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A Framework for CAD Design Projects: Combining Scaffolded Milestones, Design Review, and Reflection

Dr. Jamie Szwalek, The University of Illinois at Chicago

Jamie Szwalek is currently a Clinical Associate Professor at University of Illinois at Chicago in Mechanical Engineering and has over ten years of teaching experience.

Christopher Carducci, The University of Illinois at Chicago

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Abstract

This paper provides a framework for instructors to maximize student learning and communication skills in a third year mechanical engineering course that uses computer aided drafting (CAD) for a design project. The current framework mirrors the review process that takes place in industry and motivates students to keep up with major deadlines. Students need to learn how to accept feedback, review other's work, and communicate their designs to be successful in industry. The framework has been developed over three semesters and incorporates scaffolded milestones, (peer) design reviews, and reflection. This paper presents instructor observations of lessons learned and graduate TA observations from lab with the goal of making the framework accessible to other instructors of design. The main research questions in this paper include: 1) How open are students to the design review process? 2) Which helped students to maintain steady progress on their project: scaffolded milestones, design review assignments, or both? 3) Did students benefit from design review and how? Did it impact their project or skill set? 4) Did design review affect their engineering *design* identity? Do they see themselves as designers? To determine effectiveness of the framework, an anonymous Qualtrics survey has been developed and administered to students to determine the impact on their learning experiences, skills, and engineering identity. The survey results indicate that students are receptive to constructive feedback and open to a (peer) design review process. Overall, both the students' design work and skills have benefitted; students can develop design solutions, effectively communicate design, evaluate designs, and recognize changes needed for the solution to work. Using the design review process has helped increase student learning and positively affected their communication skills.

1 Introduction

ME 347 is a third-year undergraduate design course for mechanical engineers which incorporates theory and design with CAD (SolidWorks). The course gives them the most significant design experience so far in the curriculum (ME 347 is also a pre-requisite course for senior design). Additionally, students take an earlier course, ME 250-Intro to Engineering Design, which introduces the design process and the basics of CAD modeling (simple geometry and drawings). It also incorporates building a physical model using traditional machine shop techniques and 3-D printers. While ME 250 is an important course for developing engineering identity, ME 347 actually develops the mechanical engineering *design* identity due to the open-ended nature of the project and considerations of manufacturability and practicality. ME 347 builds upon the CAD skills learned in ME 250 and incorporates more detailed geometric modeling with advanced mates and engineering drawings. Generally, about 100 students enroll in this course per semester, with 2 hours of lecture and 2 hours of lab per week. The lab sessions are smaller, with about 35 students, and run by multiple graduate teaching assistants.

This paper discusses a framework that is used in ME 347 for the first design project (Project 1), which typically takes about 9 weeks to complete. The project involves building a 3-D model in CAD, using rapid prototyping to 3-D print their respective improved best model, and doing a live demonstration of their CAD model and 3-D printed part. The final deliverable is a professional written report that includes documentation of their completed design, related engineering drawings, reflections on improvements to be made, and what they learned from doing the project.

1.1 Project Selection

Open-ended projects are a great way to promote deep understanding of engineering design principles. In ME 347, Project 1 is creation of a SolidWorks assembly and rapid prototyping. Each semester, the design challenge changes. For Spring 2023, the challenge is to create and 3-D print a standing picture frame or photo ID badge holder for a lanyard. The intention is to keep the design space large and allow for customization and creativity, but there specified constraints such as: size limitations, estimated max print time, no modifications after printing, etc. The design cannot simply be improved with "trial and error" due to finite resources and length of time needed to 3-D print. This requires students to give greater diligence to physical tolerances and manufacturing feasibility.

What is important to keep in mind when selecting a project? Actually, there is no "easy" project; many times, it may appear simplistic to the students, but later some admit that they underestimated it or they could have added in more complexity. Students often underestimate the time and effort to get from sketches to creating a final 3-D printed part. While the project should offer a challenge, instructors should have realistic expectations of the students' experiences. Often, supplemental information is needed to complete the project, but may not be known at the start. This can easily be provided to the students as needed. Brainstorming ideas with the teaching assistants (TAs) can predict many potential downfalls or concerns when selecting the project. Some concerns include:

a) Is the design space for the project large enough to ensure creativity and uniqueness?
b) Is the project interesting to students?
c) Should designs be pre-screened for over complexity or 3-D print feasibility?
d) What are the respective resolutions and limitations of the 3-D printers? Which TAs have expertise in 3-D printing to be a good reference to students for troubleshooting?
e) How will design and function aspects of the final product be quantitatively evaluated fairly and consistently across multiple TAs?

A good design challenge idea can save time later if it can be modified easily in following semesters through modifications to the design constraints or functionality. Also, the time for the instructor to develop the project decreases with the experiences gained from completing past projects and increased knowledge of 3-D printing.

1.2 Design Notebooks

All students are required to keep a design notebook, which is a commonly used practice in undergraduate mechanical engineering courses. This is a composition notebook that documents only their design work: sketches, brainstorming, tips, questions or concerns, and progress updates. Many students request to use a digital notebook; however, for ease of grading and sharing their work with fellow students, physical paper notebooks are more practical and accessible.

Students are assigned tasks related to the project in their design notebooks. To ensure completion, design notebooks are collected several times during the semester and this counts as part of the final grade. Feedback on design notebook assignments is addressed entirely within the design reviews; any inaccuracies can be corrected due to the iterative design process. As such, the grading of design notebooks is not based on accuracy, rather it is based on effort (volume) and completion of all the assignments.

2 Method

This framework presented in this paper applies three methods to a design project (Project 1) in ME 347: scaffolded milestones, design reviews, and reflection. The objective is to develop interpersonal skills that may have been hampered by the COVID-19 pandemic lockdown measures. Receiving and giving feedback is an important skill to practice. Building a sense of community and effectively communicating engineering principles in peer-to-peer design reviews are pillars of the project.

This paper presents how the framework is used in practice for mechanical engineering, instructor observations of lessons learned, and teaching assistant (TA) observations from lab. It is hoped that the current framework can be made accessible to other instructors of design who want to use it to save them time. To determine effectiveness, a survey instrument has been developed and administered to students to determine what impact (if any) it had.

2.1 Scaffolding the Design Milestones

From prior experience teaching an introduction to engineering design, students tend to rush to a final design concept and skip key steps in the design process. If they are given specific benchmarks for evaluation, they are more likely to generate alternatives, stop and reflect on what they have, and consider improvements. When designing a project, instructors should start with the end in mind and consider what deliverables can show along the way to indicate progress. Scaffolding deadlines for project tasks for undergraduate students can help them be more successful; it gives them a good example of how to manageably schedule complex tasks to meet the final deadline. For example, progress can be broken up into manageable deliverables ("milestones") that push the project forward. Here are some milestones used in Project 1:

1. Brainstorm problem definition (objectives, constraints) and concept ideas
2. Sketching
3. Proof of concept, ex. build a cardboard model
4. Create a 3-D CAD model
5. Create a 3-D printed part
6. Identify weaknesses and improve the design
7. **Final deliverable**: written report documenting the design and its process, including engineering drawings, and reflections of what improvements can be made and what they learned from completing the project.

Smaller project milestones can be completed in their design notebook, for example, brainstorming or sketching. Two examples done for their project include: (1) Sketch three (unique) design concepts in the design notebook, and (2) Decide on the top concept. Why is it the best choice? Explain in your design notebook.

It is highly recommended that milestones are graded. This can come in the form of small assignments like a design notebook assignment, an item for design review, or some other stated assignment that shows progress (i.e. part of homework). I have used the major milestones as part of the project grade. For example, they demonstrate their CAD model and functionality of their 3-D printed part in lab as large component of their Project 1 grade (25%, 30% respectively). Their report with engineering drawings is 35% of the Project 1 grade. To challenge students, creativity is also counted as 10% of the Project 1 grade.

2.2 Using Design Review

In industry, I was assigned a quality checker who reviewed all work before sending anything to a client. A similar framework can be applied to any design course: students communicate their work, gather feedback from peers, implement changes, and then submit it for a major grade (ex. Project 1 Report). This additional check replicates the workplace environment where work is reviewed by a colleague [1]. To be successful in industry, students need opportunities to practice giving and getting constructive feedback from others. Making students responsible to do peer reviews replicate the reality they will face as professional engineers where their work must be accurate and thoroughly documented [1]. In this paper, this activity is consciously called “design review” instead of “peer review” to emphasize the professional interactions and keep the focus on design improvement.

The review process can be used early in the design stage; for example, overcomplexity can be addressed before the top concept is selected. While there is no single correct answer, there are some solutions that work better. Students make many decisions along the way which ultimately affect the final design. However, this is where peers can be helpful. By taking advantage of design review, different perspectives can positively influence the design with suggestions and by pointing out potential flaws. Students learn that starting over is not necessarily a setback, but sometimes an opportunity for a sleeker, improved design.

A peer review framework has been shown to be helpful in other engineering courses. For example, at West Point, it has been used in civil engineering courses like structural analysis where students check each other’s calculations before submitting assignments for a grade [2]. Another framework has been developed for an industrial and systems engineering course at the University of Minnesota to provide constructive peer feedback on team written documents [3]. The benefit of using peer review is that students gain practice at receiving and responding to peer feedback in a way that is decoupled from the grade. Student’s reactions to feedback evolve from defensiveness to viewing critiques as a positive influence to improve their work [3].

The previous frameworks had not been applied to an engineering design course. The current framework modifies the peer review process to account for design or CAD related work, instead of engineering calculations [2]. This modified framework includes describing the top priorities for improvement. The design review form (two pages) is included in **Appendix A** for reference. Student reviewers are required to include their names on their form (Page 1) to motivate accountability in providing useful feedback [3].

The current framework uses face-to-face interaction and dedicated lab time to complete the design review. Each design review activity can easily take 20 minutes. The time allotted to do other activities or assignments in lab is decreased, so these were either removed or shifted to be done outside of lab if possible (ex. CAD tutorial). Students are given a paper form to fill out for each design review and these are submitted to the TA before the end of lab. *This is a social activity*-they need to find two reviewers. After COVID-19, many students still did not know their peers, especially in larger-sized classes. The design review process is used many times throughout Project 1, so the goal is for students to become comfortable giving and receiving feedback. Prior to the first design review activity, it can be helpful to plan activities to get them comfortable talking to each other; such as ice breakers, solving problems with think-pair-share, or sharing their ideas with the instructor or TAs.

Prior to the first design review, students need clear expectations about the review process and its goals. It is helpful to explain what makes a peer review useful, what makes it bogus (superficial or unhelpful), and examples of each; this can be presented in a handout and discussed in lecture [2]. While offering incentives for great reviews can motivate students, large class sizes tend to make this strategy logistically difficult. As such, incentives were not attempted [2]. Penalties (in general) and penalties for giving a bogus review were not attempted either [2].

Design review assignments should be graded or part of the final grade in the course. Each design review is a small graded assignment (10 points), so that students put in effort. Grading is done based on completion effort, so it can be fast to grade for larger sized classes. Not all learning activities need to be graded, but if you really want students to engage in it, it needs to be incorporated into their final grade [5].

2.3 Incorporating Reflection

Cognitive reflection is a form of *mental processing* with an anticipated outcome that is applied to a relatively complicated or unstructured idea for which there is not an obvious solution [4]. Reflection is part of active learning that allows students to apply significance to their work [5]. As an undergraduate student, it was helpful to pause and think about the tasks and why they were done. The "*why are we doing this*?" kept me engaged in undergraduate courses. When the act of reflection is linked to the human need to make meaning, the significance of the activity becomes clearer [5].

A second page has been added to the Design Review form to incorporate reflection (Page 2). This has been adapted from a peer review workshop evaluation form used for team-based project reporting that has been shown to work in an industrial and systems engineering course [3]. The second page ensures students have actually read their feedback and internalized it, thereby integrating a reflection aspect into the design review. Without including the reflection (part of the grade), it is probable that students do not bother to read the feedback. In relation to the project, the reflection asks students to read and evaluate their design feedback by rating the feedback quality as: extremely helpful, helpful, not helpful, or missing. They are given space to write down what was most helpful to them on the form from each reviewer.

At the bottom of the form (Page 2), there is an open-ended question regarding how the reviewers can make their reviews more helpful next time [3]. Suggestions for improvement usually include making feedback more critical or specific [3]. Many times students need to be reminded how to communicate with each other; this could simply be changing their tone or rhetoric, but it is open to anything they want to write. The hope is that students recognize how they want to receive information from others. Consequently, when they write reviews, theirs will become more helpful and better received. One observed recognizable benefits is that students reported that the quality of feedback they received was good or excellent, especially as they became more comfortable offering detailed feedback [3].

Reflection activities can be used in other ways. One way is to incorporate this into the design notebook assignments. For example, students can write a short progress report or discuss how their design changed after watching a video about 3-D printing. Reflection can be part of the project. For Project 1, students write a reflection paragraph in their written report's conclusion. They are asked to reflect on how their design could be further improved and what they learned from doing the project. They are asked to provide detailed explanations to support their claim and demonstrate critical thinking. One tip is to specify that a *quality reflection* is not indicative of quantity (longer is not always better). Students can discuss anything, so this is graded by effort and seriousness. Common issues include "barely there" or "on the surface" reflections that are too general or vague.

2.4 Survey Development

A survey instrument has been developed in Qualtrics. Students who took ME 347 in Spring 2023 were contacted and asked to complete an online, anonymous survey regarding the design review process for Project 1 during Fall 2023. The hypothesis is that students have benefited directly from this framework by receiving valuable feedback to improve their design or their skill set. The main constructs investigated include: student mindset, benefits of design review (steady project progress or perceived experiential direct benefit), impact on the students' design and skills, perception of performance and competence related to their engineering design identity, and perception of recognition related to their engineering design identity. Engineering identity is related to characteristics as an engineering student and is comprised of several constructs, including students' perceptions of their own: performance/competence beliefs, feelings of recognition, and interest in the subject [7]. Only the first two constructs are examined since it is assumed that by the time students reach ME 347, they are still interested in mechanical engineering.

The research questions addressed in this paper include the following:

1. How open are students to the design review process?
2. Which helped students to maintain steady progress on their project: scaffolded milestones, design review assignments, or both?
3. Did students benefit and how? Did design review impact their design work or skill set?

4. Did design review affect engineering *design* identity? Do they see themselves as designers?

All survey questions are shown in **Appendix B.** There are seventeen statements, Q1-Q17, and many were adapted or replicated from literature [1, 6, and 7]. The statements use a 5 point Likert rating scale where: 1=strongly disagree and 5=strongly agree, or 1=no impact and 5=most impact. Additionally, there are three open-ended questions on the survey (Q18-Q20). This allows students to provide examples of how design review impacted their project work (Q18), describe any improvements they would like to see in the design review process (Q19), and describe how their design skills developed through or not (Q20).

3 Survey Results

The survey was administered in Fall 2023 to about 100 students and sent out four times. The response rate is about 20-21% since students had already finished ME 347 in spring and the timing was off. Students had taken the course the previous semester and knew their final course grade. The survey results are summarized in **Appendix B**. For simplicity, the responses have been grouped; a *negative* response corresponds to a rating of 1 or 2, a *neutral* response corresponds to 3, and a *positive* response corresponds to 4 or 5. From the survey results, overall, most of the questions received *positive* response which indicates that students have benefitted.

How open are students to the process? Figure 1 compares the survey results (Q2, Q3, and Q5). The survey results show they had a good attitude toward the design review process, indicating that it can be a powerful learning tool (Q2, 90.5% positive response). They have a growth mindset belief that with more design experience, the better they can become at it (Q3, 100% positive response). Additionally it is encouraging that they appreciate feedback from teachers, coaches, or parents (Q5, 95.2% positive response). Overall, the students seem open to the process and design review has potential to be a successful learning activity.

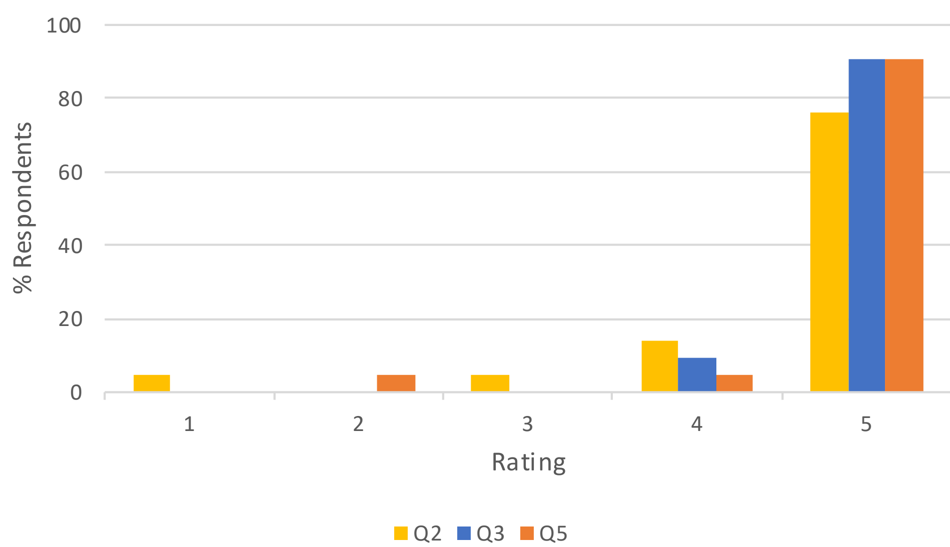

Figure 1. How open are students to the design review process (Q2-Q3, Q5)? Results shown from Q2-Q3, and Q5 with Likert scale: 1=strongly disagree and 5=strongly agree.

Which helped students to maintain steady progress on their design project: scaffolded milestones, design review assignments, or both? This was addressed in Q6-Q7 and the comparison is shown in Figure 2. Both helped students, but having scaffolded design milestones (Q6, 81% positive response) were slightly less important than having a design review assignment due (Q7, 85.7% positive response). The difference is only due to one student, so more responses are needed for certainty and suggested for future work. However, knowing that peers will read and comment on their work can provide a positive peer pressure influence for students to provide high quality work for reasons beyond a grade [3].

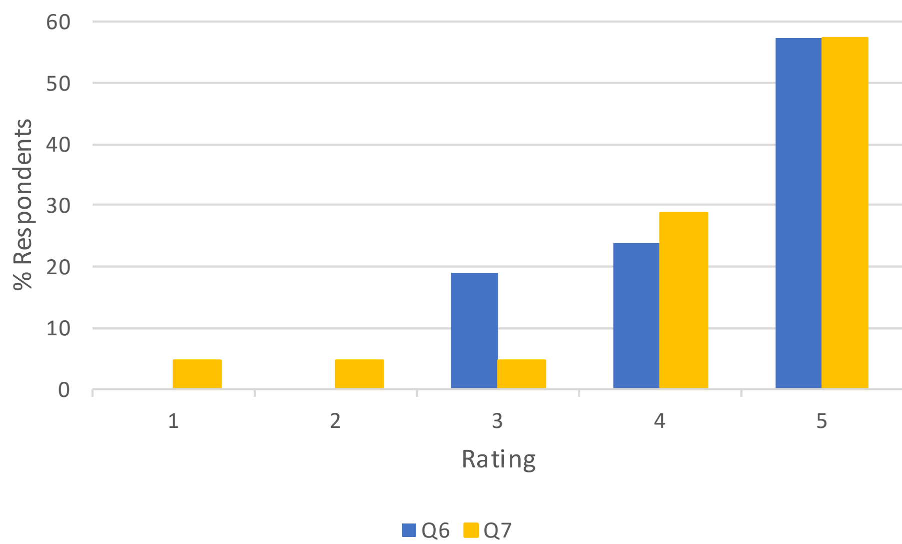

Figure 2. Did students make steady progress and how (Q6, Q7)? Results shown from Q6 and Q7 with Likert scale: 1=strongly disagree and 5=strongly agree.

Did students benefit from the design review process? Yes, students appear to have benefitted as shown in Figure 3 below which compares the results (Q8-Q9, Q14). They have benefited from reviewing their peer's design (Q8, 66.7% positive response) and from peers' reviewing their design (Q9, 81% positive response). Students perceive that they have benefited *more* from peers reviewing their work compared to benefitting themselves when they do the review. The lack of neutral responses for Q9 indicates either a negative or positive perception toward design review, with stronger leaning towards positive.

Results from Q14 indicate that students can recognize changes needed for a design solution to work, which is beneficial to them as an engineer (Q14, 81% positive response). This survey was administered after the course was completed and they have completed many design reviews so this is encouraging to see.

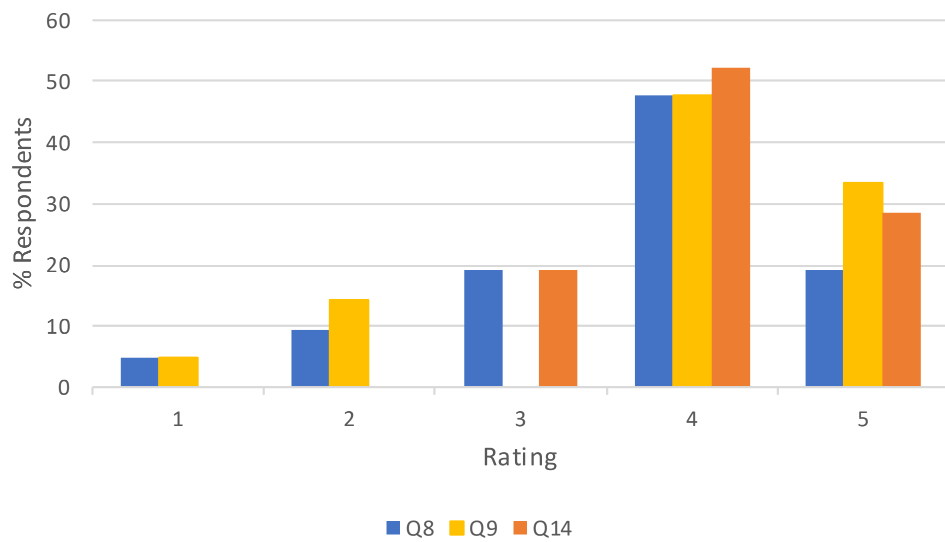

Figure 3. Did students benefit from the design review process (Q8-Q9, Q14)? Results shown from Q8-Q9 and Q14 with Likert scale: 1=strongly disagree and 5=strongly agree.

Did students' skills benefit from the design review process? Results are shown in Figure 4 (Q4, Q10). Yes, students believe that the experiences they had in the course allowed them to be better at design (Q4, 90.5% positive response). They are also asked to rate the impact that design review had on their skills to review and assess other's technical work (Q10). These results indicate a moderate to major impact (Q10, 51.7% positive response), however many students remained neutral (Q10, 38.1% neutral response). This could depend on many factors, including who did the review, how detailed the review was, whether it was a bogus review, their own engineering identity, their initial strength of their design skills, etc.

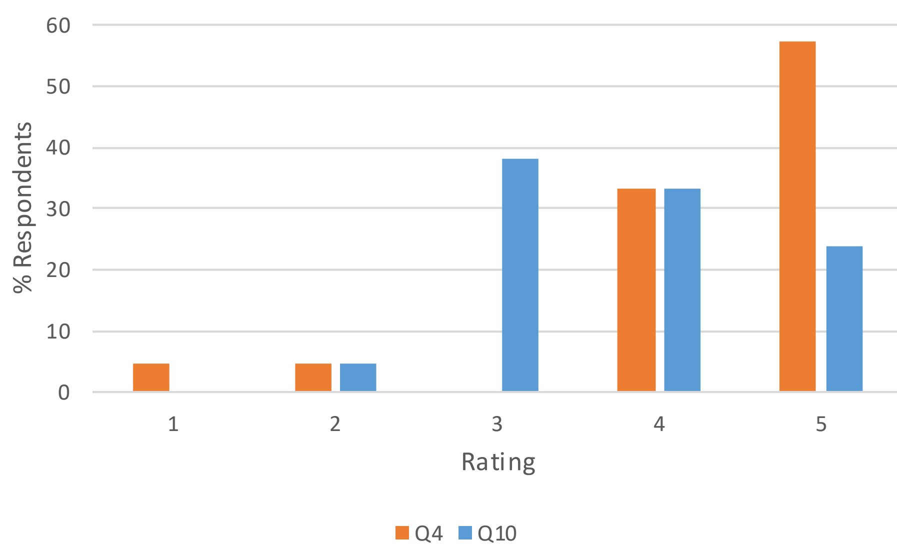

Figure 4. Did students' skills benefit (Q4, Q10)? Results shown from Q4 with Likert scale: 1=strongly disagree and 5=strongly agree. Results shown from Q10** with modified Likert scale: 1=no impact, 2=minor, 3=neutral, 4=moderate, 5=major impact.

Do students recognize themselves as mechanical engineer designers? Figure 5 shows the results of recognition, part of their engineering identity (Q15-Q17). One construct of engineering identity is their perception of performance and competence as an engineer; one example of this is that their peers notice them and often ask for their feedback (Q15). This question has been adapted to be specific to **design identity** [7]. Most students do not often ask for feedback (Q15, 33.3% positive response). I have seen comments on course teaching evaluations for ME 347 stating that they "felt like a mechanical engineer" for the first time, so this is investigated to see if they identify themselves as engineers during their third year (Q16). Students stated that they felt like an engineer (Q16, 50% positive response) and that their peers recognized them as an engineer (Q17, 55% positive response). There were large neutral responses for these two questions (Q16, 40% neutral response; Q17, 35% neutral response). A student's perception of how others view them is vitally important to how the student sees themselves [7]. It would be interesting to see how it changed over the semester or if it changed (at all) in future work. In general, the responses indicate that their mechanical engineering *design* identities are still developing, which is acceptable since ME 347 is a third year course and a pre-requisite to senior design.

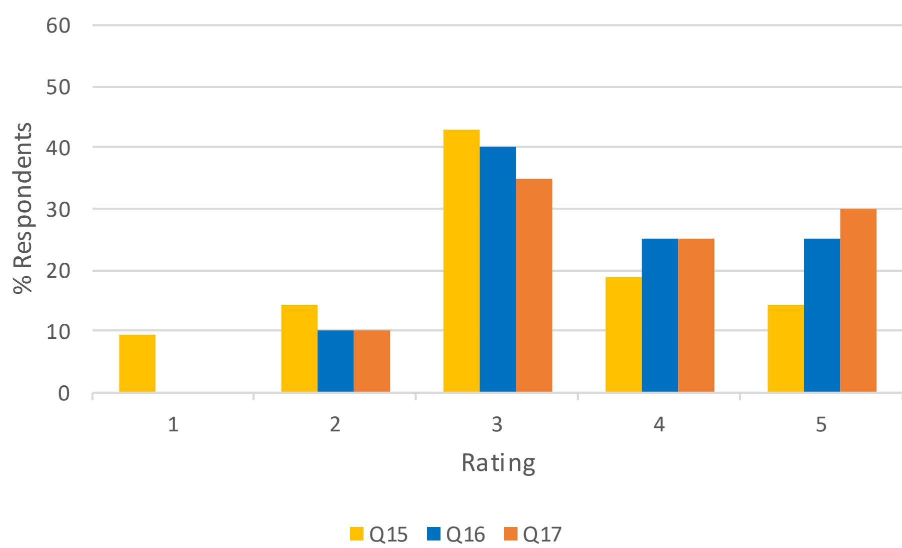

Figure 5. Do students recognize themselves as mechanical engineer designers (Q15-Q17)? Results shown from Q15-Q17 with Likert scale: 1=strongly disagree and 5=strongly agree.

Why don't their peers ***often*** *ask for their feedback* (Q15, 33.3% positive result)? It is surprising that the largest response is actually neutral (Q15, 42.9% neutral response). One reason could be that many students reported that they preferred to work on their own during the design process (Q1, 61.9% positive response). The comparison is shown in Figure 6 (Q1, Q15). It is surprising that they prefer to work alone on design, whereas in my experience, engineering design work tends to be highly collaborative and better in teams. These students are currently in senior design now and this has been observed also by our senior design instructors. This could be attributed to the post-COVID era (remote work mindset). Our senior design instructors observed that these students spend less time performing work together and instead prefer to split up the work and do it separately, noting that this seems more pronounced now than before the COVID-19 pandemic.

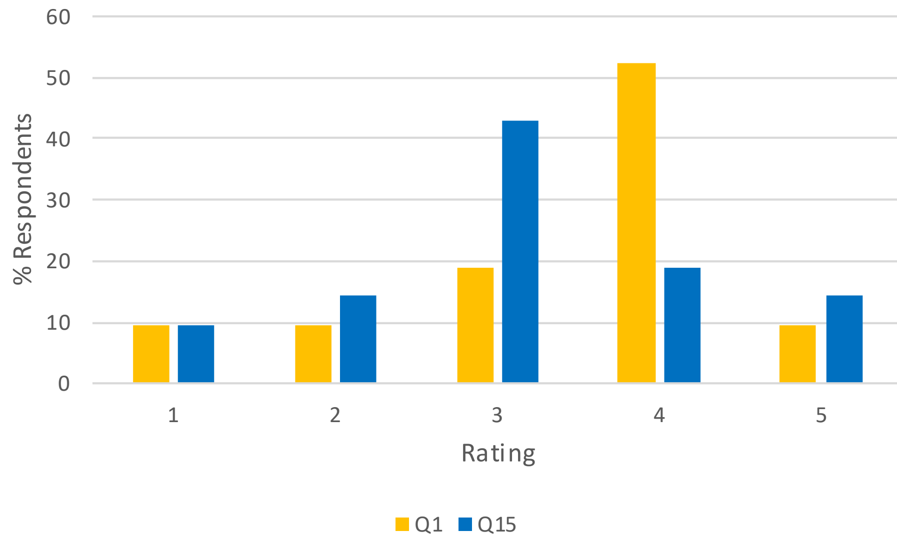

Figure 6. Did students preference to work alone (Q1) correlate with peers not often asking for feedback on their design (Q15)? Results from Q1 and Q15 with Likert scale: 1=strongly disagree and 5=strongly agree.

Do students see themselves as designers? How did the students view their performance and competence (part of engineering identity)? Figure 7 shows strong positive perception of their design performance and competence in design- they can develop design solutions (Q11), effectively communicate (Q12), evaluate (Q13), and recognize changes needed to make a design solution work (Q14). Only one student responded with strongly disagree (Q12, 4.7% negative response).

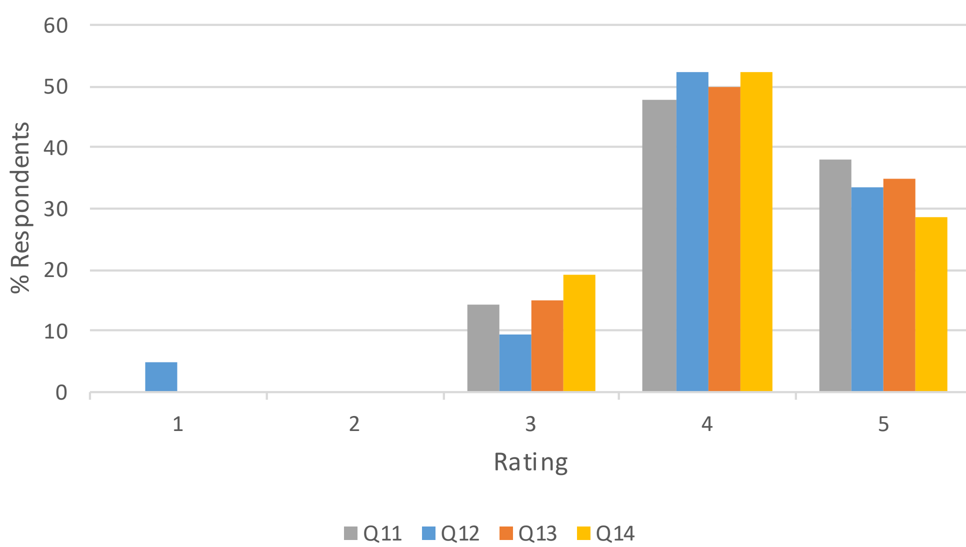

Figure 7. How did the students view their design performance and competence (part of engineering identity)? Results shown from Q11-Q14 with Likert scale: 1=strongly disagree and 5=strongly agree.

Did the design review process impact their project work? Do students become better at giving feedback with more reviews? This the first open-ended survey question and the student responses are given in **Appendix B** (Q18). Students perceive that the design review process gave them preemptive insight and different ways to approach a design problem. With early feedback, students were able to troubleshoot would-be manufacturing and functional problems far sooner than if they had worked in isolation. Additionally, students felt that they learned how to be more mindful with their written feedback so that they weren't perceived as rude or frivolous. Miller and Emery commented that student reactions to feedback evolve from defensiveness in the first few iterations to welcoming by the time they reach senior design, as they view the feedback as a positive influence to improve their work [3]. This also agrees with the observations from my TAs in the next section.

What improvements in the design review process can be made? The student responses are given in **Appendix B** (Q19). Some viewed it as just one more thing to do ("check in the box") and wanted more complexity or desired more creativity (larger design space). One suggestion is to have a "non-friend" do the design review. Reviewers are selected spontaneously during lab and always are allowed to change. In practice, students usually choose their reviewers by proximity, which tend to be friends or acquaintances. One possible suggestion for improvement is to instead assign them to a review team for the full semester so they may benefit more by seeing the project progress. Students tend to become engaged in the success of the project they review (over the semester), and this motivates them to give more critical feedback [3].

How did their design skills develop throughout the course? Some students commented that their design skills did not change much (Q20). This could be because they didn't get much out of the reviews or they already had strong skills coming into the course. This can be explored more in future work. Others noted that they had a better understanding of the process and emphasized gained knowledge and experience.

4 Observations from Teaching Assistants

The graduate teaching assistants (TA) play a great role in achieving improved student outcomes. They provide assistance and advice in lab; being approachable and friendly greatly lends to students being more comfortable in reaching out and asking for help. Expectations for TA behavior should be clear from the instructor to build the community of learners. For example, TAs are encouraged to walk around during lab and ask students questions about their work and if there are any issues or concerns. Showing interest in students' work causes a mutual effect in the students, increasing productivity and effectiveness in learning. Additionally, a mid-session announcement can be made promptly to remove any confusion if many students share a common problem. For example, this could be a brief demonstration of how to use specific CAD tools, or a quick impromptu meeting with other TAs to refine the instructions.

With larger classes, there can be multiple TAs running the lab sessions. If so, I encourage them to check in with each other on how the lab session went to ensure smooth transitions and uniformity. In my TAs' experience, the strategies listed above have formed relationships between the students and TAs that extend beyond the course. In fact, many students still enthusiastically email their TA for their advice on how to improve their design or troubleshoot SolidWorks!

After a few design reviews, the TAs observed that students took initiative to give advice that can make their peers' designs more efficient. The feedback students gave each other far surpassed superficial or low-quality comments; they would sketch three views and annotate in their design notebooks of each other's works where problematic aspects may occur, for example how tolerancing or over-complexity could hamper a good 3-D print.

My TAs have observed that students benefited from this framework. Design review is a *social activity* which helped build community and new friendships among students in the course. While the lab environment was friendly and filled with jokes, there was a general sense of professionalism. Requiring students to give detailed peer review and specific feedback on the shortcomings of each other's designs enhanced their understanding of clear and concise annotations of technical drawings. To transition from sketches to 3-D modeling, students tried to predict what difficulties could arise when using CAD. To supplement this theoretical background, students have dedicated assignments to focus on how to use the specific features of the modeling software. Heavy emphasis on exploring and using the many features of SolidWorks helped build a foundational understanding of CAD that can be extended to other software (Inventor, Creo, etc.).

Having the students design their prototypes using different media types (2-D multiview sketches, digital 3-D CAD models, and a physical cardboard model) improved their spatial perception and visualization of improvements to complicated designs. The general attitude toward building a cardboard model is typically that it is "*tedious*" and "*why bother*;" however, students need to grasp the size, shape, overall aesthetics, manufacturing feasibility, and efficiency. Consequently, many students noticed errors in the physical model that went unnoticed in the CAD model, such as comparing improper physical sizing to real-world objects like their hands or ID cards.

Many students felt gratified in having produced a final 3-D printed part for Project 1. Students who 3-D printed the ID badge holder still wear it with their intern work IDs or wallet cards. Having a unique, physical final product gave students pride in their effort and served as an excellent conversational piece during career fairs and engineering job interview processes. One student wore their badge holder to the career fair and used it as a talking point!

Time management is always a major concern for student projects. Many students ran out of time and only could print once. Some did not get to "see" how good a re-design can turn out and perhaps did not learn as much as they could have otherwise. Students still had time to improve their designs because the milestones acted as a "soft deadline" since they were low-stake assignments. This allows for a buffer so enough time and resources (especially with 3-D printers) can be allocated for students to use, instead of a massive queue close to deadline.

5 Conclusion

The current framework of combining scaffolded milestones, design review, and reflection has developed over three semesters of teaching ME 347 with improvements made each time. The framework requires considerable planning for instructors using it for the first time, but they can adapt the current framework or other peer review frameworks to their course if desired and benefit from the shared learned experiences [2, 3]. Ideally, the current framework could be used in other courses throughout the curriculum so that students can see the review process repeated and grow, but this is not currently done in our curriculum. ME 347 is selected for the current framework since it has the most significant design experience in the curriculum, excluding senior design, and all students are focused on the same open-ended project.

The Qualtrics survey was administered during the third semester of using the current framework. The student responses from the survey indicate that they are receptive to constructive feedback, open to the design review process, and that both their design work and their skills have benefitted. They are able to develop design solutions, effectively communicate the design, evaluate a design, and recognize changes needed for the solution to work. Overall, design review has helped increase learning in ME 347 and had a positive effect on their communication skills. It is hoped that this process prepares students well for senior design to give/receive constructive feedback and make better designs.

This paper presents instructor observations of lessons learned and graduate TA observations from lab. Design review can be heavily used in many lab sessions as students begin the design process (Project 1). One negative aspect is that the time allotted to do other activities or assignments in lab was decreased, so these were either removed or shifted to be done outside of lab if possible (ex. CAD tutorial). The goal of lab is to build the learning community while learning CAD and make steady progress on the design.

Future work includes re-administering the survey for increased response rate and clarification. This is currently being done (May 2024), as students finish the fourth course using the current framework. For the students who stated that their skills did not change, why was that? There was no pre-test or post-test to measure how much their design skills have improved using the current framework, but there was an open-ended question where students were asked to describe how their skills changed. It would be interesting to see if students perceived any changes to their engineering *design* identity after Project 1. If so, did the changes come in terms of competence or recognition? Future survey questions can be added or clarified to address these issues.

References

[1] Scott Hamilton, Leslie Brunell, Gunnar Tamm, and Ozer Arnas, "Peer Review in Engineering Courses as a Learning Tool." Proceedings of the 2006 American Society for Engineering Education Annual Conference & Exposition, 2006.

[2] Scott Hamilton, "Peer Review: Modeling Civil Engineering Practice, Another way to improve learning." Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition, 2005.

[3] Lisa Miller and Daniel Emery, "A Framework for Collaborative Peer Review for Group-written Documents." Proceedings of the 2018 American Society for Engineering Education Annual Conference & Exposition, 2018.

[4] J.A. Moon, "Reflection in Learning & Professional Development." London: Kogan Page, 1999.

[5] L. Dee Fink, “Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses.” 2013, John Wiley & Sons.

[6] Megan Frary, “Encouraging a Growth Mindset in Engineering Students.” Proceedings of the 2018 American Society for Engineering Education Annual Conference & Exposition, 2018. Paper ID #21522

[7] Allison Godwin, “The Development of a Measure of Engineering Identity.” Proceedings of the 2016 American Society for Engineering Education Annual Conference & Exposition, 2016. Paper ID #14814

Appendix A: Design Review Form - *Page 1 adapted from [2]*

Your name: _________________ Assignment name: **Project 1 - Top Concept 2/23**
Circle your lab time: 8-10 10-12 1-3

You cannot review your own work, find two reviewers in lab. Fill out entire sheet (**both sides**).

DESIGN REVIEWER #1 Date/Time: ____________________

Is the work complete and easy to follow? YES ☐ NO ☐ Explain below

Does the design/answer make sense? YES ☐ NO ☐ Explain below

List top priorities for improvement:
1.

2.

REVIEWER COMMENTS:

REVIEWED BY: ___________________________ Initials:_________________________

DESIGN REVIEWER #2 Date/Time: _____________________

Is the work complete and easy to follow? YES ☐ NO ☐ Explain below

Does the design/answer make sense? YES ☐ NO ☐ Explain below

List top priorities for improvement:
1.

2.

REVIEWER COMMENTS:

REVIEWED BY: ___________________________ Initials:_________________________

Appendix A Continued: Design Review Form Page 2- *adopted from [3]*

Review the feedback from your classmates. Check the box which corresponds to the quality of the reviewer's feedback: extremely helpful, helpful, not helpful, or missing.

Quality of Feedback	**Extremely Helpful (S=3)**	**Helpful (S=2)**	**Not helpful (S=1)**	**Missing (S=0)**
	I will make the changes due to this feedback and my design quality will improve.	This is good feedback, but I was already thinking about these things.	The feedback is not specific or relevant enough to have any impact on my design	No review.
Reviewer #1:				
Reviewer #2:				

What was most helpful from Reviewer #1?

What was most helpful from Reviewer #2?

What changes could the reviewers make so their reviews are more helpful next time?

Appendix B: Summarized Results from Survey

The statements for Q1-17 use a 5 point Likert rating scale where: 1=strongly disagree and 5=strongly agree. Q10 has a *different* 5 point Likert rating scale used: 1= No impact, 2=Minor impact, 3= Neutral, 4= Moderate impact, and 5= Major impact.

A negative response corresponds to a rating of 1 or 2 (strongly disagree or disagree), a neutral response corresponds to 3, and a positive response corresponds to 4 or 5 (agree or strongly agree). Note: the number of responses is 20-21, however the total response may not add to 100% due to rounding.

Construct	**Q#**	**Statement**	**Negative Response: Disagree**	**Neutral Response**	**Positive Response: Agree**
Growth Mindset	**Q1**	I prefer to work on my own through the design process.	19%	19%	61.9%
	Q2	I believe the design review process can be a powerful learning tool for design. *adapted from [1]*	4.8%	4.8%	90.5%
	Q3	I believe that with more design experience, I will become better at it. *adapted from [6]*	0%	0%	100%
	Q5	I appreciate when teachers, coaches, or parents give me feedback on my performance. [6]	4.8%	0%	95.2%
Benefits of Design Review	**Q6**	I believe that having specific design milestones helped me make steady progress on the project.	0%	19%	81%
	Q7	I believe that design review helped me make steady progress on the project.	9.5%	4.8%	85.7%
	Q8	I have benefited from reviewing my peer's design.	14.3%	19.0%	66.7%
	Q9	I have benefited from peers' reviewing my design. *adapted from [2]*	19%	0%	81%
	Q14	I can recognize changes needed for a design solution to work. *adapted from [7]*	0%	19%	81%

Impact on Design and Skills	**Q4**	I believe that the experiences I had in this class allow me to be better at design. *adapted from [2]*	9.5%	0%	90.5%
	Q10* *	Rate the effect that design review had on your skills to review and assess other's technical work. ***Different Likert scale used*	4.8%	38.1%	51.7%
Performance and Competence (Engineering Identity)	**Q11**	I can develop design solutions. *adapted from [7]*	0%	14.3%	85.7%
	Q12	I can effectively communicate my design solutions. *adapted from [7]*	4.8%	9.5%	85.7%
	Q13	I can evaluate a design. *adapted from [7]*	0%	15%	85%
Recognition (Engineering Identity)	**Q15**	My peers often ask for my feedback on their design. *adapted from [7]*	23.8%	42.9%	33.3%
	Q16	I feel like an engineer. *based on teaching evaluation comments*	10%	40%	50%
	Q17	My peers recognize me as an engineer. *adapted from [7]*	10%	35%	55%

Open-Ended Survey Questions Q18-20

Q18. Describe how design review impacted your project work. If possible, include a specific example.

- *For the project the peer reviews allowed me to review cooler design and approaches that I couldn't have thought of, especially when I was a bit behind in the design process.*
- *It lets me be more open about reviews and more open to changing my design for the better*
- *Gave me insight on how I could have done a design differently*
- *Design review gave me steady feedback on my design as I worked on making improvements, similar to a real world work situation*
- *The best impact I've received from a design review is simply to more promently show a specific aspect of my design. So I did that and it avoided questions about the design further down the line*
- *The design review helped me comprehend the print errors that would affect my design*

Appendix B: Q18 Continued

- *Helped me be a better designed by knowing my mistakes and how to improve them*
- *With design review I was able to learn how to look at somebody else's work and be able to give advice on it without feeling like I am being rude*
- *The design review simply got me thinking about how to improve and change my design*
- *Gave a different perspective on how to approach things*

Q19. Describe any improvements you would like to see in the design review process.

- *I would add maybe a manufacturing component to it, to see how some designs may or may not be feasible to manufacture*
- *I like the design review process, but majority of designs were similar to each other. It was hard to critique the same design that you had*
- *No improvements I would make. Maybe highly encourage students to have a non-friend review their design*
- *None it was pretty good*
- *N/A*
- *The designs should be more complicated, to increase the level of complexity as well as to provide more aspects to receive feedback upon*
- *It felt very much like a check in the box. Most students don't really care enough about this to have it make any meaningful design choices. Overall, if it didn't exist, my design would be virtually unaffected*
- *None*
- *Nothing at all.*
- *I think that a lot of the time it was just busy work, but I don't know how you could make people care to give more genuine reviews. Sometimes a person's design is good so there really isn't anything to add, but other times it is clear that reviewer just didn't care. I think that people only really care about reviewing when it is also their work*
- *I can't imagine any new improvements.*
- *Keep the design review sheets; I remember they were collected*

Q20. Describe how your design skills developed throughout the class. If they did not change, please explain why.

- *I believe it helped me understand the design process more*
- *For my skills, I had some helpful insights into thinking outside of the box. I am now able to identify potential flaws a lot quicker and suggest improvements*
- *They developed by accounting for more responsibilities in the design process. In the beginning and prior to receiving peer review, I didn't think certain areas were accounted for in the design process.*
- *It made me thing of more way to do things and that there's not a "right" answer*
- *Regained skills using design software; furthermore, learned how to do task at a faster, more efficient pace*
- *My design skills changed in a way that made me increasingly aware of the process I take to reach a final solution. The design review highlighted the importance of the process by which I design, instead of only rewarding the final solution. The process is more important than the result*

Appendix B: Q20 Continued

- *I feel they didn't change. At best, my usage of SolidWorks and ANSYS is a bit better but it hasn't changed how I design or my thought process behind my designs. I wish we would have been given more scenario designs where we actually must sit and think about what we need from the design rather than just doing whatever is the easiest design*
- *My book keeping skills have improved from the design process*
- *Gained knowledge and experience*
- *I learned a lot about failure, where sometimes your original design just isn't going to work out and you have to pivot to something else. Also, my SolidWorks skills greatly improved*
- *They didn't change much from before because I always liked doing CAD and on top of that I like to be creative with my design solutions. This was still a good experience to polish my skill*
- *Slowly regained past skill*s