Assess Experiential Learning Outcomes

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Integration of Weekly Reflections in an Introductory Design Class to Assess Experiential Learning Outcomes

I.   Introduction

Hands-on design courses, particularly at the introductory level, have gained popularity in engineering curriculum over the past decade. Most of these courses have a number of objectives relating to the development of traditional technical skills, including familiarization with design and shop tools, incorporation of physics into design decisions, and methods for analysis and testing. These courses, which are a form of experiential learning,, can have a number of additional broader objectives as well. These broader objectives can include fostering creativity, persistence in overcoming obstacles, making all students welcome regardless of their prior experience in design, and understanding how to work on a team and manage a project. While assessment of traditional technical and analytical skills is straight-forward to assess in exams and report questions, attainment of the broader objectives is more difficult to measure. In addition, measuring many of these objectives, in particular, creativity and persistence in overcoming obstacles, is not just about measuring a final score, but it is about understanding the students' learning process along the way.

To address this need and better understand the success of achieving the educational objectives of the design course, a weekly reflection that included both multiple choice and free response questions was implemented in an introductory design course. There were 114 students enrolled, and the course consisted of both lectures, as well as labs (which were broken into sections with 24 students maximum). The reflection questions investigated student's self-assessment of both their traditional engineering skills, as well as the experiential components of the course. Notably, students could provide written descriptions of insights on their creative blocks and breakthroughs on a weekly basis.

By analyzing the weekly reflection data, along with student grades and demographics, there is a significant amount of insight we can gain into student learning and the learning process. For this paper, we have chosen to focus our analysis on the context of better understanding student learning on creativity. This decision to focus on creativity is motivated by both its importance as an essential skill for engineers, as well as its difficulty to teach and assess.

There were three main research questions we aimed to address. (1) How did elements of our course design, including the course structure, impact student learning on creativity? (2) What can we learn from reflections about students' creativity in an experiential learning environment? And (3) How can reflections be used as a *learning tool* as well as a *formative assessment tool*? The goal of this work is to ultimately understand how instructors can use reflections to better facilitate, encourage, and foster creativity.

II.   Background
A. Course design and objectives
The course is designed as an experiential learning environment, in which students are directly implementing and using what is being studied (Tate, 1978). This means that learning goes beyond reading, listening, writing, and hearing about a concept, but also includes using these skills to tackle a challenging objective. As such, the course has both technical, as well as experiential learning objectives.

The main technical objective included learning to apply engineering analysis and tools to the design and fabrication of working machines. Computer-Aided Design (CAD), basic shop tools, power and energy analysis, and free body diagrams were the main engineering tools focused on in the course. The experiential learning objectives included creativity, teamwork, persistence, and project management. It is important to achieve these learning objectives for all students regardless of their background, so inclusivity is also an important consideration in course structure. Although these skills are critical for a successful career in engineering, they are often not explicitly included in lecture based course outcomes. Student ability and learning in these areas is also not typically assessed, likely due to the lack of metrics available to evaluate this type of learning.

We have therefore introduced a weekly reflection, including both multiple choice and free response questions, into the course structure. The importance of reflection on teaching and learning has been well documented (Boud, Keogh, & Walker; Brookfield, 1990; Dewey, 1993, King & Kitchener, 1994; Schön, 1983). Providing students with opportunities to reflect on their learning helps them develop metacognitive skills--thinking about one's own thought process--to guide and improve learning (Flavell, 1979). At the same time, engaging in reflective teaching can help instructors gain insight into how students learn (Brookfield, 1995). In addition, the experiential learning cycle developed by Kolb (1984; updated 2014), built upon the work of Dewey (1993) to include concrete experience, reflective observation, abstract conceptualisation, and active experimentation. The cycle describes the recursive nature of learning and emphasizes reflection as a critical feature of learning.

Both the technical and experiential objectives of this course were taught mainly in the context of two course projects– the first completed individually and the second completed in a team of three or four. There were a number of motivations for this specific course design. In particular, the purpose for structuring the first project, which required both design, fabrication, analysis, and testing, as an individual project, was to encourage each student to become more comfortable and confident in his or her technical skills. Particularly for an introductory course consisting of lower-level undergraduates and first-year transfer students, there tends to be a wide range of experience levels in hands-on design coming into the class. The first project aims to level the

playing field, equip students with the technical skills they need for the group project, and create a welcoming and inclusive environment, where students feel empowered by designing and building their very own working pendulum clock. The second project was formatted as a class-wide robot contest. Groups of three to four students were assigned to work together to build a robot using only the materials provided, in order to compete against other teams' robots. The competition format tends to motivate students, and the team aspect encourages student interaction and collaboration. The study was conducted under IRB approval number ######, and students were provided the opportunity to opt out of use of their data in this study.

B. Creativity
Defining Creativity

Creativity has been defined as the ability to produce novel ideas and involves idea generation, evaluation,, analysis, testing, as well as taking risks, and combining and connecting ideas in new ways (Guilford, 1956; Sternberg, 2001; Torrance, 1974; Treffinger, Isaksen, & Dorval, 2000, Weisberg, 1999). Researchers in the field of psychology categorized creative abilities into four constructs: 1) fluency—quantity of relevant ideas; 2) flexibility—variety of ideas; 3) originality—unusual yet relevant ideas; and 4) elaboration—the number of details in each idea (Guilford, 1956; Torrance, 1966). Building on these constructs and applying them to the design process of engineering, Shah, Vargas-Hernandez & Smith (2002) use the terms novelty (how unusual or unexpected an idea is compared to others), variety (measure of the explored solution space when generating ideas), quantity (number of ideas generated), and quality (feasibility of an idea and the degree to which it meets the design specifications), noting that "an engineering design must not only be novel (unusual, unexpected) but it must also satisfy some intended function(s) to desired specifications (have desired utility)" (p. 111). Creativity in engineering is also discussed as "functional creativity" by Cropley & Cropley (2005) who also highlight that engineering products typically need to serve a useful function.

Challenges to Teaching Creativity

Creativity in engineering has been identified as an essential skill, yet there are few engineering programs that offer courses that teach creativity (Charyton & Merrill, 2009). While there may be several curriculum constraints related to this, researchers highlight specific challenges to teaching creativity skills—assessment being one such challenge. To address this challenge, Shah et al. (2002) developed metrics for measuring one aspect of the creative process—ideation effectiveness. Kim (2014) proposed a Creative Process and Outcome Assessment framework that includes rubrics to assess team projects in engineering design courses. To evaluate student learning outcomes in three core design courses taught in the first three years and a capstone course taught in the fourth year of a design-intensive undergraduate engineering curriculum, Plantanitis & Pop-Iliev (2010) developed evaluation rubrics. The rubrics were used to assess student performance on design projects assigned to them throughout their four years in the program. Students' projects were assessed on multiple dimensions, including creativity and

aspects of the creative process. Applying the rubrics throughout the curriculum provided instructors with a "roadmap" to teach more effectively, clarify expectations for students, and better assess final projects.

Students' academic trajectories into engineering is another identified challenge. According to Court (1998), because of the emphasis on math and physics in engineering students' educational backgrounds, many engineering students are unfamiliar with creative thinking, and thus find it difficult and "unnatural to their normal thinking" (p. 146). Despite these challenges, creativity can be taught (Fischer, 1994; Richards, 1993; Scott, Leritz & Mumford, 2004). As Court (1998) notes, "Creativity is not a 'magical' ability. If you can think, you can learn to think creatively. Therefore, the methods for creativity should become part of the basic toolkit of designers" (p. 146).

Teaching Creativity

Opportunities for students to learn creative skills in engineering are often found in courses that incorporate experiential, open-ended, problem-based, and project-based learning into the design of the course. While shown to be effective in helping students develop higher order thinking skills and metacognition (when well designed and taught), these approaches to teaching often require instructor professional development (Capraro & Slough, 2013). Several studies in engineering education offer insights into teaching effectively using these approaches. Findings from one case study research project that examined instructional practices related creativity in seven engineering courses at one university (Daly, Mosyjowski, & Seifert, 2014), highlight the importance of course design in teaching students creative thinking skills. Specific course design suggestions include: 1) Make creativity a specific learning goal in the course; 2) Ensure that creativity is assessed and provide specific feedback related to developing creative skills. This can help students recognize the importance of these skills and provide guidance on where and how to improve; and 3) Integrate specific learning opportunities that focus on building creative skills. The complexity of these assignments can vary depending on the context and structure of the course and include such assignments as asking students to identify multiple approaches to solving a homework problem, assessing the viability of alternative concepts, and an open-ended project with multiple opportunities to build creative skills. Through a review of several publications, Liu & Schonwetter (2004) identify concrete ideas for teaching creativity in engineering by applying Treffinger's creative learning model. Incorporating systematic techniques to develop engineering students' creative skills, Bailee (2002) introduced an idea pathway model with specific exercises that can be used to teach creativity. While there are challenges associated with teaching creativity in engineering, there are many examples from which to learn.

Teaching Creativity in This Course

Creativity is not only a learning objective of this course, but it is also explicitly incorporated into the course structure. For example, there is a lecture devoted entirely to creativity, in which students learn how preconceived notions can limit one's creativity, how to use a solution neutral environment to define the problem, and how to generate functional requirements motivated by an approach described by Suh (1990). Examples are also presented of overcoming conceptual blocks using examples from Adam (2001) supplemented with instructor examples. Students watch a video of a Shopping cart redesign by the IDEO design firm, and answer a questionnaire that elicits the importance of developing a wide range of design concepts and deferring judgment early in the concept generation phase. Each student is required to develop 4 different design concepts for their robot. Moreover, the initial students' design concepts are developed individually before teams are formed in week 4. This approach prevents one student's concepts from quickly dominating the creative process and limiting the range of design solutions considered. A team of 4 students will have 16 different design concepts using a Pugh cart. Emphasis is placed on using the Pugh chart for communicating ideas rather than using the scoring alone for selection of the design concept to pursue. Students are asked to keep track of their conceptual blocks and conceptual breakthroughs during the team robot design project. A new robot contest is introduced each time the class is taught so that students have a genuine open-ended design experience. Each student has a final report to complete where a section on the design process can be filled out with an example relating to creativity.

III. Research Methods & Data Gathering

A. Critical Assignments

Although there were numerous assignments throughout the course, there were a few critical ones relevant to this analysis, as described below:

- Individual Clock Project. This is a 4-week individual project where students use CAD and a Laser cutter to create a simple pendulum clock with an escapement mechanism. They use drills, reamers, tappers, and an arbor press to build the clock. Then they write a report about the timing of their pendulum, comparing theoretical prediction of measured performance. While the mechanical design of the clock is provided to students, there is the opportunity for each student to design the shape and aesthetics of their pendulum, which also affects the clock's timing..

- Individual Concept Generation for the Robot Contest in Week 3. Each quarter a new robot contest challenge is created, so students have a truly open-ended design experience without a known best solution. Each student creates hands sketches of 4 different concepts for their robot, before teams are formed.

- Team formation in Week 4 is not an assignment per se. However it is done randomly by the course instructional team. This is meant to create more diverse teams.

- Energy Analysis in Week 5. Here teams measure the energy and power in all their kit components including geared motors, non-geared motors, and springs.
- Risk Reduction Presentation in Week 6. This a project management assignment meant to focus the team on reducing risk. Each team identifies an area of high risks and builds a proof-of-concept device to see if that concept is a viable design approach. This is presented to faculty who visit each section that week.
- Robot Scoring of Small Number of Points in Week 8. This is a high pressure deadline where students are tasked with demonstrating a fully functioning robot that can score a designated small number of points. Students that fail to reach this objective, create a plan with their section tutor. Partial credit is possible if the robot can score points within a week after the deadline. This partial credit grade is used as one the metrics used in this study to identify teams that are struggling with design challenges.
- Oral Presentation in Week 10. Each team gives an oral presentation of their robot, use of theory and project management in the design process.
- In Section Robot Contest in Week 10. This is a head-to-head contest within the 6 teams of each section. The instructor also inspects the robot at this point for determining robot hardware grading. The robot hardware grade is based on the function of the machine such as scoring points in a reliable fashion.
- Individual Final Robot Report. Each student writes a robot report on 1 component of the robot. This includes a theoretical analysis as well as a discussion of the design process they went through.
- Classwide robot contest during finals week. This contest is meant as a celebration for the class, and poor performance in this contest does not negatively impact the course grade. But good performance in this contest can boost the grade.

B. Reflection assignments

Three sets of reflections were created. The first set was assigned during weeks 2-4 when students were working on their individual clock project. The second set was assigned during weeks 5-10 when students were working on their team robot project, and it consisted of the same set of questions from the first set plus additional questions relating to teamwork and project management. And the final reflection End-Of-Quarter reflection incorporated additional questions relating to the amount learned throughout the entire course in the areas of CAD, Shop Tools, Engineering Analysis, Teamwork, Project Management, Creativity, Machine Design, Oral Presentations, Written Reports, and Ability to Overcome Obstacles.. Completing the reflection was worth very few points (0.3% each week), and if students did decide to complete it, only the multiple choice questions were required. All qualitative free responses were fully optional and provided no grade benefit. The multiple-choice questions asked students to rate their level of comfort, effectiveness, or confidence on a 5-point Likert scale. They were also given the option to select "not applicable". The free response questions were all encouraged but not required, and focused on students' creative blocks and breakthroughs, positive and negative team experiences,

and use of math or physics. See the Appendix for a full list of the reflection questions. The focus of this paper was to analyze responses to questions related to students' creativity, but we also looked at other factors that correlated with student reflections..

IV. Analysis and Results

A. Quantitative Results

A reflection assignment by its nature is a self evaluation of performance in the class. This study aims to correlate weekly reflections to learning that occurs in the class. Grades on assignments are a traditional way of quantifying learning. However, in a design class with team projects, grades do not necessarily capture the full extent of the learning. For example, in open-ended design projects some initial designs concepts may work well off-the-bat while others may lead down a deadend or require a much more iteration. Thus, in MAE 3, the final robot performance and grade on the robot project may not fully capture the learning that occurs during the design process. Furthermore, teammate performance also has an impact on an individual's grade on the project. Since there are so many factors that impact hardware performance in a project, if we looked only at grades we would be missing much of the learning. Another metric for learning is the End-Of-Quarter multiple-choice ratings where students self-assessed their learning throughout the quarter. While this is a subjective measurement, it is especially useful for quantifying the learning in the broader objectives of the course such as creativity and persistence. Accordingly, we looked at correlations between weekly reflections, assignment grades, and End-Of-Quarter multiple-choice ratings.

There were a total of 114 students in the class. This portion of the analysis is of the 77 students who completed reflections in weeks 2, 4, and 10. We started by looking at positive correlations to the Robot Hardware grade, since this was an objective score related to the ability of the students to design effectively and any correlation with hardware performance would be especially interesting. To encourage risk management in the design process we instituted a week 8 deliverable for robots to score a set number of points. If no points were scored in week 8, then students could still earn partial credit based upon how many days later they were able to score. The final robot performance was evaluated in week 10.

We found there to be a significant positive correlation ($p<0.05$) between final robot grade and the ability to score points in week 8 (r= 0.37, p= 0.00091). Of the 77 students in this analysis, 23 of them did not get full credit for their Week 8 Point Scoring Assignment. Even though this sub group of 23 students is small relative to the 77 students in the analysis, this is an especially interesting group. These 23 students were quantitatively shown to be in the position where they needed to overcome significant challenges; some of these robots needed significant redesign while others needed project management and teamwork improvement to make sure they could meet deadlines. We took a closer look at this subgroup to see what were the factors that correlated with students' ability to improve a robot that was not working well. For this subgroup we defined a metric for Robot Improvement based on the change of grade between week 8 (ability to score points) and week 10 (robot hardware grade).

A correlation was found between Robot Improvement and the End-Of-Quarter Reflection score for Self Rating of Creativity learned in the class (r=0.31, p=0.146). While these results do not pass the threshold for statistically significant $p<0.05$, they do show that students generally rated

their creativity learned as higher also had a higher robot improvement. These results are plotted in Figure 1 (fewer than 23 points visible because some points are on top of each other), with a least squares fit slope of 8.6 robot grade percent increase per Likert scale creativity rating. Robot Improvement in the subgroup was significantly correlated with an improvement in their final oral presentation grade (r=0.52, p=0.01), indicating that students who improved their robots were able to convey their achievements well.
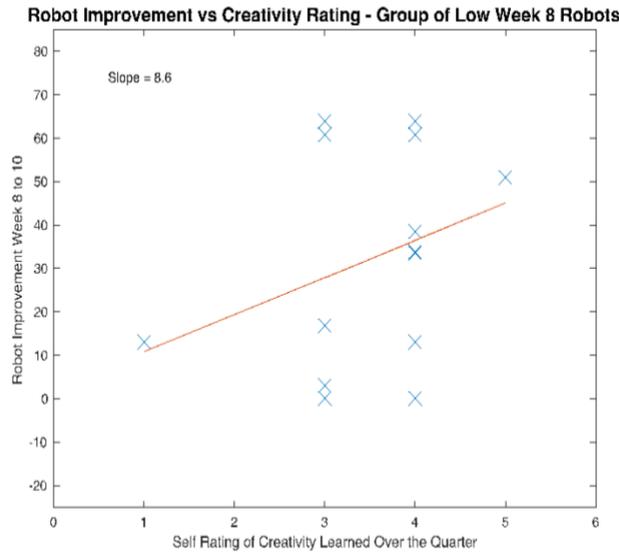

Figure 1: Robot Improvement Grade vs Self Rating of Creativity

Other quantitative correlations included one within the End-Of-Quarter ratings which showed a statistically significant positive correlation between a self rating of the amount of creativity learned and ability to overcome obstacles (r=0.75, p=2.7E-15). Another one was the amount of text characters written in the week 4 reflection which showed a statistically significant positive correlation to the grade on a students final report on their robot (r=0.35, p=0.001). This correlation indicates a predictive ability between week 4 and week 10.

Another comparison done was between U.S. domestic students (62 students) with international students (15 students). Correlations are shown in the table below, and it should be noted that interpretations of this analysis are limited given that we do not know each student's level of English proficiency. International students had a shorter average length of their reflections, as quantified by the average number of characters in free response sections. For international students whose first language is not English, comfort-level with reflective writing may have impacted the length of their responses. Writing conventions across cultures also vary and could have impacted student responses. However, international students did rate the amount learned from the reflections (3.6/5) as much higher than the domestic students (2.6/5). Key comparison results between domestic students and international students is shown in the table below.

Table 1: Comparing Domestic and Foreign National Students

Compare Domestic(n=62)to International(n=15)	Domestic	International
Wk4AdditionalCommentsTextLength	88.48	2.00

Wk10AdditionalCommentsTextLength	149.94	24.50
Wk2AdditionalCommentsTextLength	123.79	59.57
Wk2CombinedTextLength	399.58	212.54
Wk2WeekDescribeCreativityTextLength	217.31	118.08
QtrWhatWouldYouDoDifferentlyTextLength	228.15	131.60
Wk2DescribeEngineeringTheoryTextLength	130.90	77.42
Wk4CombinedTextLength	325.27	203.70
Wk10WeekDescribeCreativityTextLength	125.48	79.50
Wk4DescribeEngineeringTheoryTextLength	187.98	122.30
QtrLearnedFromReflectionNum	**2.60**	**3.40**

B. Qualitative Data Analysis and Results of Free Responses

In the weekly reflection survey, one of the questions students were asked to respond to was, "Describe any creative breakthroughs or creative blocks that you became aware of this past week. Do you know what helped your creativity?" For this study we analyzed responses for the start of the course (week 2), the end of the individual project and start of the team project (week 4), and the end of the course (week 10). To analyze student responses to this question, we used the qualitative research tool, ATLAS.ti, to code the reflection responses. Using grounded theory guidelines (Charmaz, 2005; Strauss & Corbin, 1990), we identified similarities across responses and created open codes. A total of 100 cases were coded, and as larger themes emerged, we linked the open codes with larger axial codes– three related to creative blocks and four related to creative breakthroughs. To ensure reliability, two members of our research team first coded independently and then reviewed each other's work. We identified discrepancies, clarified meanings, and agreed on each code. Findings from this analysis are discussed below and shown in the table.

Table 2: Text Analysis Codes

Axial Codes	Supporting Open Codes
Ability* (41)	Experience lack(20) Idea generation/creativity lacking (13) Difficulty of task (4) Uncertainty(4)

Self blocked* (12)	Emotional response (7) Blaming (5)
Constraints* (11)	Time (6) Assignment constraints (5)
Course Design** (72)	Learning tasks (21) Learning with/from peers (15) Course materials (13) Opportunity for creativity (12) Personalized project (7) Deadlines (4)
Self** (39)	Persistence (26) Attitude (10) Asking for help (3)
External Resources** (13)	Examples (10) Internet (3)
Creative Process** (23)	Reflection (6) Simplicity (6) Workspace/workplace (5) Seeing possibilities in other objects (4) New perspective (2)

*Related to describing challenges and blocks
**Related to overcoming challenges

Theme 1- Creativity blocked by ability
A noticeable theme when analyzing student responses, is that many felt their ability was a major block for their creativity. At the start of the class, this lack of ability manifested itself heavily in students being inexperienced, particularly with using software tools, such as AutoCAD and Autodesk Inventor. A number of students commented on how their lack of experience with the software affected their ability to make creative designs for their pendulum clocks. One student wrote:

"My Thursday section was the first time I ever was exposed to 3D engineering software. It was a completely new tool to me that made me reconsider how I can look at designs. I feel that my creativity is still limited due to my inexperience with Inventor and AutoCAD so far."

Another student reflected:

"In terms of designing objects online, I'm still getting accustomed to inventor. The instruction we received in section made it seem really intuitive, but designing projects on our own time proved a bit more challenging. There are just a lot of rules and steps to insure that designs are fully dimensioned and constrained, but i think that will just improve with experience and time."

Other students reflected on how their lack of experience limited their ability to execute creative designs, as one student explained:

"Coming up with a design for the pendulum was a struggle. I felt like what I had designed previously was too simple or incorrect for the assignment based on what I had seen in examples and from other classmates."

Another student wrote:

"I need to know more fundamentals design principles in order to be more creative."

In addition, a large number of students described their creative block as an inability to generate ideas. They described their struggle to come up with new ideas, both in terms of coming up with a sufficient quantity of ideas, as well as in coming up with an idea they considered to be of sufficient quality or complexity. When describing the process of coming up with design sketches for the robot contest, one student wrote:

"I thought I had two pretty good sketches that were good ideas. However, I had creative blocks for the other two sketches as I was unsure of how to change up the design drastically. All my sketches were a bit similar to each other because I had trouble thinking of other ideas."

Another student reflected:

"I had issues coming up with alternative ideas for grabbing the lightsaber parts for the robot design. I had one idea and a few variations of it that I liked, but I couldn't come up with any other ideas."

Finally, many students described the difficulty in the tasks and their uncertainty in the design process.

Theme 2- Creativity blocked by self
A second theme that emerged when students described their creative blocks, was one of being self-blocked. Salient in a number of these reflections was a significant emotional response, including fear, sadness, a lack of confidence, and frustration. There were also a number of students who had a tendency to assign blame, typically aimed towards a lack of sleep. A few representative examples are as follows:

"My fear was holding me back from being confident enough to take charge and think out of the box."

"I wish I could draw better so I could convey my ideas more effectively."

"Blocks on the four drawings, big time. As usual, being tired doesn't help the process one bit."

Theme 3- Creativity blocked by constraints
The final theme relating to blocks in students' creativity revolved around various constraints they encountered. These constraints included both time constraints, as well as constraints in the

assignment. Students felt that these external constraints prevented them from fulfilling their creative potential. As two students explained:

> "My ability to be creative feels constrained by the time, tools, and material available, as well as the desired functionality of the end product."

> "A creative block that we encountered this week was that the robot chassis had to be cut in a certain area in order to be able to pick up and drop pieces from and onto platforms without preventing movement."

Theme 4: Course design helped with creative breakthroughs

While there were several aspects of course design that students indicated encouraged creative breakthroughs, learning with and from peers was highlighted most frequently. Working with peers through the brainstorming process, learning from and being inspired by their projects and ideas, and communicating effectively with peers helped them gain new insights, as described in the following:

> "Meeting a classmate and seeing his professional work inspired me to think harder on my clock project. If he can do it, so can I."

> "Creative breakthroughs we had this week was new ideas for creating a new drive train for our robot. Our creativity was helped by being surrounded by other teams and other robots with different ideas."

Regarding the importance of effective communication, another student wrote:

> "We needed to figure out a way to create balance in our robot. Brainstorming together/throwing out ideas in a non-judgmental environment helped a lot."

Students also noted how various learning tasks incorporated into the course, such as learning new tools and using them in a meaningful way contributed to their creative breakthroughs.

> "Though this may be the first week of class, my creative breakthrough comes from being able to sketch and design my own pendulum for the clock project as I decided to hand sketch and create my own raccoon pendulum by noting the significant features of the animal. With this in mind, I was able to create a raccoon pendulum using complex arches, lines, and circles that I've picked up from this course in AutoCAD."

Some students also described how opportunities for open-ended solutions and customizations, which are intended parts of the course design, contributed to their creative breakthroughs:

> "I had a creative breakthrough when the lab tutor mentioned extra credit for being creative with the pendulum design. This led to me to think of a design that no one probably has done before: an infinity mirror pendulum. What helped my creativity was the opportunity provided to personalize the pendulum design."

Theme 5: Creativity breakthroughs can be self-induced

Oneself appeared as a theme for both a cause of creative blocks, as well as a cause for creative breakthroughs. In the case of breakthroughs, many students describe a similar pattern of struggling, pushing through, and ultimately figuring out a solution. Often they write about how

this process takes a very long time. The idea of overcoming challenges and being persistent is one of the experiential learning objectives of the course, and the reflection responses help elucidate student development in this area. One student articulated this idea particularly well:

> "I discovered that there is almost always a way to fix things if you just take a second to think about it or ask for help when I made a small mistake when fabricating my clock and when I wanted to make my clock work on just one nut. Thus, consulting the TAs and taking time to think things through (and not panicking) helped me to conquer these challenges."

Another noticeable self-induced attitude that appeared in multiple responses, was to just have fun with the assignment and to try to enjoy it. This outlook appeared to help some students overcome initial frustration with creative blocks. As one student wrote:

> "I had a hard time beginning my design for my pendulum, but once I started I began to enjoy the process and I ended up making a simple but significant design to something that defines me. I think I was able to do this because I thoroughly enjoyed what I was doing."

Theme 6: External resources helped with creative breakthroughs

The open-ended nature of the course projects, along with the competition structure, encourages students to be creative in their design concepts. Many students find that related examples– in particular, examples from previous students, shown in class, or found online– can help them overcome creative blocks. Typically students discuss how these examples help to inspire them when they are stuck. One student reflected on the experience of designing the customized component of the pendulum clock:

> "Past pendulums and examples inspired my design and showed me how creative I could get with the pendulum."

It is interesting to see that not only can examples help directly inspire designs, but they can help students understand the extent to which they can use their imagination to be original. Another student wrote about how examples can be helpful for getting a sense of what already exists versus what would be new or novel:

> "Considering preexisting designs for grabbing objects, then considering what designs I don't see was helpful in getting over that initial hump of no ideas."

Finally, some students found that the examples did not need to be directly related to what they were trying to make, but instead any clever mechanical design could be helpful in overcoming creative blocks:

> "Shopping in the bestbuy is one of the effective ways for me to help my creativity since there are several mechanical designs to help me to come up with some ideas."

Theme 7: The creative process helped with creative breakthroughs

In writing about what helped their creativity, a number of students described elements that are a part of the creative process. For example, students described the need to take a step back or take a break from their designs in order to reflect. Once they came back to their designs at a later time, they were able to overcome initial creative blocks. This reflection process was described by some students as follows:

> "Taking a break and then going back to my work gave me time to reflect. I had drawn a bunch of sketches for my pendulum, but I ended up making a whole new one that made me happiest."

"Taking a step back to look at the issue differently helped a lot."

Many students also described how simplicity was key for them to push past creative blocks. And others described how objects in their daily lives helped them see new possibilities for their designs. For the pendulum clock in particular, students mentioned happening upon signs, logos, stickers, and symbols that sparked new ideas right when they felt stuck. There was also a recurring theme of looking at things from a new perspective, trying to understand the problem in different ways, and sometimes thinking of a completely new direction to take. For example:

> "I had issues coming up with alternative ideas for grabbing the lightsaber parts for the robot design. I had one idea and a few variations of it that I liked, but I couldn't come up with any other ideas. I got around this block somewhat by trying my best to look at the problem in different ways and looking at my surrounding for random inspiration."
> "I was able to find a design for a claw that fit all of the different pieces. I was able to come up with this by looking at the parts from all directions looking for similarity in shapes."

Finally, some students noted that their work environment was a big factor in helping their creativity. For some, the environment itself was inspiring, and for others, the environment seemed to help put them in the right frame-of-mind for letting their creativity flow.

> "When I was creating the robot sketches, I drew each one in a slightly different environment. One was in my room when it was silent, another was in my room with people talking. Another was downstairs while everyone was playing smash."
> "When coming up with designs for the robot, I was in a nice environment and I was able to come up with really good ideas."

It should be noted that there is the potential to perform quantitative analysis based on the various groupings obtained from the qualitative analysis. This analysis could include comparisons on performance on critical assignments between those within one or more of the coded groups and those who are not. Due to the small sample number in many of the groups, this type of analysis proved challenging in this study and is left for future work.

V.   Discussion and Conclusion

One of our research questions was how do we use reflection as both a learning tool and formative assessment tool? Formative assessments are typically low-stakes or no-stakes assignments that help students assess their understanding and help faculty gauge what students are learning and where they might be struggling.

The length of the free responses is displayed in Table 1, which compares domestic and international students. We see that consistently domestic students have longer reflection responses. However, the Likert scale rating for the amount learned from the reflections showed a higher rating for foreign nationals. This indicates the importance of using multiple methods of assessment to better understand student learning, as well as the significance of the content of student reflections.

The content of the reflections was analyzed through coding the responses in the categories shown in Table 2. Correlations of the reflection content are shown in Table 3 and 4. In both tables students who did not reply to the reflection question on creativity had low robot scores and clock report scores. The differences between the groups that had content relating to self-blocking relative to the content of persistence, did not show as big a difference. Further analysis and with a larger number of students, may identify additional correlations.

Additionally, we believe that student reflections could possibly improve faculty teaching. It should be noted that due to the recent rise in popularity of freshmen hands-on courses, many of the instructors of these courses did not experience such a course themselves. Accordingly, when an instructor reads students' reflections, they become more familiar with the anguish and triumph as students tackle difficult challenges early in their college experience. Accordingly, reflections by students may also end up increasing instructor familiarity and empathy for students going through the process. This topic was not addressed in this study, but is a possible future use of reflection assignments.

Regarding teaching creativity in the college classroom, and in particular in the context of this course that is taught in ten weeks, there is a tension between creating environments that allow for understanding creative tools, overcoming inhibitions, assuming frame of mind, and stimulating creative thinking (Court, 1998) and asking students to learn new tools, learn how to work as a team, and submit a working project for which they will be assigned a grade. Incorporating low-stakes assignments that allow students to learn from mistakes and failure can help alleviate this tension.

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Appendix

Full List of Reflection Questions

Question Type	Question	Response Type
Individual questions (given in Weeks 2-10)	How comfortable do you feel in using the CAD tools for the past week's assignment?	1-6 (1=very uncomfortable, 5= very comfortable, 6= NA)
	How comfortable do you feel in using the Design Studio shop tools for the past week's assignments?	1-6 (1=very uncomfortable, 5= very comfortable, 6= NA)

	Rate your effectiveness in making progress on your design project this past week.	1-6 (1=very ineffective, 5= very effective, 6= NA)
	How much engineering theory did you use in your project this past week?	1-6 (1=none, 5= very significant amount, 6= NA)
	How confident are you of the correctness of your engineering analysis you did this past week?	1-6 (1=very unconfident, 5= very confident, 6= NA)
	How many hours did you spend outside of assigned lecture and lab times for this class?	1 hour- 15 hours (in increments of 1 hour), or greater than 15 hours
	To what extent do you feel included and welcome in the class and lab activities?	1-6 (1=not at all, 5= very significant amount, 6= NA)
	To what extent did the class and lab this week motivate you to continue to study engineering?	1-6 (1=not at all, 5= very significant amount, 6= NA)
	Describe any creativity breakthroughs or creative blocks that you became aware of this past week. Do you know what helped your creativity?	Free response
	Describe uses of math or physics theory in this past week. How confident do you feel that your analysis was correct?	Free response
	Any other comments you would like to add? (For example: was there anything that was particularly confusing this week? Or anything that you found particularly helpful?)	Free response
Teamwork questions (given	How effective was the teamwork in your group for the past week?	1-6 (1=very ineffective, 5= very effective, 6= NA)

in Weeks 4-10)	How effective was the project management in your group this past week in areas such as risk reduction and setting milestones?	1-6 (1=very ineffective, 5= very effective, 6= NA)
	Describe any positive or negative team experiences this past week. Did you or will you take any actions to improve teamwork? (This can include project management)	Free response
End-Of-Quarter questions (given in Week 10)	Over the quarter, how much did you learn in the following areas? 1. CAD 2. Shop Tools 3. Engineering Analysis 4. Teamwork 5. Project Management 6. Creativity 7. Machine Design 8. Oral Presentations 9. Written Reports 10. Ability to Overcome Obstacles	1-5 (1=none, 5=a very large amount)
	Over the quarter, how much did you learn from the following activities? 1. Individual work on clock project 2. Working with teammates on robot 3. Interacting with TAs, tutors, staff, and instructors 4. Lectures 5. Reading and web 6. Homework theory assignments 7. Physically working with hardware 8. Weekly reflection assignment	1-5 (1=none, 5=a very large amount)
	If you were going to do a similar project again, what would you do differently and what would you make a point to do the same?	Free response