Transforming an Engineering Design Course into an Engaging Learning Experience using a Series of Self-Directed Mini-Projects and ePortfolios: face-to-face versus online-only instruction

Miss Taylor Tucker, University of Illinois at Urbana - Champaign

Taylor Tucker graduated from the University of Illinois at Urbana-Champaign with a Bachelor’s degree in engineering mechanics. She is now pursuing a master’s degree at UIUC through the Digital Environments for Learning, Teaching, and Agency program in the department of Curriculum and Instruction. She is interested in design thinking as it applies to engineering settings and lends her technical background to her research with the Collaborative Learning Lab, exploring ways to to promote collaborative problem solving in engineering education and provide students with team design experiences that mimic authentic work in industry.

Dr. Ava R Wolf, University of Illinois at Urbana-Champaign

Ava Wolf, PhD supports faculty in developing courses that emphasize active and engaged learning, and conducts research on interactive learning spaces, effective teaching strategies, and the integration of technology.

Mr. Nattasit Dancholvichit, University of Illinois at Urbana - Champaign

Nattasit Dancholvichit was born in Bangkok, Thailand in 1990. He received a B.A. degree in mechanical engineering from the University of Michigan in 2014. He received an M.S. degree in mechanical engineering from the University of Illinois Urbana-Champaign in 2017. He is currently a Ph.D. student in Mechanical Science and Engineering at the University of Illinois Urbana Champaign. He carries out research in the field of micro-manufacturing, precision control, manufacturing, and mechatronics. His research also includes control optimization and system identification. He is also a graduate teaching assistant of design for manufacturability.

Dr. Leon Liebenberg, University of Illinois at Urbana - Champaign

Leon is a Teaching Associate Professor in mechanical science and engineering at the University of Illinois at Urbana-Champaign. He is also a Fellow of the UIUC’s Center for Innovation in Teaching and Learning. Before coming to UIUC, he was a professor of mechanical engineering at two South African universities (University of Pretoria; North West University) and a higher education consultant in Switzerland where he worked with colleges of engineering and technology management. Leon is passionate about multidisciplinary research, particularly in the fields of energy engineering, biomedical engineering, and engineering education. Together with UIUC colleagues in the ENGagement In eNgineering Education (ENGINE) instructional innovation team, Leon is evaluating a wide array of pedagogies of engagement. The intention is to promote deep learning and improved engagement of students in subject matter. Leon teaches a variety of subjects, including: Innovation; Statics; Dynamics; Thermodynamics; Fluid Dynamics; Design for Manufacturability; Mechanical Design; Heat Transfer; Energy Conversion Systems; Aerodynamics; Aeronautics; and Advanced Heat and Mass Transfer. He holds a doctoral and two master’s degrees from Imperial College London and from the University of Johannesburg.

©American Society for Engineering Education, 2021
Abstract

Contemporary educational challenges have become amplified through the adoption of online-only modes of instruction due to the Covid-19 pandemic. When planning and delivering online instruction, even more than when delivering face-to-face instruction, engineering educators need to involve students at cognitive and emotional levels that encourage authentic, meaningful, and immersive learning experiences. During traditional online learning, students often feel disconnected from their learning communities. They also report a lack of motivation. Emotional engagement is therefore a necessary complement to cognitive engagement, while further helping to facilitate intrinsic motivation and feelings of delight, surprise, understanding, empathy, and trust. This study analyzes the use of scaffolded mini-projects (complex design projects divided into smaller segments) combined with comprehensive electronic portfolios (ePortfolios) in a sophomore-level Design for Manufacturability course. By emphasizing progressively more complex learning experiences and pairing these with electronic portfolios, students may become more attuned to cognitive learning processes such as effective planning and communication of complex ideas. We also hypothesize that they may develop awareness of, and competency in, skills with an emotional component including self-directed learning, autonomous exploration, and creative inspiration.

For the purposes of this investigation, mini-projects may be independent from one another or connected as a series. Lessons from previous mini-projects are built into subsequent projects, and each offers loosely-defined analytical questions and open-ended design questions that require independent research. The unfolding of scaffolded mini-projects offers an orderly mechanism for students to grow and demonstrate important engineering competencies, especially when offered in tandem with teaching-learning-assessments via ePortfolios. ePortfolios have been shown to be effective in documenting learning competencies, enabling meta-analysis and personal reflection, and improving skills in the use of social media to communicate ideas. In effect, mini-projects combined with ePortfolios may help to facilitate deeper understanding of course content, make the curriculum more relevant for students, and build connections between classroom and professional learning competencies.

This study offers a comparative analysis evaluating the efficacy of using mini-projects and ePortfolios in a face-to-face learning environment (Fall 2019) and in an online-only learning environment (Fall 2020). Participants in the face-to-face Fall 2019 \((n = 104)\) course completed a questionnaire that evaluated specific engagement constructs. The completed questionnaires were evaluated using descriptive statistics and factor analysis. Data from the Fall 2020 \((n = 64)\) course were evaluated using the same assessment methodology. It is hoped that findings from this work may contribute to the development of self-directed learning strategies that enhance students’ cognitive and emotional engagement in their learning during online-only and face-to-face instruction.
Introduction

Undergraduate students today are experiencing significant challenges as they are forced to adjust to online learning. The competitive, autonomous nature of contemporary engineering education further challenges them to take responsibility for their learning to succeed. Learning to become an engineer has always been rigorous, but the added stress of learning online has increased the need for students to develop self-regulation skills that enable them to understand and manage various facets of their learning such as motivation, organization, and time management [1], [2]. Development of self-regulation skills includes learning practices like goal setting, self-evaluation, reviewing answers to previous work, and other self-regulating strategies that require students to act of their own volition during the learning process. The development and enhancement of self-directed learning skills are not only crucial for self-regulation, but also help strengthen students’ ability to navigate learning online. This is especially pertinent in light of the tendency of online learning environments to rely on students’ autonomy by requiring them to initiate the bulk of their learning activities themselves (e.g. viewing pre-recorded lecture videos, participating in online discussions, and managing group work remotely) [3].

For most students, self-directed learning skills are not inherent but instead must be fostered through the development of agency, or awareness of one’s own competence, and effective coaching in productivity and teamwork. Both modes of development come together in the practice of design thinking (or human-centered design), now widely employed by engineering educators [4], [5]. Incorporating the design thinking process into engineering courses helps students learn the values of empathizing with end-users and co-creating solutions. Yet while engineering instructors are typically able to teach students how to develop empathy for others, they often neglect to empathize with the learning needs of their students.

One way of showing empathy for student learning needs could be to offer them opportunities to make autonomous discoveries in team-based design projects. Another might be to recognize that engineering students, who are taught to communicate design decisions through technical tools and software, often struggle to describe complex information effectively to a lay public. These subtle but important considerations in becoming empathetic to the needs of engineering students make up an important component of effective teaching. It follows that implementing this type of consideration in engineering curricula is necessary for preparing students for a modern-day workforce that is less focused on academic achievement (knowledge and scholarship) and more on emotional intelligence and skills like personality, independent thinking, and ability to work effectively in teams. Indeed, Kamp [6] writes that personal attributes like autonomy, organizational sensitivity, and empathy are increasingly important in job applications.

Developing such a skillset requires that students master the ability to make emotional connections among theoretical concepts [7]. This means that engineering educators need to involve students at cognitive and emotional levels in authentic, meaningful, and immersive learning experiences amidst a full curriculum. This study, which uses mixed methods to compare data from two semesters (one face to face, one online only) of the same Design for Manufacturability course, seeks to address this need by investigating the following broad research question: How might engineering educators leverage pedagogies of cognitive and emotional engagement to support the development of students’ self-directed learning skills?
Background

Overview of mini-projects
Per mini-project structure, course material is divided into “bite-size” chunks, with each chunk representing a core aspect of the syllabus. These chunks are then crafted into a series of mini-projects, usually between five and eight, that are offered as team-based or solo assignments. These projects made up the bulk (60%) of formative assessments in the evaluated Design for Manufacturability course, thereby shifting the focus from high-stakes exam performance to lower-stakes project performance. The decision to assess student performance on mini-projects was intentional, signaling to students that they would be assessed on both technical skill development and the acquisition of knowledge necessary to understand, utilize, create, and communicate their ideas. This assessment method also adapts well to both face-to-face and online course settings, making it both a practical pedagogical strategy and one that allows for comparative data collection on student learning experiences in-class and online.

It is important to note that the series of mini-projects offered to students is not simply a collection of discrete learning units, but rather a scaffolded learning platform that is flexible enough to accommodate the individual needs and desires of students. The use of such a platform aims not to simply cede control of the learning process to the student, but to intentionally add a degree of freedom and flexibility often missing from academic coursework. Allowing students some ability to shape their learning experience enables them to advance their personal skill set and interests in new and constructive ways. Pedagogically, the mini-projects aim to move students from a simple to a complex level of understanding; for example, moving beyond simply grasping how a tool is employed to understanding its purpose, the need(s) it addresses, and the expectations surrounding its use. In short, students learn how to think about tools and operations that are viable, feasible, and desirable. Adding opportunities for flexibility in pursuing some of their own interests can further challenge students to look beyond the tools employed in the engineering profession and recognize the fundamental relationships between acquiring foundational knowledge and developing personal expertise.

Supporting self-direction through mini-projects
As students progress through the sequence of mini-projects, their tasks become more complex and ill-defined to require independent research. The value of allowing students to engage with an ill-defined problem space, especially before they have obtained much of the knowledge necessary for analysis and design, is that doing so can lead them into a state of productive struggle that can foster a capacity to identify and take responsibility for their own knowledge needs. Students learn to become more self-sufficient and resourceful in finding the knowledge they require and then directing that knowledge toward the problem at hand. Self-directed learning also fosters personal autonomy and student agency, which can positively influence their ability to form individual academic identities. In this manner, learning becomes more about the individual and less about the course.

Strategic scaffolding in mini-projects
The first mini project in a series is typically team-based and meant to build confidence in foundational concepts. Each subsequent project builds on the previous, eventually culminating in students performing solo-based mini projects. The projects begin with well-defined tasks and progress to open-ended design tasks with ill-defined questions. The removal of scaffolds over time relies on the assumption that students are adapting to, and developing strategies for, these tasks, meaning that as they develop as designers, they are more capable of exploring and
planning within an open-ended space. Indeed, students seem to derive a sense of personal accomplishment from doing this work, which may provide further motivation and contribute to their ongoing maturation in insight and work quality [8].

Analysis, design, and reflection in mini-projects
In each mini-project, students are tasked with solving both well-defined analytical problems and open-ended design problems that require guided, self-directed learning. While some questions contain background theory and hints, the tasks are intentionally designed to require students to perform rigorous research in order to identify theory-backed solution techniques. Students are also prompted to reflect specifically on how their learning meets ABET accreditation outcomes. These reflections, which are incorporated into students’ ePortfolios, provide instructors with personalized insight into students’ experiences [13].

Indeed, using ePortfolios to support student reflection practices can be beneficial in many ways. Through the process of reflecting, students combine “how to” with “why” questions and learn to form individualized value judgments. Reflective exercises also activate emotional awareness which can lead to students “knowing that they know something” [14], [15]. Furthermore, the use of ePortfolios for self-assessment fosters the process of developing and mastering personal and professional competency in that the emotional associations students forge with course content (and with the instructor) can further prompt cognitive processes [16]. Reflective work also helps students to identify patterns and trends in the ways they work and learn, thereby composing a repertoire of strategies they might use for making future choices in contextualizing coursework and professional work [17].

Appendix A provides details of a typical mini-project, where each assignment is contextualized, followed by a series of analytical, design, and reflective questions.

Peer learning in mini-projects
The mini projects are peer-graded by other teams (and checked by teaching assistants) so that students can learn from one another’s work and reflections. This process helps students to 1) develop confidence in sharing knowledge and learning from others and 2) strengthen and defines their own areas of expertise, which in turn helps to support future problem solving and knowledge-making [18]. To facilitate effective peer grading, teams are provided with detailed grading keys and grading rubrics—where teams are asked to comment on each question instead of only providing a score. This ensures that an expected level of rigor is maintained while promoting curiosity and critical evaluation of peer approaches. Students and teaching assistants are further required to provide feedback specifically designed to help their peers to improve their “thinking” and “feeling” competencies. For ease of workflow, peer grading is performed on the Google Forms platform.

Overview of ePortfolios
Students report their mini-project work (analysis, design, and reflections) in comprehensive teaching-learning-assessment (TLA) ePortfolios. The ePortfolio format allows all students to present their findings in an efficient and accessible manner. ePortfolios also help to link a range of individualized learning experiences with diverse learning perspectives that help them build upon competencies that will be relevant to both their current studies and their future professional careers, including applying for a job by citing a link in a program or course ePortfolio [19], [20]. While engaged in this type of thinking, students inherently develop their own models of understanding that could later be utilized in their professional careers [21].
The adaptable nature of ePortfolios also allows them to incorporate a wide variety of project formats, such as PDF-type reports, augmented reality apps, or graphic novels [8]. The opportunity to customize their modes of expression.

**Figure 1.** Screenshot of a student’s ePortfolio, showing various template sections that required completion.

**Methodology**

**Design**

This study is part of an ongoing exploration of pedagogies of engagement that aims to evaluate the efficacy of several pertinent pedagogies (i.e. mini projects, ePortfolios, guided self-directed learning, peer learning, analysis & design) in a sophomore-level Design for Manufacturability course [8].

**Participants**

All undergraduate engineering students enrolled in a sophomore-level Design for Manufacturability course in the Fall 2019 (face-to-face) and Fall 2020 (fully online) terms were sent a survey designed to measure their cognitive and emotional engagement as they experienced the use of ePortfolios embedded in a series of mini projects. All content and assessments were identical in both terms, and all students were required to participate in the course activities. No incentive or other enticement was offered for participating in the survey. Survey participants were assured that their responses would be fully anonymized. Data from anonymous teaching evaluation questionnaires was also collected. Of the 160 of surveys sent there were 104 respondents from the Fall 2019 term, and 62 respondents from the Fall 2020 term. The disparity...
between 2020 and 2019 participants is most likely influenced by factors related to the pandemic, which impacted students’ ability and willingness to participate.

**Analysis**
Student engagement was measured using a series of questions to evaluate cognitive engagement and emotional engagement that were devised by following the guidelines and factor-groupings in Halverson and Graham’s extensive meta-study [33]. All questions were written in such a manner that aligns high positive values with a desired agreement response. Response options corresponded to the following Likert scale: strongly disagree, disagree, slightly disagree, slightly agree, agree, strongly agree. Questions were preassigned to the following 13 factors: anxiety, attention, comfort with ambiguity, creativity, curiosity, willingness to embrace risk, empathy, enjoyment, lack of boredom, lack of frustration, optimism, teamwork, and (conceptual) understanding. All responses were coded numerically to indicate positive and negative tendencies; “strongly disagree” corresponded to -3, “disagree” to -2, “strongly agree” to 3, and so on. Factor analysis was used to measure the correlation of students’ responses to task-related experiences. Appendix B lists the questionnaire questions.

**Results**

**Quantitative**
Questionnaire prompts were grouped according to the above factors. Figure 2 summarizes the salient results captured by the questionnaires for both face-to-face instruction (Fall 2019, \( n = 104 \)) and online-only instruction (Fall 2020, \( n = 62 \)). A tendency toward the positive x-axis indicates a more positive response to the factor captured by the questionnaire prompt; in other words, a higher value means that students on average tended to more strongly agree/identify with the prompt. A negative value indicates that students on average tended to disagree or did not identify with the prompt.

![Figure 2: Salient results of student evaluation questionnaires from online-only instruction in Fall (2020) and face-to-face instruction (Fall 2019).](image)
Table 1 presents statistical data of the 32 questions grouped in 13 factors.

**Table 1. Statistical Results of Questionnaires for Face-to-Face (Fall 2019) and Online-Only (Fall 2020) Instruction**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Mean, $\bar{X}$</th>
<th>Standard Deviation</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anxiety</td>
<td>0.252</td>
<td>0.460</td>
<td>1.939</td>
</tr>
<tr>
<td>Attention</td>
<td>1.439</td>
<td>1.489</td>
<td>1.665</td>
</tr>
<tr>
<td>Comfortable with Ambiguity</td>
<td>1.223</td>
<td>1.769</td>
<td>1.437</td>
</tr>
<tr>
<td>Creativity</td>
<td>1.515</td>
<td>1.185</td>
<td>1.284</td>
</tr>
<tr>
<td>Curiosity</td>
<td>1.328</td>
<td>1.301</td>
<td>1.412</td>
</tr>
<tr>
<td>Embracing Risk</td>
<td>-0.223</td>
<td>0.656</td>
<td>2.005</td>
</tr>
<tr>
<td>Empathy</td>
<td>1.097</td>
<td>0.839</td>
<td>1.517</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>1.233</td>
<td>0.790</td>
<td>1.518</td>
</tr>
<tr>
<td>Lack of Boredom</td>
<td>-0.364</td>
<td>2.048</td>
<td>2.066</td>
</tr>
<tr>
<td>Lack of Frustration</td>
<td>0.282</td>
<td>1.184</td>
<td>2.013</td>
</tr>
<tr>
<td>Optimism</td>
<td>1.602</td>
<td>0.870</td>
<td>1.218</td>
</tr>
<tr>
<td>Teamwork</td>
<td>2.289</td>
<td>1.337</td>
<td>0.828</td>
</tr>
<tr>
<td>(Conceptual) Understanding</td>
<td>1.073</td>
<td>1.057</td>
<td>1.806</td>
</tr>
</tbody>
</table>

Table 1 and Figure 2 show that participants responded overwhelmingly positive (averaging responses of at least “Slightly Agree” on a six-point Likert scale ranging from “Strongly Disagree” to “Strongly Agree,” $\bar{X} > 1.000$) for factors pertaining to attention, comfort with ambiguity, creativity, curiosity, empathy, enjoyment, optimism, teamwork, and conceptual understanding for face-to-face instruction. Participants responded overwhelmingly positive for factors pertaining to attention, comfort with ambiguity, creativity, curiosity, lack of boredom, lack of frustration, teamwork, and conceptual understanding for online-only instruction. Factors pertaining to attention, curiosity, and conceptual understanding received the same responses across both conditions to within one decimal place. For the face-to-face condition, teamwork received the best correlated response; this was the only factor to receive responses averaging at least “Agree” on the Likert scale. For the online-only condition, lack of boredom received the best correlated response; this was the only factor to receive responses averaging at least “Agree” on the scale.

**Qualitative**

**ePortfolio reflections**

In each of the ePortfolios that accompanied the mini projects, students had to reflect (independently) in no less than 300 words on her / his learning experience on specific mini projects. Below is a sample of excerpts from students’ reflections (names have been changed):

“I’ve found that my strengths include formulating processes to be more efficient and that my ability to create diagrams for explanations is better than I thought. However, when it comes to weaknesses, I am terrible at time management. Mini Project 10 was the most...”
planned-out project I have ever done, and even on the last day I was still cramming in work.” (Susan)

“I enjoyed working in the team because of how well we were able to delegate work – although we were together for the entirety of the project, we still managed to all work on separate things when it was required, allowing us to finish our ePortfolio efficiently while still covering all of the necessary content.” (Jermaine)

“Supplementing mini projects with the in-class lectures helped me get a much better understanding of design for manufacturing as opposed to just sitting down in class and taking notes. The mini projects and ePortfolios completed throughout the semester allowed me to improve my critical and creative thinking skills while learning valuable knowledge outside of the classroom. The most beneficial part of the mini projects and ePortfolios was that we had the opportunity to solve the problems being presented in our own fashion.” (Tony)

“If I had to highlight any aspect of ME 270, it would be the mini projects and ePortfolios. It was the part of the course that I spent more time working on. The fact that it was based on a research activity taught me where to look for reliable information. It was a challenge to give the best of me in order to not fail my team.” (Francine)

“The first Mini Project we were assigned, we quickly gained skills in reverse engineering a product and, much to my surprise, honed skills in communicating our ideas in a formal report format. It is my belief that this first task was integral to our success in the course as it formed the foundation for skills and thought processes that were later relied on heavily as the course proceeded.” (Sirius)

ABET program learning goals
Teams were asked to discuss each ABET program learning goal. All teams and individuals performed this activity in detail, indicative of their interest to learn how they are learning and how their learning addresses ABET learning outcomes. Below is an extract from one team’s answer regarding the following ABET learning outcome: “An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.”

“Mini-Projects: The mini projects in this course challenged our team to analyze complex engineering problems from various perspectives, and in some cases tasked us with ideating unique design solutions. In the analysis portion of the mini project, we were frequently tasked with formulating solutions by researching and applying equations and principles from authoritative engineering textbooks. In the design portion, we were given the open-ended task of identifying problems from inefficiencies in design, to possible reasons products were discarded. The design portion also challenged us to solve these perceived shortcomings through simple design solutions, such as reducing the number of parts in an assembly or choosing a more durable material.

Homework/quizzes: The homework and quizzes met this learning target by ensuring we could rigorously apply mathematical equations and insights in the appropriate contexts.
Labs: Many of the labs provided us with a solid framework to analyze and solve engineering challenges. For example, in the design of experiments lab, we used an extensive statistical analysis to gain insights into the effects of factors on a given response - a process which is very applicable in many areas of engineering.

Lectures: Though we did not typically need to apply our knowledge in lecture, we gained the knowledge we needed to identify engineering problems.

Independent learning of modules: Independent learning was crucial to solving the engineering problems faced in the mini projects for this course. Using credible online resources, textbooks and journal articles proved vital to understanding and applying the principles needed to solve engineering challenges” (Alison, Robert, Jackson, and Michelle).

Open-ended feedback
Students also had the opportunity to provide open-ended anonymous feedback in end-of-semester teaching evaluation questionnaires. A sampling of their responses is provided below:

“I enjoyed the mini projects and the ePortfolios. Very interesting + learnt a lot”
“Using ePortfolios helped me distill my thoughts”
“More ePortfolio work, please, from freshman year to senior year”
“Self-directed learning is not my preferred style of learning, but it fosters a responsibility for oneself”
“The projects and ePortfolios helped me to strongly connect with the various topics”
“The ePortfolios forced me to work better, as others in class could see my work”
“Producing the portfolios made me feel more like a student engineer than an engineering student. I loved it!”
“I had a blast working on mini project 10 as there was very little structure forced on us and we could do our own thing, and then display it all with our ePortfolios”

Our participants’ comments in each of these formats support their apparent cognitive and emotional engagement in the learning activities which featured ePortfolios as part of a series of mini projects.

Discussion

Quantitative
For the face-to-face condition, anxiety, willingness to embrace risk, and lack of frustration were deemed to be of lesser importance (−0.3 < \(\overline{X}\) > 0.3). In comparison, all factors received positive responses (\(\overline{X} > 0.3\)) for the online-only condition. The positive tendency of anxiety during face-to-face instruction (\(\overline{X} = 0.25\)) can be deemed as having positive or negative attributes. Pekrun noted that on simple tasks anxiety does not affect, or may even enhance, performance; however, learning may become impaired on complex or difficult tasks that demand
cognitive resources [22]. Thus, anxiety may be deleterious to emotional and cognitive energy reserves in complex learning contexts.

The factor of attention enjoys a relatively large positive reaction ($\bar{X} = 1.489$ for face-to-face instruction and 1.439 for online-only instruction). This cognitive engagement factor is seen by many as the gatekeeper for information processing [23] and is therefore one of the basic indicators that students are engaging mental effort in the learning process. Participants also report that the ePortfolio-based activities supported their conceptual understanding become immersed in subject contents ($\bar{X} = 1.073; 1.057$). This is indicative of students becoming more deeply absorbed in the subject contents, which may be a sign of deeper flow, which is described by Csikszentmihalyi as “a state in which people are so involved in an activity that nothing else seems to matter” [24]. Students’ potential engagement with subject content is further supported by a similarly positive response for curiosity ($\bar{X} = 1.328; 1.301$). When combined with the qualitative results in the following section, these findings indicate that students perceived the mini projects and ePortfolios to be personally relevant. As Dewey noted, “situational interest may develop into individual interest, which is characterized by curiosity and self-guided exploration” [25].

It is now accepted that emotions cannot be separated from thinking in guiding rational behavior, memory retrieval, decision-making, problem solving, and creativity, among others [26]. As it follows that positive emotions assist learning, it is heartening to see that the participants experienced the series of mini projects and related ePortfolio assignments as enjoyable ($\bar{X} = 1.233$ for face-to-face instruction; 0.790 for online-only instruction). Although enjoyment (i.e. situational interest) is deemed to be a short-lived affective state [27], it nevertheless focuses attention, enhances cognitive performance and learning, and improves integration [28]. If mini projects and ePortfolios indeed spark students’ interest, it follows that students are better engaged. In this respect, the factor of enjoyment is also seen as a short-lived factor, but one which may be associated with increased creativity and cognitive performance [29]. The factor of optimism, which can be considered like a sense of a confidence, may precede and facilitate engagement, as students are more likely to exert effort in tasks if they believe that they have the capacity to succeed [30]. Likewise, this attitude can also indicate engagement, as it depends on events that occurred in solving the previous problem and not on students’ incoming beliefs [31].

Overall, the quantitative results suggest that the production of ePortfolios as part of a series of mini-projects increased participants’ cognitive engagement (e.g. attention, curiosity, teamwork) and emotional engagement (e.g. enjoyment, lack of frustration, optimism) in an interconnected manner.

**Qualitative**

From reviewing students’ comments across opportunities for both self-reflection and course evaluation, findings indicate that students not only enjoyed a meaningful and deep learning experience but also had fun in the process. Students reported that involvement in assessment of their peers’ mini projects led to them taking more responsibility in their own (future) mini projects and enhanced self-learning management.
Results also suggest that students’ awareness of peer assessment improved their activation more than the quality of the feedback itself. Peer grading further helped students to understand what elements are appreciated in an answer and to identify common mistakes or deficiencies. This insight provided students with a meta-perspective on their own understanding and learning; other research substantiates this finding [32]. As students gave and received feedback from their peers, they enjoyed the benefits of incorporating other views and perspectives into their progress to help identify, strengthen, and consolidate their learning experiences.

Conclusion

A sophomore-level Design for Manufacturability course was transformed using a series of 10 self-directed mini-projects in which students worked in teams (for the first nine projects) or alone (for the tenth project) and reported their work using ePortfolios. Working in this way provided a scaffolded course that incorporated authentic projects, real-world products, self-assessment, competency showcasing, and reflective practice, all underpinned by peer grading to enhance conventional evaluation. Of importance to this investigation was the emphasis placed on 1) personal reflection in the context of developing required competencies in engineering practice and 2) the intertwined connections of cognitive and emotional engagement.

Preliminary results suggest that mini-projects and ePortfolios help foster self-directed learning, as well as enhance self-awareness, by providing students with valuable insight into their own learning styles. The awareness gained from this process in turn helps students to regulate, change, and improve learning behavior, while also fostering the development of critical thinking skills by prompting students to conceptualize and articulate their thinking in a disciplinary context.

Our findings indicate that students took ownership of their learning through reflective engagement and were able to create compelling product (or process) ePortfolios with minimal faculty intervention. The students also enjoyed crafting their ePortfolios and sharing them with other users. They took charge of their learning in realms outside of the lecture room and laboratory and became responsible for their individual knowledge and skills. Prompted by the mini-projects, students acquired most of their course-related knowledge and skills independently and with minimal guidance. They also effectively reflected on their learning experiences and on meeting ABET program goals, further suggesting meaningful and self-directed learning.

The strength of mini-projects and ePortfolios lies in their capacity to build reflective ability. When used in formative assessment formats, feedback from peers, instructors, and teaching assistants helps students to identify their strengths and stimulates the development of future learning goals and strategies. Successful ePortfolio-based projects require unambiguous and detailed grading rubrics, which provide students with well-defined objectives and explicit assessment criteria. The use of comprehensive grading rubrics also supports faculty and teaching assistants in providing feedback to support student learning and progression. In this study, students effectively collaborated with each other on team-based mini-projects while also producing meaningful individual mini-projects. Comparison of ePortfolios for the first mini-project compared to the last mini-project shows immense growth in knowledge, skills, and reflection.
This study sheds light on innovative ways to utilize mini-projects and teamwork to help cultivate self-directed autonomous leaders. Our investigation has revealed that mini-projects and comprehensive ePortfolios support and streamline student assessment in ways that enrich their learning experience while satisfying the need for institutional accountability (such as ABET accreditation). Mini-projects and ePortfolios have the potential to facilitate deeper understanding of course content, make the curriculum more relevant for students, and help build connections between classroom and professional learning competencies. To ensure quality of learning, mini project-based teaching and learning activities must be aligned with, and supported by, authentic assessment activities. The successful integration of ePortfolios with project-based learning (such as a series of mini-projects) enables a course to be transformed into a series of engaging learning experiences.

**Future Work**

Although the findings of this study have been overwhelmingly positive, there are areas that merit further investigation. In future work, student performance in final exams will be collected for documentation and comparison to determine whether ABET and other learning outcomes achieved through creation of ePortfolios are similar or different to those achieved through traditional instructional and assessment methods. Other questions for future investigation, which will require follow-up interviews and questionnaires, are listed below:

1) How do mini project and Portfolio-based activities affect the development of student expertise over time?
2) Do e-Portfolios help students to reflect on their achievement of both course and program learning goals?

This study does not include rigorous analyses to quantify statistical significance of data. This will be done in follow-up work.

**Acknowledgements**

This study benefited from a grant of the Academy for Excellence in Engineering Education (AE3), University of Illinois at Urbana-Champaign. The study was approved by the UIUC IRB, protocol #19162, “Evaluation of Pedagogies of Engagement”. The authors greatly benefited from discussions with fellow team members of the ENGagement In eNgineering Education (ENGINE) strategic instructional innovations project team, University of Illinois at Urbana-Champaign: Justin Aronoff PhD, Robert Baird PhD, Cheelan Bo-Linn, Yuting Chen PhD, David Favre PhD, Tim Hale PhD, Chad Lane PhD, Kate LaBore PhD, Lewis Lehe PhD, Mina Mikhaeel PhD, Jessica Mingee, Shelly Schmidt PhD, Saad Shehab PhD, Esmee Vernooij, and Jim Wentworth. Thank you also to the several anonymous reviewers who provided incisive comments and excellent suggestions.
Appendix A: Typical Mini-Project

Mini-project 9B: Re-purposing, Reuse and Recycling [200 points]

**CONTEXT**

*Re-purposing and Design-for-Re-purposing*

How can design facilitate a solution to this problem? Design for re-purposing presents a strategy for incorporating the concept of re-purposing in production-system design, which aims to extend the longevity of products by intentionally designing features or details that facilitate re-purposing.

Re-purposing is creating a new or a second life for an end-product by making some small modifications to it. It is a common practice. People have been transforming things in ways that were not originally envisaged since they begin re-purposing objects.

Large-scale re-purposing of existing objects can also be observed during times when a population experiences a shortage of products or materials. A good example of this is the post-war period in Germany, where some objects experienced a significant transformation when it came to re-purposing, for instance, children's clothing made from military uniforms, and instruction manuals for the construction of cooking ovens out of discarded suitcases.

The use of Coca-Cola in some countries is another example of total transfer of function and meaning. In feudal Japan, the Coca-Cola bottles are symbols of luck and are now placed on altars. In Mexico, Coca-Cola is often used as a drink (chance) [2]. In Nepal and Cambodia, some pots are commonly used to filter water. These objects are taken out of their original contexts purposes and functions and transformed and used in a different environment for purposes that are very different to be used.

Re-purposing is a rich source of invention. It means, “to use more than once”.

By taking useful products and enhancing them, reuse helps save time, money, energy, and resources. An object is not discarded, but reused for the same function, without suffering any transformation. A freer concept is one that is reusable.

It is therefore apparent that re-purposing offers several benefits:

- **Re-purposing can save costs.** Creative use of available products in life-saving functions, such as using commercial air filters for medical face mask material or using cheap non-renewable products to function as ventliners for critically ill patients.
- **Re-purposing can save energy.** The amount of energy consumed when re-purposing is minimal compared to the energy required to acquire and transport raw materials from their source. Also, the energy destined to re-purposing is saved.
- **Re-purposing preserves environmental conditions and reduces pollution.** It helps the environment by minimizing the energy spent on industrial production and recycling (which creates toxic materials that pollute the environment).
- **Economic benefits.** Re-purposing saves money by producing new products from raw materials. These expenses include the entire production cycle starting from acquiring the raw materials, transforming them from their origins to production plants, processing, manufacturing, and disposal cost.

- **Re-purposing cuts the need for raw materials.** Most of the landfill sites are filled up with a lot of used products. Some of these waste materials belong to non-degradable materials, which take a long time to decompose. Re-purposing avoids releasing damaging objects by expanding products longevity.

**Design for Re-purposing**

Design for re-purposing sets the conditions for re-purposing. It is an evolved design strategy that proposes that it is possible to design a product with features and details that facilitate re-purposing. It is in fact also possible for design to enable future re-purposing, even though the condition of re-purposing might not be fully known in advance. When designing for re-purposing, the designer does not necessarily control or direct the ultimate re-purposing, but only sets the stage for possibilities. In this way, design for re-purposing and the set of re-purposing are distinctly different (but complimentary) acts.

Design for re-purposing aims to add to the abundance of products we discard of everything that is not designed solely for composting, reusing or represent any kind of danger to human beings, and whether the original materials are not necessarily reproducible. In the original design, products are abnormally given quantities that facilitate their transformation into another product with different purpose-function once their first life span has expired. The main goal of this strategy is to extend products’ longevity, but this act may also save lives.

**Re-purposing and Design-for-Re-purposing**

Re-purposing needs to be understood in comparison to other practices. The commonly understood definition of recycling is to collect similar materials and reprocess into them new products. Most recycling, however, depends on materials quality existing in ‘down-cycling’, i.e. with such recycled materials, the quality of materials such structures and construction. Recycling is often thought of as the great solution for unwanted or broken objects and materials. However, it comes with several disadvantages, such as the need to reproduce the original material and the energy required to accomplish this task.

Re-purposing is essentially the reverse of manufacturing products; go in; and materials come out. It is well-balanced and highly developed practice but is not mainstream built. For instance, the scale of recycling actions is currently unmeasured and although recycling usually has a beneficial effect on the environment, it is primarily an economic activity, thus to be made money.

More importantly, although products are manufactured using specific production facilities, they are assembled and discarded in bulk, with different types of products ending up in the same waste stream and they are then processed together. It is therefore important to know in which waste stream your product is likely to end up and how.

The manufacturing fraction of waste, cost, and quality can also be used to interpret recycling streams with products. Certain products can be easily recycled into separate high-quality materials, whereas others cannot (or only at high costs). The concept that explains this trade-off is the grade recovery curve.
2. DESIGN CHALLENGE [100 points]

Find a disassembled product that you can reassemble (i.e. a toy or a different application than initially intended). Your reassembled product may or may not be used in medical applications.

2.1. Describe the product that you will reassemble using the design concept of reverse engineering, whilst also considering recycling and reusing. Show a high-resolution and clear picture of your chosen product which you will reassemble. Provide descriptive text about its assembly. Briefly describe your design objective (e.g. producing a do-it-yourself, cheap and effective children’s toy using existing machine parts).

2.2. Research. Your task is to determine if children are interested in reassembling a product similar to your chosen product. Loan out your product to children and find out who would be interested in reassembling it. Also, perform a survey to find out what parts of the product would be used in the reassembly process.

Next, research the materials and parts that are used in the reassembly process. Use these materials and parts to reassemble the product in a similar manner to the original product. (This link to Question 2.2)

2.3. Details for disassembly and assembly:

- Provide a detailed description of your reassembled product, including the official product name, model number, cost (if newly purchased), and URL. Use sites such as Amazon.com or McMastersCn.com.

- Clearly list all the parts of the reassembled product using a [list of Materials and parts] and whether they will be reassembled. Identify all parts that will be used in the reassembly process, state whether they are suitable for recycling or reuse. Also, based on your research, identify what materials your product or its parts are made of, and what manufacturing method (e.g., plastic injection molding) was used in its manufacture. (This link to Question 2.2)

- How would you simply and safely separate the components of the product which you want to reassemble? What tools would you use to reassemble it? (e.g., screwdrivers, knives, pliers, hammer) to assemble the product which you want to reassemble?

- Ask the DRA (Design for Assembly) questions in Chapter 12 of Mike Philpot’s text book (and included in your student note) of each part to identify opportunities for simplification by reducing the number of parts in your reassembled product. What are its (a) Number of Parts in the assembly, and (b) the “Theoretical Minimum Number of Parts” in the assembly? Ask any ideas that you have for combining or simplifying parts.

2.4. Details for materials:

- In products designed for reassembly, materials and components are desirable and capable of functionally as well as another role. It is ideal that materials are less-labour-intensive (e.g., stainless steel). Describe how your reassembled product or parts feature durable materials, and list these materials.

- Discuss the materials, and provide a list of the materials used in the reassembly process. (This link to Question 2.2)

- In a paragraph of two sentences, describe the manufacturing process for the reassembled product. This may include the use of metal or plastic injection molding, as well as the tools or equipment used to produce the product. (This link to Question 2.2)

2.5. Informational: Explain how many of the reassembled components might offer multiple functions, such as transportation, health, or air filtration. State to ensure that potential in the newly configured design.

2.6. Coding, easy and obvious: How will you display design data on the product (e.g. child who needs it to be developed)? Your reassembled product will be effective if it makes the reassembly a child-friendly experience or be in smaller units and clear explanations.

2.7. CAD modeling of the reassembled product: Develop a full 3D CAD model of your reassembled product. Detailed engineering drawings must be supplied as well as a solid model.

2.8. Foldable/attachable design: how would you perform a durability design of the product with which you would want to display your reassembled product. Follow the steps below.

- Step 1. Identify the performance variables and design variables.
- Step 2. Define (given) the natural layout of the reassembled product. Construct a suitable layout with your process: evaluate.
- Step 3. Plan the prototype testing by developing an experimental matrix, choosing the number of trials, levels for each design variable, number of replicates, and how the response will be measured.
- Step 4. Generate individual (but physically appropriate) data for each of the trials and replacents.
- Step 5. Analyze the results by constructing an appropriate statistical analysis. Construct the average variance of a subset of design variables and the standard deviation of the regression model. (This link to Question 2.2)

3. ePortfolios (15 bonus points)

Note: production of this ePortfolio is not a mandatory task.

If you want to earn 15 bonus points, produce a high impact ePortfolio about your Mini Project.

You may choose from any five ePortfolio platforms such as Wix, Weebly, Google, Tumble, Joomla or Drupal.

What? The ePortfolio is an online visual-based representation of this assignment. Refer to the rubric to evaluate the presentation of your project and other materials. (Use the rubric like this).

Why? The ePortfolio will help you to display your level of commitment to research, computational, and design for manufacturability, and reflection skills.

An online ePortfolio is a great way to convey your personality and highlight your achievements and experiences in a more user-friendly format, and to share that with a variety of audiences.

---

GRADING RUBRIC WHICH WILL BE USED TO EVALUATE YOUR MINI PROJECT (Only for TA’s and the Instructor will grade this assignment.)

---

---
Appendix B: Questionnaires

Participants were provided an online questionnaire with questions that could later be ordered in terms of (a) cognitive engagement and (b) emotional engagement. These questions and their ordering into factors are based on the extensive meta-study reported in [33]. All questions were answered on a 6-point Likert scale.

A) Cognitive Engagement

Attention

The mini projects / ePortfolios focused my attention on specific topics.
The variety of design challenges and research work in the mini projects / ePortfolios kept my attention.

When I worked on the mini projects / ePortfolios, I devoted my full attention to my work.

Curiosity

When I am in class, I feel curious about what we are learning.
The mini projects made me feel like I was discovering new things.
I feel safe taking risks with my team.

Creativity

The mini projects helped me use my creativity to effectively solve complicated problems.
The mini projects encouraged me to be creative.
My evaluation of my peers’ mini projects / ePortfolios helped me develop my own design skills.

Embracing Risk

The open-endedness of the mini project tasks made me more comfortable with taking risks.
I feel safe making mistakes with my team.
I feel safe taking risks with my team.

Teamwork

I would prefer to work in a team than alone on the mini projects.
I feel that every individual team member makes a difference in my team’s work.
The mini projects helped me to quickly connect and build relationships with fellow team members.
I feel free to introduce new or different ideas for my team’s projects.
In my team, the work is divided evenly over the team members.

Understanding
In my reflections, I was able to connect what I learned in this course to knowledge from other courses as well as to possible future applications.
The reflection tasks helped me to better understand what I learned in the mini projects.
Doing the mini projects increased my understanding of design for manufacturability.
The mini projects helped me understand concepts better as compared to traditional class format.

B) Emotional Engagement

Anxiety
Working on the mini projects / ePortfolios caused me to feel anxious.
Working on the mini projects / ePortfolios took more time than I wanted to spend.

Boredom (translated on graph)
I was bored when doing the mini projects / ePortfolios.
Working in a team on the mini projects was boring to me.

Comfortable with Ambiguity
I feel comfortable interacting with my team members.
I felt comfortable sharing my knowledge with my mini project teammates.
I feel comfortable asking the team for help when I do not understand something
I feel safe discussing tough project issues with my team.
I feel comfortable learning new things with my team.
I am comfortable working with people who have different perspectives and abilities from mine.

Empathy
The mini projects helped me to empathize with the concerns of other people.
Working in a team on the mini projects / ePortfolios was boring to me.

Enjoyment (situational interest)
I would rather work on the mini projects / ePortfolios than do work for other classes.
I enjoyed the fact that a solution to a mini project problem could result from an unexpected direction.
I enjoyed doing the mini projects.

**Frustration (translated on graph)**

Working in a team on the mini project problems frustrated me.
I feel my effort is undermined by others in my team.
In my team, the work is done by a small minority of team members.
I was dissatisfied with the open-endedness of some of the mini project tasks.
The real-world scenarios in the mini projects were frustrating to me.

**Optimism**

The mini projects / ePortfolios helped me realize that I desire to have an impact on people around me.

Working on the mini projects / ePortfolios caused me to see myself in a positive light.

My experience working on the mini projects showed me that I can overcome difficult challenges.
References


