.com/watch?v=y7b3vbbWJJw

- The cardboard chair in the first video is a simple and sturdy design that can hold a lot of weight without needing complicated assembly.

https://www.youtube.com/watch?v=xVnz92YkWoc

- The second video shows a foldable cardboard chair that's easy to carry around and set up.

https://www.alibaba.com/product-detail/Popular-High-Quality-Cardboard-sofa-Cardboard_60702871092.html

- The cardboard sofa on Alibaba is made to be both strong and comfortable, using good quality folds for long-term use.

https://www.kartent.com/en/camping-chair.html

- The KarTent camping chair is lightweight and ergo-friendly, made for easy transport and outdoor use.

TEST SOLUTION/ REPEAT DESIGN PROCESS

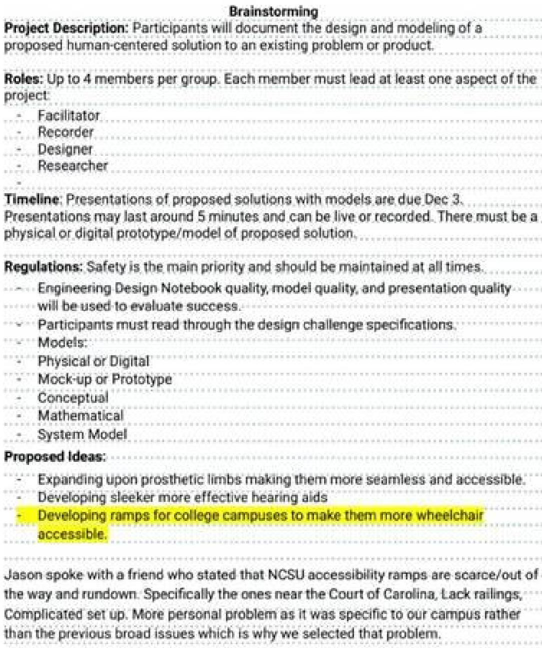
After we scaled the design on paper and made sure all the slots were labeled and the measurements were accurate before cutting the cardboard. Then, we built a 1/5 scale model. This was our first step in getting a clearer glimpse at the 3D model, this was mostly done by Elliot.

Once this was completed we moved towards making our first model, were I worked on cutting the foundation, and Moayad and Elliot focused on cutting the brackets. Unfortunately, the chair was a bit wobbly and couldn't support much weight, so we realized we needed more support at the base. This was a task that we carried on to the next class session.

By 9/12, we added more brackets and glued extra cardboard inside for stability, which made the chair more stable. However, it was still wobbling under 110 pounds, so we're planning to make further adjustments to the base to handle the full 125 pounds in our final test.

Creativity (36 references in student responses)

Many students discussed how both physical and digital notebooks influenced their creative process. They highlighted features like sketching, spontaneous idea generation, multimedia incorporation, and free-form brainstorming.



Brainstorming

Project Description: Participants will document the design and modeling of a proposed human-centered solution to an existing problem or product.

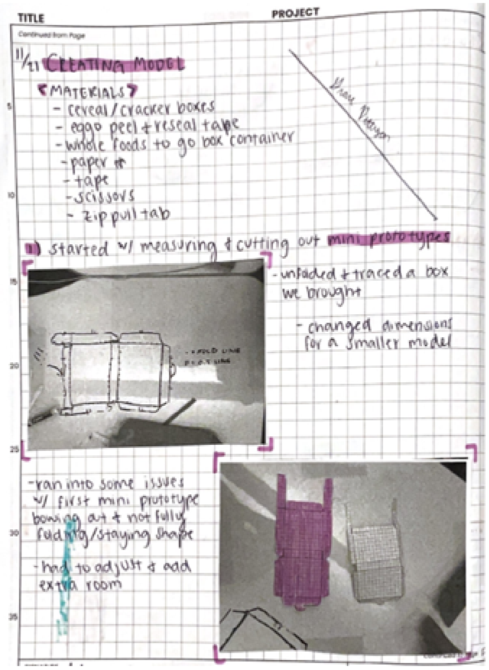
Roles: Up to 4 members per group. Each member must lead at least one aspect of the project:
- Facilitator
- Recorder
- Designer
- Researcher

Timeline: Presentations of proposed solutions with models are due Dec 3. Presentations may last around 5 minutes and can be live or recorded. There must be a physical or digital prototype/model of proposed solution.

Regulations: Safety is the main priority and should be maintained at all times.
- Engineering Design Notebook quality, model quality, and presentation quality will be used to evaluate success.
- Participants must read through the design challenge specifications.
- Models:
- Physical or Digital
- Mock-up or Prototype
- Conceptual
- Mathematical
- System Model

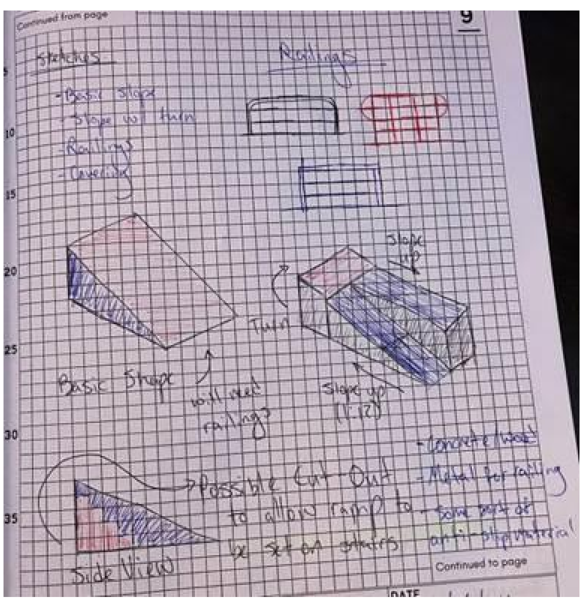
Proposed Ideas:
- Expanding upon prosthetic limbs making them more seamless and accessible.
- Developing sleeker more effective hearing aids
- Developing ramps for college campuses to make them more wheelchair accessible.

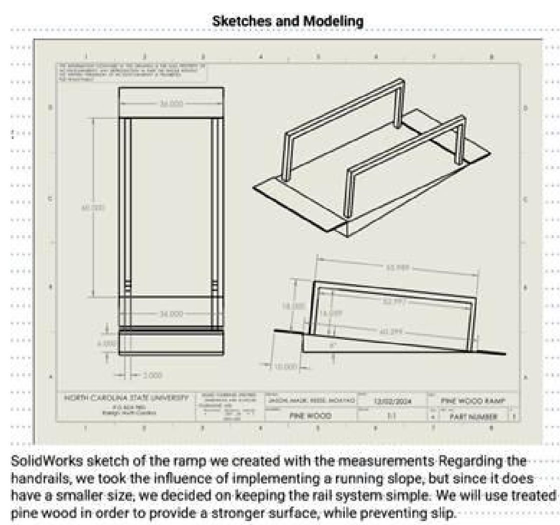
Jason spoke with a friend who stated that NCSU accessibility ramps are scarce/out of the way and rundown. Specifically the ones near the Court of Carolina, Lack railings, Complicated set up. More personal problem as it was specific to our campus rather than the previous broad issues which is why we selected that problem.



Making and Doing (52 references in student responses)

Responses frequently mentioned how physical notebooks facilitated easy flow of hands-on engagement, such as sketching, while digital notebooks offered tools for experimenting with and iterating on designs through CAD drawings.





Sketches and Modeling

SolidWorks sketch of the ramp we created with the measurements Regarding the handrails, we took the influence of implementing a running slope, but since it does have a smaller size, we decided on keeping the rail system simple. We will use treated pine wood in order to provide a stronger surface, while preventing slip.

Collaboration (32 references in student responses)

Student responses highlight how digital notebooks excelled in enabling collaboration through shareability and simultaneous editing. Physical notebooks were viewed as more personal but less suited for collaborative environments due to only having one copy and one individual working in it at a time.

TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE	10/29	10/31	11/5	11/12	11/14	11/19	11/21	11/26	12/3
Ideation Phase														
Diversity and Design	All	10/28/24	10/28/24	0	100%									
Identify Problem	All	10/29/24	10/31/24	2	100%									
Gantt Chart	All	10/29/24	11/5/24	6	100%									
Research Specifications (e.g. dimension, etc)	Tyler	11/5/24	11/5/24	0										
Ideate Design Choices	All	11/5/24	11/5/24	0										
Brainstorm Design Theme	All	11/5/2024	11/5/24	0										
Generate Concept Drawings	All	11/5/24	11/5/24	0										
Generating Solutions														
Create a Final Sketch	All	11/5/24	11/12/24	7										
Construct a Digital Model	All	11/12/24	11/19/24	7										
3D Print Model	All	11/19/24	11/21/24	2										
Testing														
Fit Test Using Trainer	All	11/21/24	11/26/24	5										
Presenation														
Create a Presentation	Lucas	11/19/24	12/02/24	13										
Present to Class	All	12/03/24	12/03/24	0										

Discussion

Qualitative student feedback establishes foundational information contributing to this work-in-progress study that investigates the utilization of engineering notebooks. Such input allows for the development of curricula support in pre-college engineering education by leading to the formation of an interactive, open-access engineering notebook template, as well as potential professional development opportunities. This involves comparing formats and identifying strengths and weaknesses, as well as communicating resources for teachers.

Physical Notebook Strengths and Weaknesses

Physical notebooks offer several strengths, including fostering spontaneous creativity through tactile engagement and the use of simple, readily available tools. Students often express a preference for the hands-on nature of physical notebooks, feeling less restricted and more creatively fluid compared to the potential constraints of digital interfaces. However, these strengths are not without their limitations.

One commonly expressed weakness of physical notebooks is the difficulty of incorporating digital tools and media. Challenges with printing costs and limited access to color printers often discourage the inclusion of images. Furthermore, physical notebooks hinder collaboration within design teams due to their single-copy nature and limited space. Sharing becomes a challenge, especially in remote work scenarios, and the need for multiple notebooks to accommodate ongoing work can be inconvenient and potentially confusing.

Digital Notebook Strengths and Weaknesses

Digital notebook strengths include greater flexibility in the forms of media that can be incorporated into the documentation. This includes screenshots, CAD drawings and renderings, animations and videos, software-developed charts and data tables, photos, and even hand drawings using a stylus. A digital notebook also allows for real-time collaboration on a single workspace or platform over long distances.

Weaknesses, or downsides, of a digital notebook format included student feedback reflecting a feeling of disconnect from free-form brainstorming. This is an attribute that was commonly able to be provided by the physical notebook formats. A lack of tactile engagement when using a digital format can inhibit the creativity and thorough design process that is desired when engineering a solution. Additionally, users of a digital engineering notebook require knowledge of digital tools. A need for knowledge means there is a need for time and resources to teach such tools to students and educators using such notebook formats in the environment. Student feedback reflects that a lack of knowledge of digital tools complicated the use of a digital notebook and led them back to the use of a physical notebook.

Comparison between physical and digital notebooks

While both formats of digital and physical notebooks possess strengths and weaknesses, they also hold similarities. A key similarity is that both formats support critical thinking, creativity, and the utilization of tools to document an engineering design process. Such similarity fosters the opportunity for students to apply design thinking and to express both their individual and collaborative ideas.

Student responses and observations revealed distinct advantages for both physical and digital engineering notebooks. Physical notebooks were favored by students who preferred a "messy" and rapid design process, enabling quick sketching, note-taking, and brainstorming due to their tactile nature. Students often perceived physical notebooks as more personal and conducive to spontaneous ideation. Conversely, digital notebooks excelled in organization, collaboration, and the seamless integration of digital media, mirroring current industry practices. Furthermore, digital formats offered enhanced portability and accessibility to notebook information and tools, leveraging the increasing availability of technology in pre-college engineering education.

Alignment with the Engineering Workforce and STEL

While engineering notebooks, in both physical and digital formats, are capable of demonstrating evidence of all practices within the Standards for Technological and Engineering Literacy, students' responses highlight and reflect upon the practices of communication, creativity, critical thinking, collaboration, and making and doing. Reflection is a key process to retaining information in a learning environment, and student input shows that not only are students reflecting on the practices, but that such impactful practices are taking place in both physical and digital notebooks, even though both formats offer their strengths and weaknesses. It is key that, regardless of notebook format, evidence of these practices is present while evaluating the technological and engineering literacy of students, which plays such an important role in succeeding in an engineering workforce.

Implications for Educators in Pre-College Engineering Education

Engineering notebooks are not a new concept in pre-college engineering education environments, and both formats are used throughout formal and informal learning environments. To prepare students for success in an engineering future, they should be familiar with the tools and practices of industry, including digital documentation of a design process. This requires a tool that allows pre-college engineering educators to assess the elements of the design process, including the practices found in the Standards for Technological and Engineering Literacy. To support this, a digital engineering notebook template is being developed by researchers of this study. There are standard templates for physical notebooks, but openly accessible digital templates that have been evaluated in classroom environments are limited.

In addition to the development of an open-access digital engineering notebook, the team seeks to develop professional development opportunities for pre-college engineering educators to practice utilizing digital engineering notebooks to promote current engineering industry design tools and practices in the classroom. While the study is not seeking to prefer one notebook format over another, the team does want to explore current options and how to incorporate them into pre-college engineering education learning environments to more effectively prepare students for what they may experience in their engineering futures.

The version 1 template can be openly accessed using the following short URL address and QR code shown in Figure 1 with the understanding that it is a work-in-progress available under a Creative Commons Attribution 4.0 International License (CC BY 4.0) meaning it is free to share, copy, distribute, and adapt the material for any purpose, provided proper attribution is given to the original source.

Figure 1: QR Codes for Open Access Engineering Notebook Template

https://bit.ly/Engineering_Design_Notebook

Limitations and Future Study

This study has limitations, including a limited sample size from a specific institution, potential bias due to access to various tools and graded assignments, and researcher bias in the evaluation process. These limitations suggest the need for further research across diverse contexts and with broader evaluator involvement. Future research directions include investigating the use of an in-progress digital template in various courses, evaluating alignment with other relevant standards, and developing professional development opportunities for educators on the effective integration of digital tools and practices in engineering education.

Conclusion

This study demonstrates that both physical and digital engineering notebooks possess unique strengths and weaknesses in supporting pre-college engineering education. While physical notebooks excel in fostering spontaneous creativity and tactile engagement, digital notebooks offer enhanced collaboration, multimedia integration, and alignment with modern engineering practices. Both formats can effectively support the application of practices outlined in the Standards for Technological and Engineering Literacy, including communication, critical thinking, creativity, collaboration, and making and doing. However, the choice of format depends on individual learning styles, the specific design challenge, and the available resources. This research contributes to the development of an open-access digital notebook template and informs the need for professional development opportunities for educators to effectively integrate digital tools and practices into their pre-college engineering classrooms, ultimately preparing students for the demands of the ever-evolving engineering workforce.

References

[1] M. R. Emami, M. C. Bazzocchi, and H. Hakima, “Engineering design pedagogy: A performance analysis,” *International Journal of Technology and Design Education*, vol. 30, no. 3, pp. 553–585, 2020.

[2] K. N. Silvestri, M. E. Jordan, P. Paugh, M. B. McVee, and D. L. Schallert, “Intersecting engineering and literacies: A review of the literature on communicative literacies in K-12 engineering education,” *Journal of Pre-College Engineering Education Research.*, vol. 11, no. 1, p. 1, 2021.

[3] J. Han and H. K. Park, “Engineer’s notebook as a cognitive device: Developing a realtime collaborative engineer’s notebook iOS application,” *Technology and Engineering Teacher.*, vol. 82, no. 5, pp. 20–26, 2023.

[4] L. Berland, W. McKenna, and S. B. Peacock, “Understanding students' perceptions on the utility of engineering notebooks,” *Advances in Engineering Education.*, vol. 3, no. 2, p. n2, 2012.

[5] P. Fernandez-Velasco, J. Nijman, and R. Casati, “The cognitive advantages of the notebook,” *Cognitive Semiotics.*, vol. 16, no. 1, pp. 3–21, 2023.

[6] International Technology and Engineering Educators Association (ITEEA), *Standards for Technological and Engineering Literacy: The Role of Technology and Engineering in STEM Education*, Reston, VA: ITEEA, 2020.