Teacher and Student Perception of Engineering Design Notebook Utility

Michael Dunham, Purdue University

Michael Dunham is an undergraduate at Purdue majoring in Mechanical Engineering, and has worked with the DeBoer Lab in Purdue's school of Engineering Education Research since 2022. His work has focused on the use of educational tools in engineering curricula in displaced communities

Prof. Jennifer Deboer, Campbell University

Jennifer DeBoer is currently Assistant Professor of Engineering Education at Purdue University. Her research focuses on international education systems, individual and social development, technology use and STEM learning, and educational environments for

Dr. Dhinesh Balaji Radhakrishnan, Purdue University at West Lafayette (COE)

Dhinesh Radhakrishnan is a postdoctoral research associate in the School of Engineering Education at Purdue University.

Nrupaja Bhide, Purdue University at West Lafayette (PPI)

Nrupaja is a PhD student at the School of Engineering Education at Purdue University. She is interested in exploring how Indigenous Knowledges can be centered in STEM curricula.

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Abstract

Design is not the only important aspect of engineering, but it is "widely considered to be [its] central or distinguishing activity" [1]. Mastering design skills requires students to practice design in authentic contexts and engage in thoughtful reflections for meaning-making. Engineering design notebooks are gaining attention by instructors to integrate their facilitation (structured, semi-structured or open) and reflections, as the notebook serves the dual purpose of learning and assessment. The notebook (product or process-focused) is intended to record the thoughts, design iterations, and research conducted by students, while the instructors are able to assess student progress in a formative and/or summative manner.

While the structure can vary significantly, we can make an important distinction between process- and product-based notebooks. A product-based notebook focuses more on reflection after the product is finished, such as a design portfolio that documents the sequential design stages. Design portfolios have been used as authentic assessment tools by instructors [2]. By contrast, a process-based notebook focuses on reflection throughout the design process. Engineering design notebooks can be structured intentionally to highlight this distinction, with a format intended to encourage reflection and emphasize process-based engineering as critical to applying design strategies in novel contexts. Thus, both students and teachers share the utility of the engineering design notebook. Students can use the notebook as a space for reflection and brainstorming, which is especially useful as a tool for instructors to have additional insight into their students' thought processes. This additional insight provided to teachers particularly becomes a valuable asset in blended and online learning environments.

Our blended learning international program works with learners who are displaced and their teachers, where student-teacher contact is limited and inconsistent. Our program recognizes local knowledge spaces and enables their role in the development of long-term community-oriented engineering solutions. To provide additional structure for students' learning and support facilitators with the scope for consistent formative assessment we developed a process-based engineering design notebook. The notebook was constructed to mirror the course content, with significant space for brainstorming, design ideas, and reflection.

In this paper, we investigate the perceived utility of the engineering design notebook to both instructors and students, as the notebook is meant to serve the needs communicated by the students while additionally being a valuable resource for teachers. We conduct qualitative analysis through teacher and student interviews. We will apply thematic analysis and draw overall themes on the perceived utilities of design notebooks described by the instructional team and their respective students. As a result, we demonstrate how engineering design notebooks help teachers support their students in an international blended learning program. This paper is relevant to engineering educators interested in increasing access to quality

engineering learning in displaced contexts, and to understand their students' design thinking processes.

Introduction

Design is one of the foundational aspects of engineering, and it is often a significant feature of engineering curricula. While a design process can be codified in a transferable way, there are elements of a design process that are highly personal, unique to each individual engineer. Thus, an important consideration for instructors is how to develop and deliver class content that allows a student's design capabilities to be effectively and accurately assessed. Similarly, given the importance of design in engineering practice, instructors must also design a curriculum that allows students to effectively engage in design thinking and practice design in authentic contexts. One tool that is being increasingly utilized by instructors is the engineering design notebook [3]. Design notebooks "are an essential pedagogical tool in the area of design", as they provide spaces for reflection, brainstorming, and documentation [4]. Utilizing design notebooks in an engineering context has the potential to be an effective means of supporting and encouraging design-based activities among students. Simultaneously, they provide instructors with a useful tool to assess and understand their students' design capabilities. Traditional methods of assessment often focus on a student's technical capabilities and on the final product, but less on the design process [5].

Engineering design notebooks can take many forms and vary significantly based on their intended use. Some professions emphasize the benefit of primarily blank notebooks, which are used to record data and sketch ideas, among other things [4]. However, Bergsman highlights the benefit of including more structure in an engineering design notebook, noting that it "[provided] scaffolding for design thinking" as well as for "learning and engaging with the engineering design process" [3]. This is especially beneficial when working with students that have limited experience with design notebooks, as they often express confusion about what should go in a blank notebook and uncertainty regarding the value of unguided documentation [6]. The structure of a design notebook can vary, with different formats being useful for different contexts. An important distinction can also be made between process- and product-based notebooks [5]. Product-based notebooks focus on reflection and documentation after a project is complete, with an emphasis on skill-based competency. Normally, instructors are the audience of a product-based notebook, as the notebook is often used for student evaluation. A process-based notebook emphasizes intra-project reflection, with space for initial ideas, brainstorming, and design justifications. A process-based notebook can also be used for student evaluation, as it gives instructors insight to their students' design capabilities and thought process.

In this paper, we explore the effects of utilizing process-based design notebooks within engineering curricula. Specifically, we investigate the utility of using such a tool among students within refugee camps in Kenya. Our Localized Engineering in Displacement program, or LED, is used as a scaffold to develop engineering programs that support the education of displaced learners. The LED program highlights the importance of recognizing

existing knowledge among learners and helps students develop problem solving skills that are applicable and relevant within their communities. For refugee camps in Kenya, the DeBoer Lab designed a process-based engineering notebook that was intended to provide the students with a relevant foundation in engineering and support facilitators of the class despite limited and infrequent student contact.

Literature Review

Several existing studies that evaluate the role of design notebooks primarily focus on their role in aiding individuals throughout a design process. As a pedagogical tool, design notebooks have been shown to be essential in the area of design, as they are valuable tools that aid in reflection, documentation, and brainstorming, as the simple act of writing and recording thoughts is a critical component of meaning-making [4], [7]. Design notebooks have the ability to enhance student learning through their various pedagogical and cognitive benefits [7]. Additional studies have examined the distinction between process-based and product-based design notebooks and their respective impact in the classroom. Process-based design notebooks enhance many of the benefits a design notebook provides, primarily through an emphasis on inter-project reflection. They can support student learning by "making their thinking visible and providing an opportunity for them to connect course material to the real world" [5]. They can also provide a scaffold for various epistemic practices and engineering learning [8]. This notebook style can allow students to work on conceptual and technical questions in the same place [9].

Research demonstrates that process-based notebooks benefit not just the students but assist instructors in a classroom as well. Process-based design notebooks, per their name, allow teachers to evaluate their student's thought processes and not simply the end product [10]. Notebooks can enable teachers to "get inside the student's head" and see what they are really thinking, and how well they are processing the information [11]. This is due to the reflective nature of the design notebook, which results in a "meaningful assessment tool for student learning" [12]. They allow teachers to give individual feedback to a student, even if they are part of a team-based project [10]. Furthermore, this kind of insight teachers have into their students forms the foundation for effective dialogue as instructors can provide feedback and adapt class content to individual students [13].

Given the fundamental role of design in engineering, we can see that design notebooks are a valuable component of an engineering curriculum. However, few studies delve into what an engineering design notebook might look like in practice. Ekwaro-Osire and Orono state that "well-formulated design notebooks" increase student learning and assist instructors with evaluation [4]. But what does "well-formulated" mean? The structure of product-based notebooks is relatively well explored, but the structure of process-based design notebooks varies significantly between institutions, and current research "does not provide clear descriptions of intended notebook contents" [5]. Furthermore, while there is a large body of research connecting design notebooks with aiding individuals in a design process, almost all focus on American universities and schools. There are significantly fewer studies

investigating the relationship between the use of design notebooks to aid learners in displaced contexts. Additionally, while there are several investigations that examine the role of an engineering notebook in the field of engineering education, very few highlight or focus on using specifically process-based notebooks, and what effect the structure of the notebook has on the learners and instructors [5]. Likewise, while it was mentioned above that design notebooks can provide a more effective dialogue between students and teachers, there is little existing research investigating the role of design notebooks in improving relationships between teachers and students. This is especially relevant if student - teacher contact is limited or unpredictable, as it is important for teachers to feel connected to their students and their work even if there is a physical distance.

Context

Our team worked to develop a process-based notebook consistent with LED principles that could be utilized by students in the Kakuma refugee camp. Two main objectives of the design notebook were to provide students with a place for reflection and a place to complete class assignments. An additional objective was to provide teachers with a tool to help structure the class and provide feedback for their students, as the teachers had minimal methods of assessing their students in previous engineering programs. This is a work in progress paper, because it is one part of a larger LED program that is still on-going regarding the facilitation of design notebooks. Additionally, we have not exhausted our data sources for a detailed and rigorous evaluation of the thoughts of facilitators and students. Similar implementations of the design notebook are occurring in the Dadaab refugee camp and in Senegal among high school learners. Therefore, it was important that the product we designed would be applicable not only to students in Kenya but that the scaffolding of the notebook could be applied as a tool to assist other groups of displaced learners as well.

While the camp suffered from known internet connectivity issues, after consulting with students and teachers our team determined that it still made the most sense to deliver the course content on online platforms such as Google Docs and Qdex. Through communications with students we learned that almost all students had Android phones, and Qdex is an application that works well with Android phones where the class content could be delivered in the form of slides that could be downloaded. Our team decided that the design notebook would be delivered in an online format for two reasons. First, we wanted it to be a dynamic system because we were communicating with the learners and instructors while the design notebook was being used, and so we wanted to make quick changes based on learners' and instructors' insight. Secondly, printing the notebook would have been a problem because the students didn't have access to a printer in the learning center where they attended classes. Printing the notebook would have required them to spend money to travel to town to where there was a printer. We also learned that Gmail use was prevalent, and so all students already had access to Google Docs. As virtually all the course content was presented in the form of Qdex slides, very little content was actually contained in the notebook itself. Instead, we concentrated on providing space for student reflection, both regarding individual activities and about the design process as a whole. A blank page associated with each lesson was

designated for students to record any thoughts the students had. An example of this can be seen below in Figure 1. However, some structure was included, as the notebook mirrored the course content with activities and guided questions. An example of this semi-structured format is presented below in Figure 2. Additionally, reflection prompts were provided to help students reflect on the best ways to apply the information they were learning in their communities. We attempted to work with instructors to provide images and questions that were relevant for the student's learning environments, and to improve the applicability of non-relevant prompts and exercises in future iterations of the notebook. Teachers were also encouraged to use translations in the local language and local examples to clarify the prompts as needed. An example of these prompts can be seen below in Figure 3.

Figure 1: Space for Lesson Reflection

Figure 2: Semi-Structured Format

Figure 3: Community-Relevant Reflection Prompts

Methods and Data Analysis

Our team conducted a qualitative case study utilizing semi-structured interviews to assess the utility of design notebooks in aiding both teachers and students. Qualitative studies are often used to answer questions that deal with perspective, experience, and meaning [14], and our team determined that a qualitative study would be the best method to help us answer the research questions *"How do engineering facilitators in displaced contexts perceive the utility of engineering design notebooks to assess and connect with their students?"*, and *"How do engineering students in displaced contexts perceive the utility of engineering design notebooks to learn class content and connect with other students?"* Two interviews were conducted over Zoom by the first author. In the first interview, the participants included two teachers. The teachers selected were chosen because of their role as the facilitators on the ground throughout the engineering course. In the second interview, the participants included three students, who volunteered to participate. The interviews were recorded, and while basic field notes were taken during the interviews, most analysis was conducted using transcripts of the recordings. The interviews on average lasted for 60 minutes, and instructors were asked about their experience using the design notebook, its role as a tool for evaluation and a documentation of students' thought processes, and how the instructors believed it affected their students' ability to engage in design thinking. The students were also asked about their experience using the design notebook, its role in helping them learn the class content, and how it affected their relationship with other students.

A third-party software transcribed recordings of the interviews. The first author verified the transcriptions by listening to the recordings. Our team analyzed the transcriptions to answer the research questions and in this way, three main themes were explored. The first was assessing the design notebooks' utility to students: if it contributed to a broader understanding of the class content, of the design process, and of the ability to problem-solve within their community. Second, we investigated the design notebook's ability to aid teachers in assessing their students' learning within the engineering curriculum. Third, we evaluated the design notebook's ability to assist students with connecting with other learners in the class and teachers with connecting with their students.

Findings

Theme 1 - Utility to Student Learning

The facilitator interviews revealed their perception of the design notebook's utility for the students, and one of the main utilities emphasized by the facilitators was that the design notebook was an important additional tool to help students solve problems in their communities.

Teacher 1: *"And then we design from the notebook…". "… [the community] want the student to progress this program and then we approve the solution to create another solution to cover this challenge, yeah."*

Teacher 1 highlights how the design notebook facilitates the iteration and development of potential solutions to problems, demonstrating how the design notebook can be used to help students in their quest to craft solutions that are specific to the needs of their community.

During the student interviews, two students had a conversation describing how and when they were utilizing the design notebook.

Student 2: *"But [the notebook] was very helpful in terms of brainstorming. It is a lot of questions and repeating coming, it was making we as learners to brainstorm, to repeat so that we can find the really correct answer."*

Student 1: *"Very often according to me, once I have free time is when I was using this notebook as a tool for reflection."*

Student 2: *"To me, I do join this class in the afternoon, and in my free time I do go to notebook, scroll, read, brainstorm, and I submit, I write the notebook."*

Student 1: *"To mean that if there's something you still need to see, you still want to understand, you can go back to the design notebook where you can remember anything. I can say that notebook was helping online and also offline. Yeah, this is all I can say. I used it when I want to remember something it helps me."*

The students highlighted the effect of the design notebook as well, emphasizing the use of the notebook as a place for reflection and brainstorming. Student 1 highlighted that having an available offline resource was valuable for remembering and reflecting on recorded information, especially if network connectivity issues prevented them from being accessible. Student 2 noted that the brainstorming opportunity that the notebook provides supports them in problem-solving.

Student 3: *"But since this is an online learning through notebook platform, at least it has helped me to record all the learning experiences on the notebook …"*

Student 2: *"[The course facilitators] were recommend to show us how we can use this notebook. This makes us easy to continue and complete the course."*

Students 2 and 3 further expound on how the notebook provides utility to student learning, as they discuss how the notebook allows them to record experiences, thus supporting the class curriculum and providing a resource and tool for students to use with the accompanying material.

Teacher 2: *"But for the student, I have seen most of them they are very curious. They're willing to learn. That's what I have seen from them during the class time"*

This statement from Teacher 2 serves as further evidence that engineering curricula should be designed to encourage and support curiosity, especially throughout the design process. As the process for creating a design notebook for displaced communities becomes more refined, it is important that it serves to help students sustain their interest throughout a potentially challenging class.

Teacher 1: *"... I have some challenge from the community because Kakuma, it is a region and it is ... arid, but I have the challenge from water and then I have a challenge from electricity, the power. And then but the student, we get this challenge and then we create a solution."*

Student 1: *"It can be very interesting for us to extend this period of learning because the course we are taking now are very important to us like community engineering. I try to practice some of what I've learnt about implementing electricity in the community. Now I tried to implement charging at home. A small business of charging phones in the Kakuma Refugee Camp using solar system."*

Teacher 1 reflects on the difficulties their region faces, and also talks about the mindset he has for his students and the importance of creating a community-based solution. Likewise, Student 1 highlights the importance of community engineering classes and the real-life effects that these courses can have. While these quotes do not directly mention the design notebook, and thus do not demonstrate the role the design notebook played in helping to create community-based solutions, it does speak to the importance of ensuring the design notebook is able to support such endeavors.

When discussing differences in the current class as opposed to past classes that did not utilize the design notebook, Teacher 2 also identifies a similar thread, stating "*The only different maybe that I have seen is you can find that in our time we identified the different problem and problem I maybe the new student now the student who are learning now, they come up with a different problem that they identify within the community. Because within our community there's a lot of problem that people can identify*".

Teacher 2: *"one of the issue was the network issue that we are ... during the class because when there's no network, a student they not be able to download the desired notebook on their phone or on their laptop, so it was quite difficult for us"*

Student 1: *"No matter how it looks like, but to be in a way everybody who is studying from a tough condition like Kakuma, can be able to join a lesson and also maybe even later, and also access the lesson and also maybe go through it, so that you can get and can understand everything you are putting inside."*

An important point mentioned by Teacher 2 was the effect that network connectivity issues had on the class. Student 1 also brought up this point, emphasizing the importance of being able to access the content even if internet service is unreliable, so that learning can continue. Having a design notebook that requires internet service to use or course content that is connection-based can be challenging to use effectively in communities with displaced learners.

Theme 2 - Student Assessment

Our conversations with the teachers provided several important insights regarding the instructors' use of the design notebook to assess their students.

Teacher 1: *"it is being called easy because the notebook it is available, and then the student will do work and then we will comment…"*

Teacher 2: "*Actually what we do for evaluation, we normally have that notebook, so the student can go through the notebooks and then they do some of the exercise within the class. After they have done with classes, now they go to Google Docs. That is where now they will submit their assignment. When they submit the assignment, that's where now we view the work."*

What both teachers highlight is their ability to consistently use the design notebook as a method for formative and summative assessment within their classes. The design notebook was accessible to students via Google Docs, so Teacher's 2 reference to submitting their assignments on Google Docs highlights the student's ability to complete assignments in the design notebooks and for the instructors to grade them.

Teacher 2: *"Maybe there's some area that we need to improve on, we tell the student that is the feedback that... To work on it again. And then after they work on it, we also require the online tutor also to view the work again, after it has been approved, that's when we move to the next classes."*

Teacher 1: "*Yes, because when the student finished the class, the assignments from the design book, me and [Teacher 1], we'll check the correction... We will check the answer and then when to prove the answer it is good."*

What both teachers emphasize is how the design notebook provided the necessary structure that the instructors needed to provide feedback to their students. Additionally, Teacher 2 describes the process wherein the online tutors, which refers to our team, review the work the students have done and how the design notebook is being used. This demonstrates that the design notebook can be used to assess students' work even by instructors who are not present in the classroom. Therefore, there is potential in using the design notebook as a method of assessment for students who are not able to be physically present with their students.

Theme 3: Student and Teacher Connection

Our conversations with the students highlighted another important point regarding the role of the design notebook in helping students form connections with one another.

Student 3: *"But since this is an online learning through notebook platform, at least it has helped me to record all the learning experiences on the notebook, and I'm able to interact with my peers using that notebook."*

Student 3 remarks on how the notebook allows them to interact with their peers, and thus help improve and maintain relationships with fellow students in the class.

Based on the literature review, we thought it might be a possibility that the design notebook would improve relationships between students and teachers. Increased teacher presence has been shown to increase students' participation and improve their overall experience in a virtual class setting, and we hypothesized that the design notebook might play a similar role by increasing teacher immediacy [15]. In the literature review we expound on how design notebooks can enable teachers to "get inside the student's head" and see what they are really thinking, how and how well they are processing the information, due to the reflective nature of the design notebook [11]. Furthermore, this kind of insight teachers have into their students can form the foundation for effective dialogue as instructors can provide feedback and adapt class content to individual students. Our team was wondering if teachers might feel closer to their students, given that the teachers would have a clearer picture of their students' thought processes. Likewise, we were curious if students might feel closer to their teachers, given that teachers were able to leave better and more specific feedback. However, neither trend was apparent in the interviews, even as some questions were directed specifically at that topic.

Theme 4: Community Specific Solutions

Additionally, the interviews supported a key characteristic of the LED curriculum, which is the importance of using engineering tools to create community-specific solutions. One potential idea the teachers suggested to further develop this characteristic in the design notebook was having prompts within the notebook that were specific to a community-related project students are working on. This section of the interview is shown below.

Teacher 2: *"Yeah, what I was saying [is] that the design notebook... They should have that design notebook the way it has been designed, but they have to create some of the project, which are some of the challenges within the camp. ... So for them, they should have different projects apart from the design notebooks. So they will continue learning the design notebook but they have different project that they can do, so that's what I was suggesting."*

Interviewer 2: *"Are you also suggesting the design notebook to have specific assignments or information that supports a single team on the specific project that they do? Let's say for example, if the students are doing wind, maybe there are specific prompts related to collecting data related to wind, to test the feasibility of the project. ... So are you saying we should integrate those project specific types of activities and prompts and questions in the design notebook as well to reflect their individual projects?"*

Teacher 2: *"Exactly, that's what I was thinking about that."*

Discussion

Through this ongoing investigation we have drawn preliminary understandings of the common results and processes of using a design notebook in engineering curricula in displaced communities. One theme that immediately stood out to us was the contribution of the design notebook to student learning. Instructors and students mentioned its impact in this respect both directly and indirectly. This was consistent with prior literature, which found that design notebooks have the ability to enhance student learning through their various pedagogical and cognitive benefits [7]. Students mentioned its utility in allowing them to record their thought processes and as a tool for brainstorming and reflection. This supports literature from Stephen, Orono, and Kerka, who wrote that design notebooks aid in documentation, brainstorming, and reflection [4], [7]. Instructors mentioned the use of the design notebook to help craft community-specific solutions. This supports research done by Berland, McKenna, and Peacock who found that design notebooks make students' thinking visible and "provides an opportunity for them to connect course material to the real world" [5].

Another theme highlighted was the usefulness of the design notebook for instructors and facilitators to formatively and summatively assess their students. Once again this was found to be consistent with prior literature, which found that design notebooks allowed instructors to see what their students are really thinking, and how well they are processing the information [11]. The design notebook provided instructors with the necessary structure they needed to evaluate their student's work, even if their work was in a group. This supports research by Merzdorf et al., who found that process-based design notebooks allow teachers to give individual feedback to a student, even if they are part of a team-based project [10].

While the network connection is still a problem, using the design notebook on an online platform such as Google Docs would allow our team or the instructors to alter the design

notebook based on the teams' projects, which would result in a much more personal and perhaps relevant experience.

The instructors also commented on some difficulties they encountered that were not related to network issues. Teacher 2 noted that *"students, especially when they're [just] starting class one to class four, there's some challenges, you find most of them they are very new, they have not [gotten] used to the system"* ... *"So the problem that we normally see is not that the design notebook is hard, but it is only that for them... But when they get used to [it], we have seen that it is quite simple."* While there was a learning curve using the design notebook, Teacher 2 highlights that it is due to the use of a new system, and not due to the design notebook being poorly designed. In fact, Student 2 noted that the notebook assisted with supporting the curriculum, even if the content was difficult, stating *"[The instructors] were recommend to show us how we can use this notebook. This makes us easy to continue and complete the course."* This provides important context for evaluating students' feedback regarding the notebook, especially if the feedback comes within the first few weeks of the notebooks' implementation into the curriculum.

Given the design notebook's ability to help teachers gain more insight into their students' thought process, as explored by Korgel, we thought we might find a change in the relationship between students and teachers [11]. However, we didn't identify any substantial information in the data that connected the relationship between students and teachers. We did however find that the design notebook helped students connect with their peers. One future iteration of the design notebook involves turning the notebook into more of a textbook style format. The same space would be kept for student assignments and reflections throughout the curriculum, but the course content would be included in the textbook as well. This was developed as a potential way to overcome connectivity issues often faced by displaced learners. As touched on above, both the students' and instructors' main critique of the design notebook format was that much of it ended up relying on an internet connection.

Conclusion

Through this investigation, our team answered the research questions *"How do engineering facilitators in displaced contexts perceive the utility of engineering design notebooks to assess and connect with their students?*, and *"How do engineering students in displaced contexts perceive the utility of engineering design notebooks to learn class content and connect with other students?"* We found that the design notebook was viewed in a positive manner, and its ability to help the students complete assignments as well as being a method for formative and summative assessment were highlighted by the instructors. The students liked how it provided a space for reflection and brainstorming and noted that it helped them connect with other students. The instructors viewed the notebook as a tool that would be useful in helping students design community specific solutions. Contrary to our hypothesis, we did not find any connection between the use of the design notebook and a change in relationships between students and teachers. Our team learned that network connectivity issues hampered the ability to use the notebook as often as the instructors would have liked,

but overall, we found that did not prevent the notebook from being an effective tool for the instructors and students.

There were several limitations to this study, which we hope to address in future investigations. Primarily, due to time and logistical constraints, we interviewed significantly fewer people than we wished. We will also target an expanded representation of roles for those who would pilot test and provide feedback for the design notebook. Additionally, both teachers who were interviewed were only from our program implementation in Kakuma and at this stage we were unable to interview teachers from other contexts. While that does not disprove its effectiveness, one of our goals is to understand what elements of a design notebook are effective throughout and transferable to different contexts. For example, our team works with displaced LGBTQ+ youth in Indianapolis, and it would be interesting to investigate what elements of the design notebook would transfer over to their engineering curriculum.

This paper and its findings contribute to our team's continued investigation into the LED program. We learned about the potential of using existing technology to create tools that can be flexible and change throughout the engineering curriculum. This is useful as students explore their interests and learn about projects for which they are interested in investigating and designing potential solutions. This supports community-based learning and problem-solving, a key component of the LED curriculum. This paper also investigates one potential structure for a design notebook; a semi-structured process-based notebook with spaces for reflections and assignments, and brainstorming. Our results are also relevant in the field of engineering education. We explore trying to optimize tools for engineering curricula using existing technology while also dealing with the attached drawbacks, which can be a difficult problem to mitigate or solve for any educator.

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