# 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

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# WIP: Transforming an Engineering Design Course into an Engaging Learning Experience using a Series of Self-Directed Mini Projects and ePortfolios


## 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, [8] 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 [9]. 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 [6]. 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 [10], [11]. 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

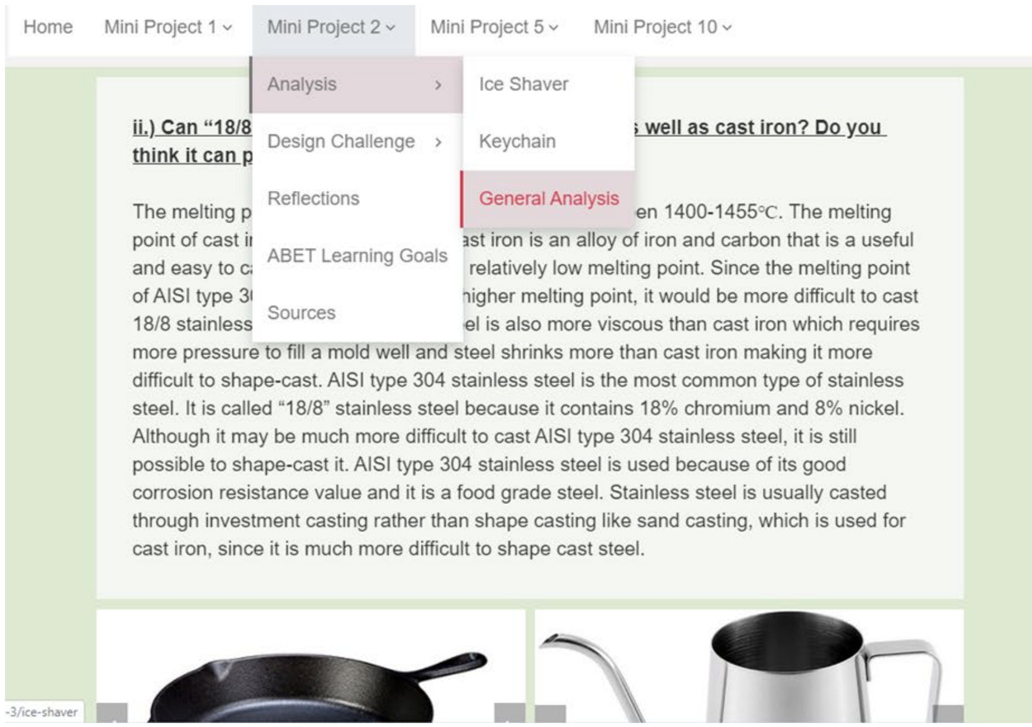


*Figure 1. Screenshot of a student's ePortfolio, showing various template sections that required completion.*

## 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.

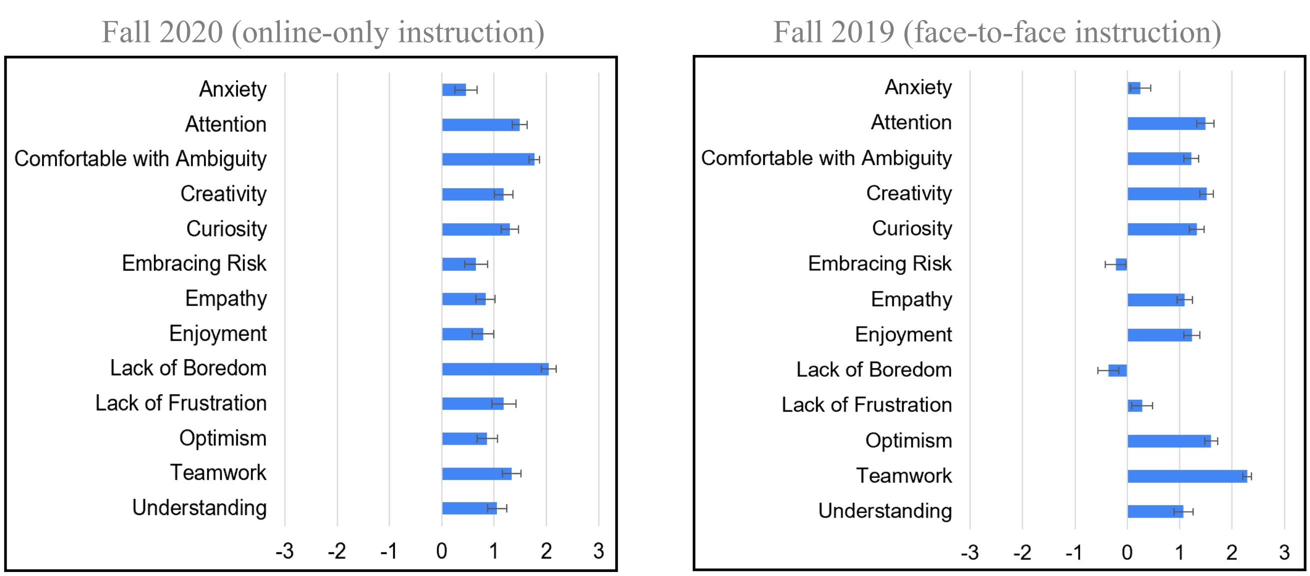


*Figure 2. Salient results of student evaluation questionnaires from online-only instruction in Fall (2020) and face-to-face instruction (Fall 2019).*

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

| **Factor** | **Mean, $\bar{X}$** | | **Standard Deviation** | | **Standard Error** | |
|---|---|---|---|---|---|---|
| | **2019** | **2020** | **2019** | **2020** | **2019** | **2020** |
| Anxiety | 0.252 | 0.460 | 1.939 | 1.687 | 0.190 | 0.214 |
| Attention | 1.439 | 1.489 | 1.665 | 1.123 | 0.163 | 0.143 |
| Comfortable with Ambiguity | 1.223 | 1.769 | 1.437 | 0.807 | 0.140 | 0.102 |
| Creativity | 1.515 | 1.185 | 1.284 | 1.411 | 0.126 | 0.179 |
| Curiosity | 1.328 | 1.301 | 1.412 | 1.281 | 0.138 | 0.163 |
| Embracing Risk | -0.223 | 0.656 | 2.005 | 1.738 | 0.197 | 0.221 |
| Empathy | 1.097 | 0.839 | 1.517 | 1.439 | 0.149 | 0.183 |
| Enjoyment | 1.233 | 0.790 | 1.518 | 1.634 | 0.149 | 0.208 |
| Lack of Boredom | -0.364 | 2.048 | 2.066 | 1.128 | 0.203 | 0.143 |
| Lack of Frustration | 0.282 | 1.184 | 2.013 | 1.812 | 0.197 | 0.230 |
| Optimism | 1.602 | 0.870 | 1.218 | 1.544 | 0.119 | 0.196 |
| Teamwork | 2.289 | 1.337 | 0.828 | 1.390 | 0.081 | 0.177 |
| (Conceptual) Understanding | 1.073 | 1.057 | 1.806 | 1.439 | 0.177 | 0.183 |

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, curisotiy, 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 ($-0.3 < \bar{X} > 0.3$). In comparison, all factors received positive responses ($\bar{X} > 0.3$ ) for the online-only condition. The positive tendency of anxiety during face-to-face instruction ($\bar{X} = 0.25$) 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 intsruction 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.

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# Appendix A: Typical Mini-Project

**Mini-project #8:** ***Repurposing, Reuse and Recycling*** *[200 points]*

***CONTEXT***

***Repurposing and Design-for-Repurposing***

How can *design* facilitate a solution to this problem? *Design for Repurposing* presents a strategy for incorporating the concept of repurposing in product/system design, which aims to extend the longevity of products by intentionally designing features or details that facilitate repurposing.

*Repurposing* is creating a new or a second life for an existent product by making some transformations to it. It is a common practice. People have been transforming things in ways that were not originally envisaged since they began appropriating objects.

Large-scale repurposing 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 meaning; for instance, children's clothing made from military uniforms, and instruction manuals for the construction of cooking boxes out of discarded aluminum.

The use of Coca Cola in some countries is another example of total transfer of function and meaning. In Russia, women use it to smooth wrinkles (!). In the Japanese Island of South Ryukyu, the Coke bottles are symbols of luck and now are placed on altars. In Mexico, Coke is often used as a drain cleaner (!!). In Nepal and Cambodia, ceramic pots are regularly used to filter water. These objects are taken out of their original contexts/purposes/functions and transformed and used in a different environment for purposes that for many seem to be "wrong".

*Water filter made from a ceramic garden pot, Cambodia*

Repurposing is a closer relative to *reuse*. It means, "to use an item more than once". By taking useful products and exchanging them, reuse helps save time, money, energy and resources. An object is passed along, but used again for the same function, without suffering any transformation. A sweater passed onto a sibling is one of many examples.

It is therefore apparent that repurposing offers several benefits:

- *Repurposing can save lives.* Creative use of available products in life-saving functions, such as using commercial air filters for medical face mask material or using cheap (non-medical) products to function as ventilators for critically ill patients.
- *Repurposing saves energy.* The amount of energy consumed when repurposing is minimal compared to the energy required to acquire and transport raw materials from their source. Also, the energy destined to recycle objects is saved.
- *Repurposing preserves environmental conditions and reduces pollution.* It helps the environment by minimizing the energy spent on industrial production and recycling (which creates toxic material that pollute the environment).
- *Economic benefits.* Repurposing saves money demanded to produce new products from raw materials. These expenses include the entire production cycle starting from acquiring the raw



materials, transferring them from their origin to production places, processing, manufacturing and disposal costs.
- *Repurposing eases the need of space for waste disposal.* Most of the landfill sites are filled up with a lot of waste products. Some of these waste materials belong to nonbiodegradable objects, which take a long time to decompose. Repurposing avoids discarding objects by expanding products longevity.

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

Design for repurposing aims to deal with the abundance of products we discard of everyday (if they are not designed already for composting, reusing or represent any kind of danger to human beings), and where the original materials are not necessarily reprocessed. In the original design, products are intentionally given qualities 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!

***Recycling and Design-for-Recycling***

Repurposing needs to be understood in comparison to some other practices. The commonly understood definition of *recycling* is to collect similar materials and reprocess them into new products. Most recycling however degrades material quality resulting in 'down-cycling', i.e. with each recycle, the materials lose structure and concentration. 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 reprocess the original material and the energy required to accomplish this task.

*Recycling* is essentially the reverse of manufacturing: products go in, and materials come out. It is a well-established and highly developed practice but is often misunderstood. For instance, the scale of recycling operations is routinely under-estimated, and although recycling usually has a beneficial effect on the environment, it is primarily an economic activity, done to make money.

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

The manufacturing triangle of function, cost, and quality can also be used to interpret recycling issues 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.



***Reusing parts***

To *reuse* components, we need to extract them without damage and at low cost. We can extract them either by cutting them out (like metal parts) or by disassembling a product into its parts. So, it seems obvious that products should be designed with mechanical fasteners (such as nuts and bolts) so they can be taken apart later. However, there are several other requirements too, mainly driven by the fact that disassembly is much more expensive than assembly. A key to this is because, unlike assembly where tasks can be standardized to gain economies of scale, in disassembly each task is different, so costs more.

Looking for opportunities for future reuse, the ideal components would be those that can be easily separated from their parent product and can be reused directly or require only superficial change or simple trimming.

**1. ANALYSIS** [100 points]

1.1. Discuss the manufacturing process or processes suitable for making the products listed below (a – h) Explain whether the products would require additional operations (such as coating, plating, heat treating, and finishing). If so, make recommendations and give the reasons for them. (25 points)

a. Steel paper clips versus plastic paper clips;
b. Forged vs. cast crankshafts;
c. Forged vs. powder-metallurgy connecting rods;
d. Plastic vs. sheet-metal light-switch plates;
e. Glass vs. metal water pitchers;
f. Sheet-metal vs. cast hubcaps;
g. Steel vs. copper nails;
h. Wood vs. metal handles for hammers.

1.2. Discuss the factors that influence the choice between the following pairs of processes to make the products indicated. (25 points)

a. Sand casting vs. die casting of an electric motor housing;
b. Machining vs. forming of a large-diameter bevel gear;
c. Forging vs. powder-metallurgy production of a cam;
d. Casting vs. stamping a sheet-metal frying pan;
e. Making outdoor summer furniture from aluminum tubing vs. cast iron;
f. Welding vs. casting of machine-tool structures;
g. Thread rolling vs. machining of a bolt for high-strength application;
h. Thermoforming a plastic vs. molding a thermoset to make the blade for an inexpensive household fan.

1.3. What is a *circular economy*? Briefly describe with the help of a diagram from a published journal paper (or papers). Be sure that your explanation and diagram also include *reuse*, *repurposing*, and *recycling*! (5 points)



1.4. What is a *cradle-to-cradle* approach? What are its benefits? (Read Chapter 16 in the Kalpakjian book for context.) (5 points)

1.5. Make a list of several (a) disposable and (b) reusable products. Discuss your observations and explain how you would go about making more products that are reusable. (5 points)

1.6. Select three different products commonly found in homes. State your opinions about *(a)* what materials were used in each product, and why, and *(b)* how the products were made, and why those manufacturing processes were used. You are encouraged to investigate each product and, based on a review of the topics described throughout your Kalpakjian textbook, comment appropriately on each of the questions. (10 points)

1.7. *Grade* is a measure of quality and it captures concentration levels (i.e., how pure a certain fraction is). If grade captures quality, then *Recovery* is a measure of quantity: it describes how much of a certain material in the input stream is made available for reprocessing.
A recovery of *R*% means that (100 - *R*)% of the material going into the process is lost, ending up either in mine tailings or as a contaminant in one or more fractions.

By weight, copper wire contains about 70% copper and 30% PVC. Suppose we process 1 ton of wire per hour into a copper fraction of 0.74 ton/hour, of which 0.69 is copper and 0.05 is PVC. What is the weight and composition of the tailing? And what are the grade and recovery of the copper? (10 points)

***Hint:*** You should find that the recovery is very high (not surprising, given the value of copper) and the grade is somewhat lower, but still "quite" high.

1.8. Consider the following table with the energy and price data for various primary and secondary materials.
Now, for a commercial coffee making machine, determine the total potential recover able value of the materials, and give a range for your answer.

| Material | $GER_{primary}$(MJ/kg) | $GER_{secondary}$ (MJ/kg) | $Price_{primary,}$ (\$/kg) | $Price_{secondary,}$ (\$/kg) |
|---|---|---|---|---|
| Low carbon steel | 29–35 | 8–10 | 0.45–0.55 | 0.40–0.50 |
| Wrought aluminum | 200–215 | 18–19 | 1.80–1.90 | 1.60–1.70 |
| Copper | 68–74 | 17–19 | 5.10–5.60 | 4.80–5.30 |
| Polypropylene (PP) | 85–105 | 36–44 | 1.40–1.50 | 0.80–1.00 |
| Borosilicate glass | 24–26 | 11–12 | 3.00–4.50 | 1.00–1.20 |

*GER, gross energy requirements.*

The main unit of the coffee machine contains 0.20 kg of steel, 0.10 kg of wrought aluminum, 0.12 kg of copper, 0.70 kg of PP (polypropylene), and 0.28 kg of glass, with a total mass of 1.40 kg. (It also contains small amounts of rubber and PVC, some ceramics, and some solder; ignore those for brevity.) (15 points)

## 2. DESIGN CHALLENGE [100 points]

Find a discarded product that you can repurpose (i.e. reuse but with a different application than initially intended). Your repurposed product may not be used in medical applications.

2.1. Describe the product that you will redesign using the design concept of repurposing, whilst also considering recycling and reusing. Show a high-resolution and clear picture of your chosen product which you will repurpose. Provide descriptive text where necessary. Briefly describe your design objective (e.g. producing a do-it-yourself, cheap and effective children's toy using washing machine parts). (5)

2.2. *Research, Empathizing:* Now, do extensive research on the product which you will redesign. You must provide at least ten websites that you researched, and at least two journal articles related to your chosen product. Summarize your findings about the manufacturing and use of your chosen product from all the cited research works in no less than 100 words, preferably with the use of diagrams, photos, and/or sketches. (15)
*Hint:* Your discussed findings must clearly convey that you understand the problem with the existing product and that you have deep insight into its use (empathizing!) and that you understand the opportunities that exist to use repurposing to produce a new product (like a children's toy) simply, cheaply and effectively. Provide at least three design concepts (with design sketches and descriptive text) for repurposing the product that you identified.

2.3. *Design for disassembly and assembly:*

- Provide a detailed description of your repurposed product, by giving the official product name, catalog number, cost (if newly purchased), and URL, using sites such as Amazon.com or McMasterCarr.com (5)

- Clearly list all the parts of your repurposed product using a Bill of Materials and state and whether they will be repurposed. If there are parts that will not be used in the repurposing process, state whether they are suitable for recycling or reuse. Also, based on your research, clearly state what materials your products or its parts are made of, and what manufacturing method (e.g. plastic injection molding) was used in its manufacture. (This links to Question 2.2.) (5)

- How would you simply and safely separate the components of the product which you want to repurpose? What tools would you use (e.g. screwdriver, knife, pliers, hammer) to disassemble the product which you want to repurpose? (5)

- Ask the DFA (Design for Assembly) questions in Chapter 12 of Mike Philpott's text book (and restated in your lecture notes) of each part to identify opportunities for simplification by reducing the number of parts in your repurposed product. What are (a) the Number of Parts in the assembly, and (b) the "Theoretical Minimum Number of Parts" in the assembly? Add any ideas that you have for combining and/or eliminating parts (20)

2.4. *Durable materials:* In products designed for repurposing, materials and components are durable and capable of functioning well in another role. It is ideal that materials are long-lasting (e.g. stainless steel). Describe how your repurposed product or parts feature durable materials, and list those materials. (5)



2.5. *Immediate functionality:* Explain how some of the dismantled components might offer immediate functionality, such as containers, vessels, or air filters. Strive to retain that potential in the newly configured design. (5)

2.6. *Inviting, easy and obvious:* How will your repurposed design invite the repurposer (e.g. child who needs your toy) to develop it? Your repurposed product will be effective if it engages the repurposer (e.g. a child) by its material quality or by its inherent simplicity and clear explanations. (5)

2.7. *CAD modeling of the Repurposed Product:* Develop a full 3D CAD model of your repurposed product. Detailed engineering drawings must be supplied as well as a solid model. (20)

2.8. Hypothesize how you would perform a rudimentary *Design of Experiment* with which you would be able to test your repurposed product. Follow the steps below. (10)

- Step 1: Identify the performance variables and design variables.

- Step 2: Define (guess) the typical target values for the response and boundaries for the design variables. Provide reasonable values with your guesses / estimates.

- 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 responses will be measured.

- Step 4: Generate hypothetical (but physically appropriate) data for each of the trials and replicates.

- Step 5: Analyze the results by constructing an appropriate statistical analysis. Calculate the average of the variances of the replicates; determine the overall standard deviation from the average variance and compare the standard deviation to coefficients of the regression model. After determining the significant results, use the regression model and/or graphs to make design changes to the redesigned component (or sub-assembly)

## 3. ePortfolio [15 bonus points]

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

If you want to be eligible for 15 bonus points, produce a high-impact ePortfolio about your Mini Project 8.

You may choose from any free ePortfolio platform, such as Wix, WordPress, Reddit, Tumblr, Issuu, or Digication.

*What?* The ePortfolio is an online visual-based representation of this assignment. Refer to the ePortfolios which you and your team mates produced in Mini Projects 1 and 5 for ideas.
*Why?* The ePortfolio will help you to display your level of competence in analytical, computational, design-for-manufacturability, and reflection skills. An online ePortfolio is a great way to convey your personality and highlight your accomplishments and experiences in an easy-to-digest format, and to share that with a variety of audiences.



*How?* Document the required evidence, complete any additional work, and present using your chosen ePortfolio platform.

*Things to collect:* Your ePortfolio should contain a record of all the work for this mini project, including your design calculations, discussions, sketches and drawings (perhaps also using an image gallery), conceptual designs, people interviewed, pictures of products and of the manufacturing process, descriptions of design-for-manufacturability techniques and prototype redesign, personal reflections, etc.

*Inspiration:* The following mini projects by previous students may provide you with ideas regarding execution of your own projects.
https://psg203.wixsite.com/me270-petergutfeldt
https://morgan270.weebly.com

*Tips:* To ensure a high-impact ePortfolio, you should pay attention to the following: Logical flow of information; Tabs are organized and ordered; Striking (and easy-to-read) color and contrast; Use of "negative space"; Presentation of information in "bite-size" chunks; Continuity of presentation (e.g. same fonts, colors, and layout); No repetition; Legible images (e.g. photos or drawings).



**GRADING RUBRIC WHICH WILL BE USED TO EVALUATE YOUR MINI PROJECT**
(Only the TAs and the Instructor will grade this assignment.)

| Criteria | Ratings | | | | |
|---|---|---|---|---|---|
| | 9.5 – 10 scale | 9 - 9.5 scale | 8 – 9 scale | 6 – 8 scale | 0 scale |
| **1. Analysis** | Excellent solutions, with, perhaps, a minor error. Correct equations, correct implementation, brief discussion of results. | Good solutions, containing one major error or a few small errors. Correct implementation with brief discussion. | Poor solutions with two major errors or one major error and several small errors. Poor implementation with little discussion. | Very poor solutions and implementation, with minimal attempt at the solutions. | No solutions |
| 1.1. _______ / 25 | Reviewer comments: | | | | |
| 1.2. _______ / 25 | Reviewer comments: | | | | |
| 1.3. _______ / 5 | Reviewer comments: | | | | |
| 1.4. _______ / 5 | Reviewer comments: | | | | |
| 1.5. _______ / 5 | Reviewer comments: | | | | |
| 1.6. ______ / 10 | Reviewer comments: | | | | |
| 1.7. ______ / 10 | Reviewer comments: | | | | |
| 1.8. ______ / 15 | Reviewer comments: | | | | |
| **2. Design challenge** | Design concepts are novel / excellent and easy to grasp, with excellent drawings or sketches, and excellent explanatory comments. Perhaps one or two minor errors in the design or manufacturing process. | Design concepts are ordinary and not so easy to grasp; drawings or sketches are adequate, but with minimal explanatory comments. Perhaps a major error in, or improper use of, design or manufacturing process. | Design concepts are meagre and are difficult to grasp; drawings or sketches are inadequate with few or no explana-tory comments. Two or more major errors (or several small errors) in the design or manufacturing process. | Design concepts are unacceptable or incomprehensible or incomplete; drawings or sketches are meagre with few or no explanatory comments. General non-adherence to basic design or manu-facturing principles. | No attempt at addressing the design challenge |
| 2.1. ______ / 5 | Reviewer comments: | | | | |
| 2.2. ______ / 15 | Reviewer comments: | | | | |
| 2.3. ______ / 35 | Reviewer comments: | | | | |
| 2.4. ______ / 5 | Reviewer comments: | | | | |
| 2.5. ______ / 5 | Reviewer comments: | | | | |
| 2.6. ______ / 5 | Reviewer comments: | | | | |
| 2.7. ______ / 20 | Reviewer comments: | | | | |
| 2.8. ______ / 10 | Reviewer comments: | | | | |
| **3. ePortfolio (not mandatory; only for bonus points)** ________ / 15 bonus points | High-impact ePortfolio that clearly and effectively conveys information. Covers all mandatory sections. Ample evidence of competence in analytical, computational, drafting, and reasoning (reflection) skills. Detailed and highly appropriate discussions, suggestions, and critique, with ample contextualization. | An acceptable ePortfolio with some elements of excellence. ePortfolio clearly conveys information. Covers more than two-thirds of mandatory sections. Marginal evidence of competence in analytical, computational, drafting, and reasoning (reflection) skills. Discussions are brief but incomplete, provided critique is minimal, and suggestions are inadequate. | Low-impact ePortfolio, mediocre quality. ePortfolio poorly conveys information. Covers only about half of mandatory sections. Minimal evidence of competence in analytical, computational, drafting, and reasoning (reflection) skills. Discussions, critique, and suggestions are incomplete and inadequate, or inappropriate. | ePortfolio of very low quality with meagre impact. ePortfolio poorly conveys information. Covers less than half of mandatory sections. Meagre evidence of competence in analytical, computational, drafting, and reasoning (reflection) skills. Discussions, critique and suggestions are incomplete and inadequate. | No attempt to report work in ePortfolio format |
| **What grade would you give this assignment? (i.e. Criteria 1 + 2 + 3)** ________ / 200 | | | | | |

**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**


[1] W. Ali, "Online and Remote Learning in Higher Education Institutes: A Necessity in light of COVID-19 Pandemic," *High. Educ. Stud.*, 2020, doi: 10.5539/hes.v10n3p16.

[2] S. Dhawan, "Online Learning: A Panacea in the Time of COVID-19 Crisis," *J. Educ. Technol. Syst.*, 2020, doi: 10.1177/0047239520934018.

[3] L. Song and J. R. Hill, "A conceptual model for understanding self-directed learning in online environments," *J. Interact. Online Learn.*, 2007.

[4] V. Taajamaa, S. Kirjavainen, L. Repokari, H. Sjoman, T. Utriainen, and T. Salakoski, "Dancing with ambiguity design thinking in interdisciplinary engineering education," in *2013 IEEE-Tsinghua International Design Management Symposium: Design-Driven Business Innovation, TIDMS 2013 - Proceedings*, 2014, doi: 10.1109/TIDMS.2013.6981258.

[5] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, "Engineering design thinking, teaching, and learning," *IEEE Eng. Manag. Rev.*, 2006, doi: 10.1109/emr.2006.1679078.

[6] A. Kamp, "Engineering Education in the Rapidly Changing World: Rethinking the Vision for Higher engineering Education," no. June, p. 61, 2016, [Online]. Available: http://repository.tudelft.nl/islandora/object/uuid:ae3b30e3-5380-4a07-afb5-dafd30b7b433?collection=research.

[7] A. W. Astin, "Student involvement: A developmental theory for higher education," in *College Student Development and Academic Life: Psychological, Intellectual, Social and Moral Issues*, 2014.

[8] T. Tucker, E. Vernooij, A. Wolf, Bo-C. Linn, R. Baird, N. Dancholvichit, and L. Liebenberg, "Transforming an Engineering Design Course into an Engaging Learning Experience using ePortfolios," in *The 127$^{th}$ ASEE Annual Conference* [Technical Session], 2020. The American Society for Engineering Education: Montreal (Virtual Conference).

[9] V. Goel and P. Pirolli, "Motivating the notion of generic design within information-processing theory: the design problem space," *AI Mag.*, 1989.

[10] M. Hannafin, "Learning in Open-Ended Environments: Assumptions, Methods, and Implications.," *Educ. Technol.*, 1994.

[11] D. H. Jonassen, "Toward a design theory of problem solving," *Educ. Technol. Res. Dev.*, 2000, doi: 10.1007/BF02300500.

[12] D. C. Brandenburg and A. D. Ellinger, "The Future: Just-in-Time Learning Expectations and Potential Implications for Human Resource Development," *Adv. Dev. Hum. Resour.*, 2003, doi: 10.1177/1523422303254629.

[13] UIUC, "University of Illinois Portfolio Resources." https://illinois.digication.com/portfolio/

[14] L. Bryant and J. Chittum, "ePortfolio Effectiveness: A(n Ill-Fated) Search for Empirical Support.," *Int. J. ePortfolio*, vol. 3, no. 2, pp. 189–198, 2013.

[15] R. E. Mayer, "Cognitive, metacognitive, and motivational aspects of problem solving,"

*Instr. Sci.*, 1998, doi: 10.1023/a:1003088013286.

[16] A. L. Parsons, " Emotional Design: Why We Love (or Hate) Everyday Things20063Donald A. Norman. Emotional Design: Why We Love (or Hate) Everyday Things . New York, NY: Basic Books, A member of the Perseus Books Group 2004. 257 pp. $15.95 (paperback) ," *J. Consum. Mark.*, 2006, doi: 10.1108/07363760610655069.

[17] H. L. Chen and S. J. Patel, "Using Reflection and Digital Storytelling via ePortfolios to Support the Professional Development of Engineering Graduate Students," in *Proceedings - Frontiers in Education Conference, FIE*, 2019, vol. 2018-Octob, pp. 1–5, doi: 10.1109/FIE.2018.8659192.

[18] N. F. Liu and D. Carless, "Peer feedback: The learning element of peer assessment," *Teach. High. Educ.*, 2006, doi: 10.1080/13562510600680582.

[19] J. W. Gikandi, "Promoting Competence-Based Learning and Assessment Through Innovative Use of Electronic Portfolios," in *Handbook of Research on Promoting Higher-Order Skills and Global Competencies in Life and Work*, IGI Global, 2018, pp. 181–208.

[20] C. E. Watson, G. D. Kuh, T. Rhodes, T. P. Light, and H. L. Chen, "ePortfolios–The eleventh high impact practice," *Int. J. ePortfolio*, vol. 6, no. 2, pp. 65–69, 2016.

[21] C. Morreale and V. Zile-Tamsen, "Thinking Skills by Design: Using a Capstone ePortfolio to Promote Reflection, Critical Thinking, and Curriculum Integration.," *Int. J. ePortfolio*, vol. 7, no. 1, pp. 13–28, 2017.

[22] R. Pekrun, "Emotions as Drivers of Learning and Cognitive Development," in *New Perspectives on Affect and Learning Technologies*, 2011.

[23] R. C. Atkinson and R. M. Shiffrin, "Human Memory: A Proposed System and its Control Processes," *Psychol. Learn. Motiv. - Adv. Res. Theory*, 1968, doi: 10.1016/S0079-7421(08)60422-3.

[24] M. Csikszentmihalyi, "Toward a psychology of optimal experience," in *Flow and the Foundations of Positive Psychology: The Collected Works of Mihaly Csikszentmihalyi*, 2014.

[25] S. Nilson and J. Dewey, "How We Think.," *Philos. Rev.*, 1935, doi: 10.2307/2179725.

[26] M. H. Immordino-Yang, *Emotions, learning, and the brain: Exploring the educational implications of affective neuroscience*. 2016.

[27] H. Jang, E. J. Kim, and J. Reeve, "Why students become more engaged or more disengaged during the semester: A self-determination theory dual-process model," *Learn. Instr.*, 2016, doi: 10.1016/j.learninstruc.2016.01.002.

[28] K. Ann Renninger and S. Hidi, *The power of interest for motivation and engagement*. 2016.

[29] B. L. Fredrickson, "The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions," *Am. Psychol.*, 2001, doi: 10.1037/0003-066X.56.3.218.

[30] G. M. Sinatra, B. C. Heddy, and D. Lombardi, "The Challenges of Defining and Measuring Student Engagement in Science," *Educational Psychologist*. 2015, doi:

10.1080/00461520.2014.1002924.

[31] I. Arroyo, D. G. Cooper, W. Burleson, B. P. Woolf, K. Muldner, and R. Christopherson, "Emotion sensors go to school," in *Frontiers in Artificial Intelligence and Applications*, 2009, doi: 10.3233/978-1-60750-028-5-17.

[32] O. Mirmotahari and Y. Berg, "Structured peer review using a custom assessment program for electrical engineering students," in *IEEE Global Engineering Education Conference, EDUCON*, 2018, doi: 10.1109/EDUCON.2018.8363339.

[33] L. R. Halverson and C. R. Graham, "Learner engagement in blended learning environments: A conceptual framework," *Online Learn. J.*, 2019, doi: 10.24059/olj.v23i2.1481.