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Continued Study on Using Design Review in CAD Projects in Mechanical Engineering (Part II)

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This paper continues reporting on design review, a process for instructors to maximize peer learning and communication skills in a third-year mechanical engineering course. This incorporates both (peer-to-peer) design reviews and reflection work for a computer aided drafting (CAD) design project. To determine effectiveness, an anonymous Qualtrics survey was developed and administered to students to determine the impact on their learning experiences, skills, and engineering identity in Part I of the study. Previously, there was only one open-ended question that did not yield many responses regarding its impact. The continued study (Part II) seeks to address some of these issues and includes a re-administration of the Qualtrics survey to a second cohort of students in the class. The revised survey contains six new questions to investigate the students' perceptions of their initial design and CAD skills coming into the course, to see impact on their project, to see if their engineering identity changed while working on their design project, and if they felt more prepared for senior design and future design work. Part II not only elucidates how design review affects the mentality and self-perception of the students, but findings agree with the findings with that of Part I and confirm the conclusions previously drawn. Surprisingly, many students stated that they had strong CAD and design skills coming into the course from survey responses (65.4% positive response). How did students benefit, and did they perceive any changes to their engineering identity with respect to design? Students perceived that they could make better engineering designs after experiencing design review (96.2% positive response). The students with self-perceived strong design and CAD skills coming into the course still benefited from design review, but some felt frustrated if not given actionable and realistic feedback from their peers, especially regarding manufacturing. Students with self-perceived weaker design skills coming into the course benefited most in their preparation to make better engineering designs after design review and preparedness for senior design. Since collaboration is a key part of the engineering design process, design review prepared otherwise solo students for senior design to give and receive constructive feedback. Overall, design review positively impacted their design work (80.8% positive response) and positively changed the way the students view themselves as engineers (84% positive response).

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, and it is an important pre-requisite course for the first semester of senior design. Students take an earlier course, ME 250, which introduces the design process and the basics of CAD modeling (simple geometry and drawings) and 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 develops the mechanical engineering part of engineering identity (i.e., *design* competence - they recognize their skills as designers) 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 lectures and 2 hours of lab per week. The lab sessions are smaller, with about 35 students, and these are run by multiple graduate teaching assistants.

This paper discusses a continued study on design review that has been used in ME 347 for the first design project, Project 1, which typically takes 9 weeks to complete. Project 1 tasks students to build a 3-D model in CAD, use rapid prototyping to 3-D print their respective improved best model, and demonstrate their CAD model and 3-D printed part in a live presentation during lab. 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. Building a sense of community and effectively communicating engineering principles in peer-to-peer design reviews are pillars of the project.

1.1 Significance of Design Review

The objective of design review is to develop peer-to-peer interpersonal skills that may have been hampered by the COVID-19 pandemic lockdown measures. Receiving and giving feedback is an important skill for mechanical engineering students to practice. Design review is used early and often during Project 1, when many decisions are made which ultimately affect the final design. However, this is where peer-to-peer feedback can be most helpful. By taking advantage of feedback, 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.

In industry, it is common to assign quality checkers to review work, especially engineering calculations, before sending anything to a client. A similar process can be applied to a mechanical engineering design course: students communicate their design work, gather feedback from peers, implement changes, and then submit their final design for a major grade. 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, actionable 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 study, the activity is consciously called "design review" instead of "peer review" to emphasize the professional interactions and keep the focus on improving design work.

Peer review processes have been helpful in other engineering courses. For example, at West Point, civil engineering courses for structural analysis use peer review to have students check each other's calculations before submitting assignments for grading [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].

1.2 Engineering Identity

Engineering identity is related to characteristics of 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]. Engineering identity is the perception and recognition of themselves as an engineering professional [10]. Morelock (2017) gives a systematic literature review of engineering identity [9]. A strong engineering identity has been liked to higher retention, persistence, and success in the profession [10]. Tonso's work (2014) argues that engineering identity must be understood and acted upon by faculty to create better engineering education environment for students and institutions [9, 10]. Tonso (2014) states an excellent question – "What kind of experiences –institutional, organizational, group, and team - should educators provide students to encourage identifying with engineering?" [10] The design review process, discussed next, is implemented to align with industry expectations of accuracy, detail, carefulness, responsibility, and professionalism. Design review is meant to give students an opportunity to "feel like an engineer" while working on a course project.

1.3 Design Review Process

The design review process uses face-to-face interaction during lab sessions to complete the design review. Students are given a paper form to fill out for each design review which is then submitted to the TA before the end of lab as a small, graded assignment. The design review process is used many times throughout Project 1, so the goal is for students to become comfortable giving and receiving feedback while building their review and evaluation skills. Students use feedback to improve their project design and take charge of their learning. Each design review activity can take up to 20 minutes during lab.

Prior to the first design review, clear expectations should be provided about the process and expectations. It is helpful to explain what makes a peer review useful, what makes it superficial or unhelpful, and examples of each; this can be presented in a handout and discussed in lecture [2]. Appendix A includes the expectations of the design review (i.e., what makes it useful vs unhelpful) that was derived from Scott Hamilton's study [2]. Each design review is a small, graded assignment (10 points), so that students put in effort. Not all learning activities need to be graded, but students are motivated to engage in it if it is incorporated into their final grade [5].

A second page was added to the design review form to incorporate reflection practices as described in Part I (Page 2, Appendix B) [8]. 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 read their feedback and internalized it, thereby integrating a reflection aspect into the design review. Without including the reflection (part of the grade), students may not bother to read the feedback. 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*?" keeps students engaged in undergraduate courses. When the act of reflection is linked to the human need to make meaning, the significance of the learning activity becomes clearer [5].

At the bottom of the form (Page 2, Appendix B), 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 the 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 benefit 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].

2 Method

This paper presents a continued study (Part II) on how design review can be used in practice for mechanical engineering, instructor observations of lessons learned, and graduate teaching assistant (TA) observations from lab sessions. An earlier cohort of students in ME 347 have used the same design review process, but students had a new design challenge in Project 1: create a custom design for a manufacturing company who wants an action character or fidget toy that has moving parts which are marketed toward college students.

The method used in the study is an anonymous Qualtrics survey. The main constructs investigated in the survey include student mindset, benefits of design review, impact on the students' design and skills, perception of performance and competence related to their engineering identity, and perception of recognition related to their engineering identity. This study focuses on design specifically, as part of engineering. The same survey instrument from Part I has been re-administered to a second cohort (Part II) that used the same design review process, but six new questions were added to the survey (**Q22-Q27**) to provide further clarification regarding skills before the course and preparation levels after Project 1. For quick reference, Table 1 contains all statements covered in the survey and many have been adapted from literature, as noted in **Appendix C** [1, 2, 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.

Table 1. Survey instrument. The statements use a 5-point Likert rating scale.

Construct	Q#	Statement
Growth Mindset	**Q1**	I prefer to work on my own through the design process.
	Q27	I prefer to work on my own in my other classes.
	Q2	I believe the design review process can be a powerful learning tool for design.
	Q3	I believe that with more design experience, I will become better at it.
	Q5	I appreciate it when teachers, coaches, or parents give me feedback on my performance.
Benefits of Design Review	**Q6**	I believe that having specific design milestones helped me make steady progress on the project.
	Q7	I believe that design review helped me make steady progress on the project.

Table 1 Continued. Survey instrument.

	Q8	I have benefited from reviewing my peer's design.
	Q9	I have benefited from peers' reviewing my design.
	Q14	I can recognize changes needed for a design solution to work.
Impact on Design and Skills	**Q4**	I believe that the experiences I had in this class allow me to be better at design.
	Q10	Rate the effect that design review had on your skills to review and assess other's technical work.
	Q22	Rate how the design review process impacted your project work.
	Q23	My design and CAD skills were strong coming into this course.
	Q24	I feel prepared for senior design after giving and receiving constructive feedback in the design review process.
	Q25	I am prepared to make better engineering designs after experiencing the design review process.
Performance and Competence (Engineering Identity)	**Q11**	I can develop design solutions.
	Q12	I can effectively communicate my design solutions.
	Q13	I can evaluate a design.
Recognition (Engineering Identity)	**Q15**	My peers often ask for my feedback on their design.
	Q16	I feel like an engineer. *Based on teaching evaluation comments*
	Q17	My peers recognize me as an engineer.
	Q26	The way I view myself as an engineer has changed after experiencing the design review process.
Open-Ended Questions	**Q18**	Describe how design review impacted your project work with a specific example.
	Q19	Describe any improvements you would like to see in the design review process.
	Q20	Describe how your design skills developed throughout the class. If they did not change, please explain why.

2.2 Research Questions

The research questions addressed in this study include the following:

1. Are there noticeable differences between the studies (Part I vs. Part II)? If so, do they change any conclusions that have been drawn?
2. What new conclusions can be drawn from the new survey questions in Part II (Q22-Q27) regarding design review impact and preparation for senior design and future design work? Do students prefer to work alone in other classes (Q27) or just on design work (Q15)?
3. Based on the students' self-perceived initial CAD and design skills, which students benefited and how?
4. Based on the students' self-perceived initial CAD and design skills, does design review instill an engineering identity in terms of design work as it pertains to their performance and competence, or recognition?

There are some limitations to this study. First, no attempt has been made to measure whether the students implemented the feedback that was given to them to improve their design. This is somewhat addressed with the students' perceptions of how the design review process impacted their project work (Q22). There was no attempt to determine the students' expected grade in the course, which might have provided helpful information. Similar surveys administered after completion of senior design could produce meaningful results, but this has not been addressed since there are multiple instructors of this course and senior design.

3 Results from Survey

Students were asked to complete an anonymous online survey regarding the design review process for Project 1 after final grades were published for Part I. In Part I, the response rate was 22% and this prompted the authors to clarify some of the statements and re-administer the survey to a second cohort (Part II) earlier in the semester to obtain better response rates. For Part II, the second cohort also had roughly 100 students and the survey was sent out with requests for volunteer subjects at least four times before it was closed, but the response rate remained low, roughly 27%. The response rate could be improved greatly if incentives were used and more time in class is used to explain the purpose and impact of the research study. The survey was conducted outside of class time.

The survey results are summarized in **Appendix C** with results from the continued study (Part II) listed and then the previous study for comparison (Part I). For simplicity, all 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.

3.1 Comparison of Results from Part I to Part II

The survey results are presented in this paper and compared to Part I to determine if there are noticeable differences and if these change any conclusions drawn. This is a baseline test to verify the previous study results and confirm that the second cohort of students (Part II) are also open to the design review process, they benefited from design review, and they recognize themselves as mechanical engineering designers.

How open are students to the design review process? The responses indicate positive attitudes toward the process: design review can be a powerful learning tool (Q2, 85.2% positive response), students are growth minded regarding their design skills (Q3, 100% positive response), and feedback is appreciated from teachers, coaches, and parents (Q5, 100% positive response). Overall, the students seem as open to the design review process as Part I, giving similar positive response rates from Part I and Part II, respectively (Q2: 90.5% vs 85.2%, Q3: same 100%, Q5: 95% vs 100%, respectively).

Responses from Part II indicate larger neutral perception of design review being a useful tool for the overall process (Q2: 4.8% vs. 14.8%, respectively). This may be tied to the open-ended responses regarding improvements that could be made to the design review process; these responses indicate that there is a common drawback to having lackluster peer-to-peer review. As it pertains to engineering design principles, some students' engineering experience is underdeveloped. This can lead to some students receiving vague or counterproductive comments on how to improve their designs. However, it should be emphasized that students overwhelmingly respond that design review was conducive to learning, but there remain improvements to be made. One student commented that many students did not consider the "real life construction" (Q19). Another student noted they wanted a more structured way to get reasonable feedback and less constraints on the process itself, "*maybe require only one item that needs improvement*" (Q19).

Did students benefit from the design review process? Overall, yes. Figure 1 compares the results from four questions (Q8-9, Q14, Q22). Students benefited from reviewing their peers' design work (Q8, 80.8% positive response) and from peers' reviewing their design (Q9, 76.9% positive response). Students perceive that they have benefited *more* from their peers reviewing their work compared to when they do the review. Results indicate that students can recognize changes needed for a design solution to work, which is beneficial to them as an engineer (Q14, 76.9% positive response). Students believe the design review process had a major to moderate impact on their project work (Q22, 80.8% positive response). Overall, the positive response rates from Parts I-II are similar (Q9: 81% vs. 76.9%, Q14: 81% vs 76.9%, respectively), but more students perceive to have benefited from reviewing their peer's designs in Part II (Q8: 66.7% vs. 80.8%, respectively).

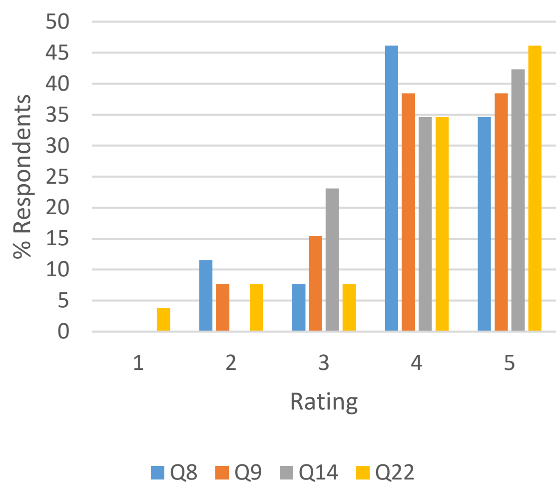

Figure 1. Did students benefit from the design review process? Q8-benefit from reviewing peers' work, Q9- benefit from their peers' review, Q14-recognize changes needed for a design solution to work, Q22-impact of design review process on project work. Results shown with Likert scale: 1=strongly disagree and 5=strongly agree.

Did students' skills benefit from the design review process? Results indicate yes. Students believe that the experiences they had with design review allowed them to be better at design (Q4, 100% positive response). They also rated the impact that it had on their skills to review and assess other's technical work; these results indicate a moderate to major impact (Q10, 65.4% positive response), however some students remained neutral (Q10, 26.9% neutral response). A neutral rating meant somewhere between a minor and moderate impact. This could depend on many factors, including who did their peer review, how detailed the review was, whether it was a superficial or unhelpful review, their own engineering identity, and their initial strength of their design skills. Overall, both studies, Parts I-II, indicate positively that students have benefited in terms of becoming better at design and improving skills to assess technical work (Q4: 90.5% vs. 100%, Q10: 51.7% vs 65.4%, respectively).

Do students recognize themselves as engineers after Project 1? Somewhat, students stated that some felt like engineers in both studies (Q16: 50% vs. 64%, respectively) and that their peers recognized them as engineers (Q17: 55% vs. 58%, respectively). A student's perception of how others view them is vitally important to how the student sees themselves [7]. One construct of engineering identity is their perception of performance and competency as an engineer [7]; one example of this is that their peers notice them and often ask for their feedback (Q15). Q15 has been adapted to only ask specifically about ***design*** competence; Godwin measured engineering identify with the general statement "Others ask me for help in this subject" [7]. It would be interesting to investigate further why there were so many neutral responses to viewing themselves as engineers and if there is something that can be done to improve upon this (Q16: 40% vs. 32%, Q17: 35% vs. 38.5%, respectively); however, this was not included in the scope.

3.2 Results from Additional Survey Questions in Part II

Additional survey questions were added to the study in Part II to provide clarification regarding the students' own perceptions of the impact of the design review on their project (Q22), their initial CAD and design skills (Q23), their preparedness for senior design (Q24), and if they are prepared to make better engineering designs (Q25).

Figure 2 presents responses for two new questions which assess how the design review process impacted their project work and the perceived strength of their design and CAD skills coming into the course. The responses indicate a moderate to major impact on how the design review process impacted their project work (Q22, 80.8% positive rate). Many agree that their design and CAD skills are strong coming into this course (Q23, 65.4% positive response). It is curious that some students indicated negative responses to the impact of design review on their project work (Q22, 11.5% negative response). Design review can be a powerful learning tool (Q2), but its success partially hinges upon useful and actionable peer feedback to proposed designs. Hence, disinterested students that leave frivolous responses for improvement or lack engineering foresight to provide feasible and physically sound design suggestions can leave a negative impact on students.

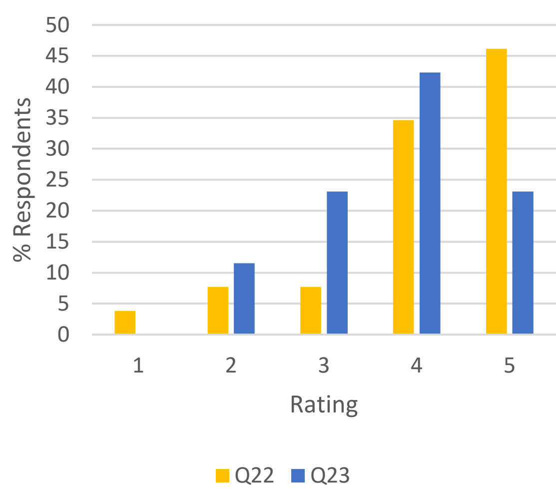

Figure 2. Who benefits from the design review process? Q22-impact of design review on project work, Q23-perception of initial CAD/design skills. Results shown with Likert scale: 1=strongly disagree and 5=strongly agree.

In the open-ended questions, one comment noted that having feedback regarding manufacturing (3-D printing) would be helpful for design and suggested that their reviewer's 3-D printing experience could be noted on the design review form (Q18). One comment noted that the structured process instilled a sense of planning insight for a better outcome and another stated that they developed a sense of consistent reflection (Q20). While anecdotal, the comments were seen more broadly in students by instructors and graduate TAs, particularly how students having prior 3-D printing experiences can greatly influence the quality of their peer review and general actionable feedback.

Do students perceive that they are better prepared for future design work? Yes, two questions investigated the students' perceptions of preparedness for continuing design work after having used the design review process. Students felt prepared for senior design after giving and receiving constructive feedback in the design review process (Q24, 84.6% positive response). Also, they feel prepared to make better engineering designs after experiencing the design review process (Q25, 96.2% positive response).

In Part I, a surprising bias towards students preferring to work alone on design work (Q1, 61.9% positive response) was noted. It was also observed that they did not ask often for feedback regarding their design work (Q15, 33.3% positive response). The responses in Part II indicate that the second cohort is slightly more group-minded (Q1, 48.1% positive response) and they asked more often for feedback on design work (Q15, 61.4% positive response). Is this how students approach all classes or is it just design? A question was added to the survey (Q27) to address this issue. Students preferred to work on their own in other classes (Q27, 44.4% positive response) *roughly the same as for* design work (Q1, 48.1% positive response). Given the often-collaborative nature of engineering design, one would expect there to be a greater internal drive among students to work together. It is unclear if these students, the majority of whom are Generation Z, tend to think of themselves as self-reliant or if the COVID-19 pandemic lockdowns have made lasting effects of isolationism in their work ethics. Another possible explanation comes from students lacking confidence in the advice or feedback from peers, as one comment stated (Q18).

3.3 Perceived Design and CAD Skills and Students' Benefits After Design Review

More than half of the students agreed with the statement that they had strong CAD and design skills coming into the course, much higher than anticipated when examining the Part II survey responses. The question then becomes about who benefits from design review and how. Based on the students' perceived design and CAD skills coming into the course (Q23), the responses were grouped by the students' Likert scale rating to see if there are any collective differences. There are a few key things to note. One limitation of this analysis is that the statistics are small – there are 27 responses in Part II. Hence, percentages may be misleading, so some conclusions may not be drawn. The largest bin size is 11 students who agree they have strong initial design and CAD skills coming into the course (Q23=4), but the smallest bin size is only 3 students for disagree (Q23=2). One student did not answer the question, so their responses could not be included. No one strongly disagreed with any of the statements, so Likert ratings of strongly disagree (rating =1) is not seen on the following figures.

Does self-perceived skill rating affect preparedness for senior design? Figure 3a shows how the students feel about their preparation level for senior design after giving and receiving constructive feedback during design review (Q24). These are grouped by their self-perceived design and CAD skills coming into the course. If the students strongly agreed or agreed (Q23=4-5) that they had strong skills, their response skewed positive (Q24, 100% positive response for Q23=5, 81.8% positive response for Q23=4), i.e. they felt prepared for senior design. Most likely, these students thought they were already prepared prior to the course, regardless of the design review. For initial neutral agreement (Q23=3), there were some neutral responses (16.7%), but mostly positive responses. For students that disagreed that their skills are strong (Q23= 2), there was a high level of neutral agreement regarding their preparation level for senior design (33% neutral response) and larger positives (67% positive response). Overall, design review gave students confidence in their abilities to communicate as effective engineers and have self-confidence in their CAD skills in preparation for senior design.

Does self-perceived skill rating affect perception of preparedness for future design work? Students agreed that they are better prepared to make engineering designs after experiencing design review (Q25, 96.2% positive response). Figure 3b shows the responses grouped by their self-perceived skills. If the students perceived strong skills (Q23= 4-5), their response was positive overall (Q25, 100% positive response). For initial neutral skill perception (Q23=3), there is only one neutral rating. For initial disagreement (Q23=2), there was a high level of positive responses (100% positive response). Overall, each group did see benefits from design review in terms of preparation for senior design and future design work, regardless of self-perceived skills coming into the course.

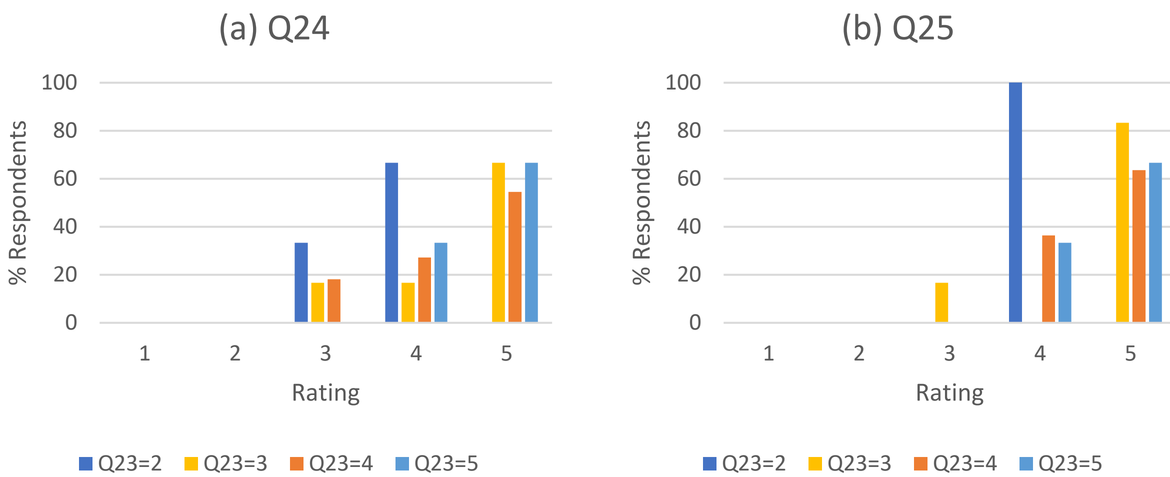

Figure 3. (a) Does perception of preparedness for senior design after giving and receiving constructive feedback (Q24) depend on initial skills (Q23)? (b) Does perception of preparedness for making better engineering designs after experiencing design review (Q25) depend on initial skills (Q23)? Results shown with Likert scale: 1=strongly disagree and 5=strongly agree.

Does self-perceived skill rating affect perception of benefiting? Figure 4a shows whether students felt that they have benefited from reviewing their peer's design based on their self-perceived skill levels (Q8). Overall, students with neutral or positive ratings of their skills report having benefited from reviewing their peers' work. However, one student indicated that they quality of the review could be improved and stated that "*a lot of students don't consider the real-*

life construction, so a lot of design reviews from peers were suggestions that is not feasible in real life."

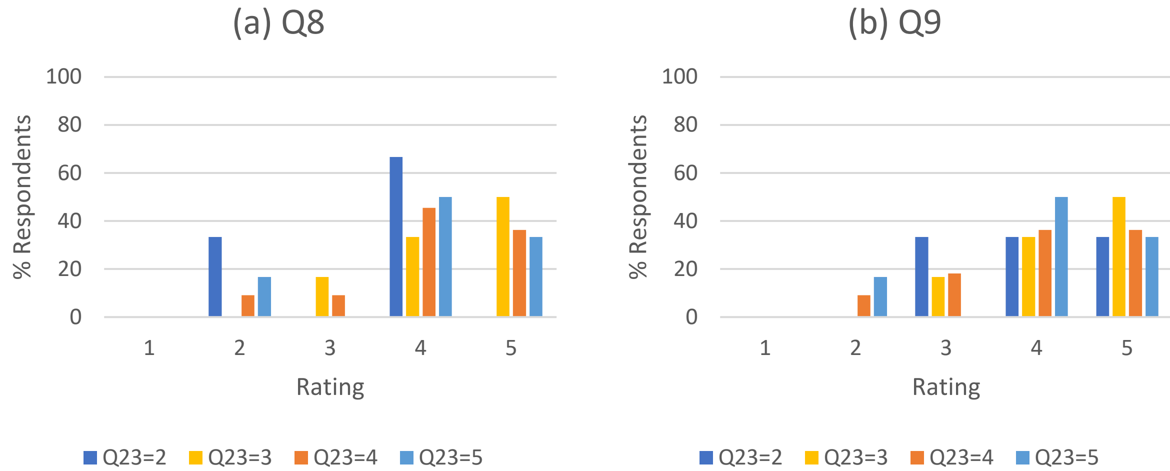

Figure 4. (a) Does perception of benefiting from reviewing their peer's work (Q8) depend on self-perceived skill rating (Q23)? (b) Does perception of benefiting from peers' reviewing their work (Q9) depend on self-perceived rating (Q23)? Results shown with Likert scale: 1=strongly disagree and 5=strongly agree.

Figure 4b examines the students' perception of benefiting from peers' reviewing their own design based on their self-perceived skills (Q9). The variation of responses is broad, but mostly neutral or positive. Possibly, students are focused on how their own designs could be made better with explicit feedback. There are a few negative responses to highlight. While giving their peers constructive criticism can give some students insight into how their own designs could be improved, some might not relate the advice given to others as being applicable to themselves or their design.

Figure 5 examines the impact of design review on their project work. Some students with self-perceived strong skills (Q23=4) did not perceive much impact from design review and some students with strong skills (Q23=4) stated "minor impact" or "no impact" and reported that "*I never really got any impactful feedback*." Again, this could be due to the quality of the feedback given to them on the design review forms, or if the student perceived that the feedback was not applicable or appropriate to their solution.

3.4 Does Engineering Identity Change After Design Review?

A new survey question in Part II indicates that the way students view themselves as engineers changed after experiencing the design review process (Q26, 84% positive response). While this question was included as an open-ended question in Part I, it did not solicit much response, so it was changed to a Likert scale statement in Part II to get quantitative data. Interestingly, about two students indicated either a neutral stance or disagree (Q26: 8% neutral response, 8% negative response), possibly due to a strong engineering identity coming into the course.

Figure 6a shows a strong positive perception of design performance and competence for Part II: they can develop design solutions (Q11, 84.6% positive response), effectively communicate design solutions (Q12, 80.8% positive response), evaluate a design (Q13, 80.8% positive response), recognize changes needed to make design solutions work (Q14, 76.9% positive response), and peers often ask for their design feedback (Q15, 61.5% positive response). These are similar levels compared to Part I. One benefit of design review is that *"I am much more confident in my skills as an engineer, and I feel like I can actually apply what I've learned in an industry setting."* Another student commented that [Q20] *"My skills were challenged with making a working and usable design. I developed a lot of good skills."*

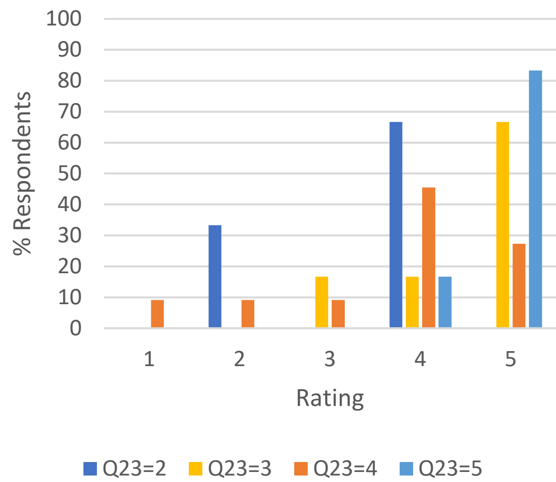

Figure 5. Does perception of design review impact on the project (Q22) depend on initial design and CAD skills (Q23)? Results shown with Likert scale: 1= No impact, 2=Minor impact, 3= Neutral, 4= Moderate impact, and 5= Major impact.

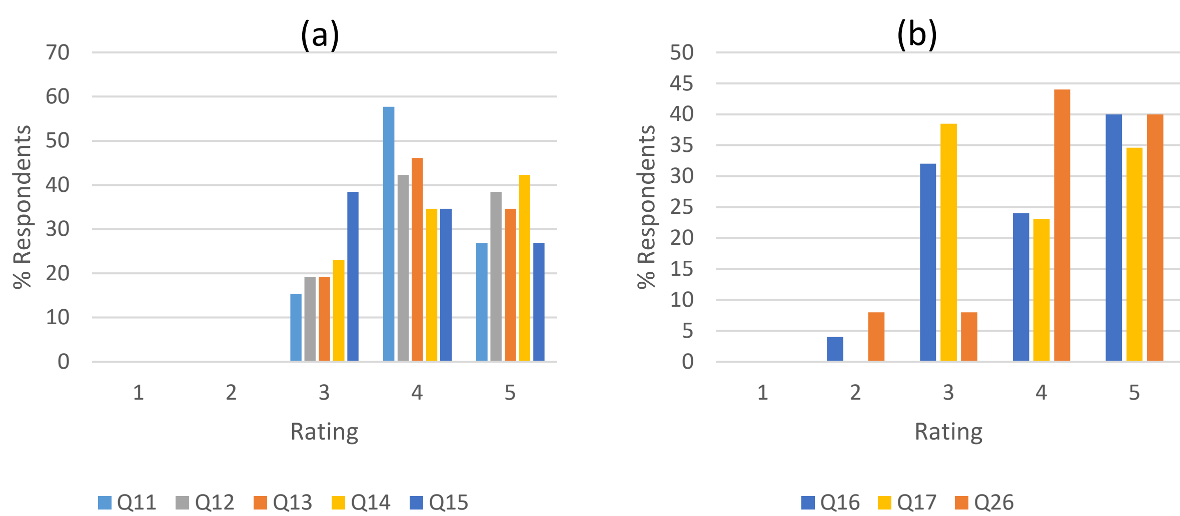

Figure 6. (a) How did the students view design performance and competence (part of engineering identity)? Q11-develop solutions, Q12- effectively communicate, Q13-evaluate design, Q14-recognize changes, Q15- peers often ask them. (b) Do students recognize themselves as mechanical engineer designers (Q16-Q17, Q26)? Q16-feel like an engineer, Q17-peers recognize them as an engineer, Q26-way they view themselves as engineers changed. Results shown with Likert scale: 1=strongly disagree and 5=strongly agree.

Figure 6b shows recognition (Q16-Q17, Q26) which has lower levels of *positive* perception when compared to performance and competence. The current study indicates a slightly more *positive* perception of recognition for asking for feedback on designs (Q15: 33.3% vs. 61.4%, respectively) and feeling like an engineer (Q16: 50% vs. 64%, respectively), compared to Part I. However, there are similar results for recognizing themselves as an engineer (Q17: 55% vs. 57.7%, respectively for Part I and Part II). One comment from a student does address recognition indirectly [Q20], "*I got to experience the mindset of what engineers do unlike my other classes.*"

Figure 7 shows the responses grouped by their self-reported initial design and CAD skills for the way they view themselves as an engineer changing after experiencing the design review process. Overall, the majority of those with strong skills positively agreed (Q23=4-5) that their view of themselves as engineers changed. For strong initial skills, there is mostly positive agreement that their identity changed, but one student's self-perception may not have changed if they "*never really got impactful feedback*." Students with the strongest self-perceived skills are most positive overall. If students come in with strong skills already, they might not feel like they have changed much so that could explain why there is a split between agree and strongly agree. One student commented "*major changes*" when asked to describe how design review impacted their project work which is encouraging to see, but they also disagreed that their view of themselves changed. It is possible that there is no correlation for that student between how much the design review process helped them, yet did not change their engineering identity.

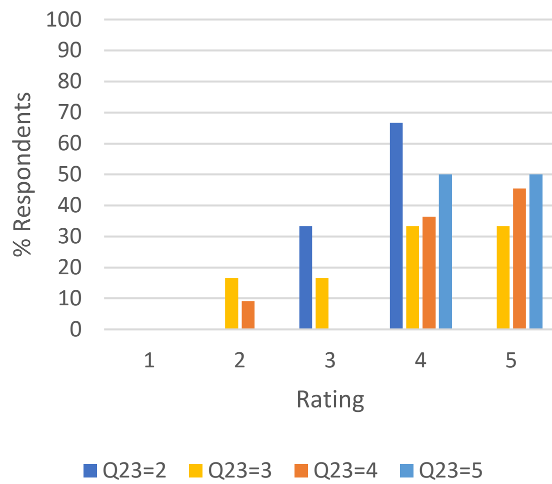

Figure 7. Does changing self-perception (Q26) depend on initial skills (Q23)? Results shown with Likert scale: 1=strongly disagree and 5=strongly agree. Q23=2 is disagreement with having strong initial skills, Q23=5 is strong agreement.

Figure 8 examines recognition, the second part of engineering identity. A student's perception of how others view them is vitally important to how the student sees themselves [7]. There is some variation in the responses between neutral and strongly agree regarding whether they often ask their peers for feedback on their design (Q15), they feel like an engineer (Q16), and their peers recognize them as an engineer (Q17). Interestingly, the students with self-perceived weaker skills (Q23=2) are more neutral than the other groups. Possibly, these students feel less confident of their abilities when trying to compare themselves to their stronger counterparts. It would be interesting to see how their *engineering* identity changed over the semester or if it changed (at all) using a pre/post survey. In general, Figures 6-8 indicate that their engineering identities are still developing during the course, which is acceptable since ME 347 is a third-year course.

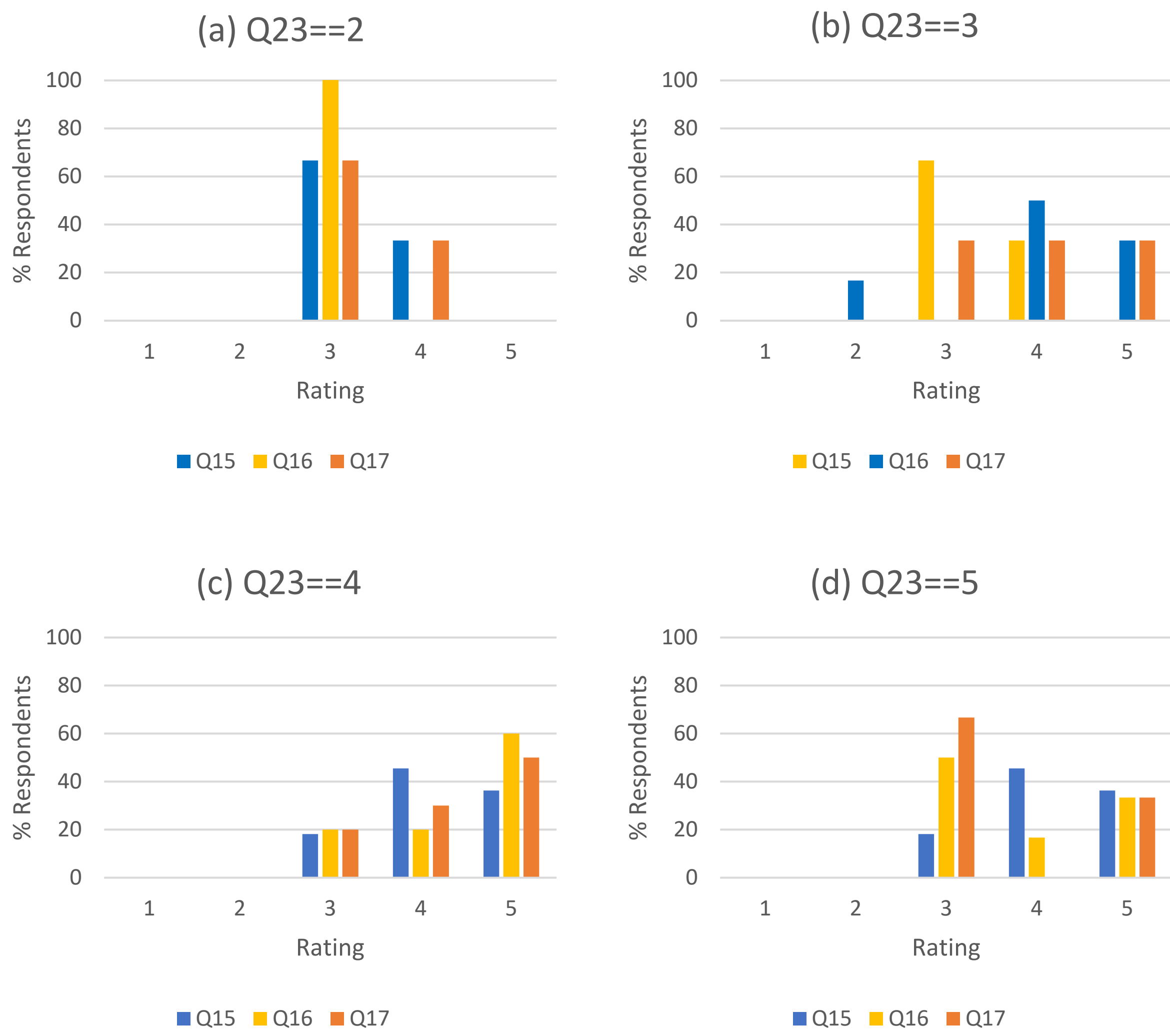

Figure 8. Does self-perception of recognition (Q15-Q17) depend on strong initial skills (Q23)? Q15- peers ask for feedback, Q16-feel like an engineer, Q17-peers recognize them as an engineer. Results shown with Likert scale: 1=strongly disagree and 5=strongly agree. Q23=2 is disagreement with having strong skills, Q23=5 is strong agreement with having strong skills.

4 Proposed Changes to Design Review Process

The design process is working well in the class, but improvements can always be made. One idea is to provide more training for students on giving feedback, for example, showing specific examples of good feedback so they can see what will be useful to their peers. Three modifications to the design review form itself (**Appendix B**) have been proposed in this paper based on the open-ended response from students: (a) ask the reviewer on the feedback form what their 3-D printing experience is so that it can be taken into account when reflecting about the reviewer's comments, (b) ask for feedback specifically on manufacturing, and (c) soften the requirement to list two top priorities for improvement to one item if nothing else needs to be discussed. To date, some of the changes have been implemented, but will be investigated in future work.

Based on the open-ended survey questions, any deficit regarding manufacturing concepts can hinder the strength of design review feedback. This relates to the survey results where neutral responses are noted: (a) regarding ability to evaluate designs (Q13, 19.2% neutral response), (b) the effect that design review had on their skills to review and assess each other's technical work (Q10, 26.9% neutral response), and (c) recognizing changes needed for a design solution to work (Q14, 23.1% neutral response). The best designs rely heavily on knowledgeable and actionable critiques on technical processes, such as manufacturability and 3-D printing. The insight from the study has led the co-author to develop new learning activities during Project 1, with the goal of providing students more background on design for manufacturing and assembly (DFMA).

Co-author Carducci has made a series of CAD models as a potential solution to a realistic material problem subjected to practical constraints (Ex. "design must be 3D-printed", "design must allow for X clearance"). Each CAD model has introduced specific design flaws in its features that may cause difficulty in manufacturing or assembly; for example, this can include features being extremely thin for FDM printing, curved blind holes for CNC milling machines, or interference fits with maximum allowances exceeding machine feature tolerances. Students are provided with additional background information and troubleshooting guides regarding the capabilities and limitations of different machining or manufacturing methods. Students are also given information as to the problem and all constraints. Then, they tasked to open the CAD model and become an engineering reviewer. Their task is to identify the problematic features, explain why these features are problematic with their respective manufacturing method, provide a revised design using text descriptions and 2-D sketches, and justify why the revised design still satisfies both the material problem and manufacturing/assembly problem.

While an impact study is being done now to determine the effectiveness of these DFMA teaching activities it is outside the scope of the continued study. Co-author Carducci has already observed some improvements and continues to fine tune the learning activities regarding manufacturing. After the manufacturing learning activity, students can offer more detailed and actionable peer review feedback, especially students with otherwise minimal manufacturing experience. With these new changes implemented and coupled with design review, the authors are optimistic that students will continue to benefit and will be better prepared to evaluate engineering designs and further their skills to review and assess each other's technical work.

5 Conclusion

Design review has helped students build community and become comfortable with giving and receiving feedback while working on a project. A peer-to-peer review process has been used previously in other courses, like civil engineering and industrial and systems engineering [1, 2, 3]. Initially, it requires considerable planning for instructors using it for the first time, but instructors can adapt the design review or other peer review frameworks to their own course if desired. Overall, students benefited as learners, not just their design skills. Some comments from students support these benefits [Q20]: *"I developed a sense of consistent reflection"* and spent "*more steps revising my own work."* It has been used to find [Q20]: *"different ways to approach* *a design and new way to improve a design, as well as learning that you can always improve the design."*

An anonymous Qualtrics survey was re-administered to a new cohort of students and added six new questions to elicit more clarification regarding the impact of design review. In ME 347, students benefitted from using design review during Project 1 in ME 347 and results from both Part I and Part II indicate similar positive perceptions of design review process. The students are open to peer feedback and benefit from the design review process in terms of preparation, skills, and impact on design work. Part II investigated whether the way they view themselves as engineers changed after experiencing design review, which is part of engineering identity (recognition), and examined preparedness for future design work (84% positive response). Many self-perceived having strong design and CAD and design skills coming into the course from survey responses (65.4% positive response).

Results from Part II indicate a positive impact of design review on their project work and increased perception of preparedness for senior design. Students were roughly split on their preference to work alone on design (Q1, 61.4% and 48.1% positive response for Part I and Part II, respectively), which matches the trend that roughly half of students in Part II prefer to work on their own in other classes (Q27, 44% positive response). Since collaboration is a key part of the engineering design process, design review prepares otherwise solo students for senior design by giving and receiving constructive feedback. Students who have strong design and CAD skills coming into the course still benefit. Students who have self-perceived weaker skills coming into the course benefited most in their preparation to make better engineering designs and preparedness for senior design.

There are mixed reviews as to whether their identity as engineers have changed. Overall, the students with self-perceived weaker skills seem to have a net-positive increase in confidence and view themselves as emerging engineers. There is limited increase in their engineering identity, potentially due to these students comparing themselves to their stronger counterparts and becoming discouraged. For the students who have strong skills, there is a net-positive increase as well. However, there is a more neutral response to the benefit of design review, especially when stronger skilled students mix with weaker skilled students. A common student comment is that students having prior technical knowledge receive lackluster critiques from their relatively inexperienced partners during the peer-review process. This led to some of the strong students feeling frustrated at the process as they did not have actionable feedback to work towards.

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Appendix A: **Design Review Expectations**
The following is part of a handout provided to students in the class and reviewed in class prior to the first design review. Derived and adapted from Scott Hamilton's study [2]

<u>Design Review</u>
This semester, your work will be reviewed during lab by your classmates. This approach is called Design Review and its objective is to increase your learning and knowledge by:

- Having students learn from their classmates
- Having to explain your work to others
- Correcting mistakes and errors in others' work
- Recognizing your abilities and limitations
- Modeling the professional aspects of having work reviewed by others

Design review is an important tool for you to develop the skills required to be an engineer and in ME 347, to do well on projects. How do you do a design review? First, you must have completed the work to review your classmate's work. There is a design review sheet that will be provided with each assignment.

What is not helpful in this process? Providing a fake design review; examples include the following, but are not limited to:

- Checking off on work you have not done yourself
- Checking off work with basic and obvious deficiencies
- Checking off work as correct that is wrong, yet you got it correct
- Giving vague comments that are not helpful for improvement

In the unlikely event that you submit a fake design review, the reviewer can be penalized with a lower grade. You will not be penalized if all design group team members come up with the wrong answer, assuming you think it is correct and there is a logical assumption based on the work shown. Also, you also will not be penalized if after the review, you think that the other's work is incorrect and no one can convince the other members to change.

Ideally, in lab, you work with at least two students. You each review each other's work, meaning your work is reviewed by other students in your lab. This might not always be the case (ex. # students in lab section is not a multiple of two). **Quality matters more than quantity; longer reviews are not necessarily better.** Especially good design reviewers, those that are thorough, clearly provide meaningful comments that will help the engineer, offer insight, and demonstrate the reviewer's care and understanding may be given bonus points at the end of the semester. Design reviews are collected by a form that will be printed by your TA and collected at the end of lab for grading.

Appendix B: **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 B 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 C: **Summarized Results from Survey**

The statements for Q1-17 and Q22-27 use a 5 point Likert rating scale where: 1=strongly disagree and 5=strongly agree. Q10 and Q22 have 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). The results for Part II are given in columns 4-6. The shaded columns on the far right show the data from Part I (cohort 1) for comparison. For Part I data, the responses are ~22. For Part II, the number of responses is ~27, however the total response may not add to 100% due to rounding error.

			Part II (Current Study)			**Part I (Previous Study)**		
Construct	**Q#**	**Statement**	**Negative Response: Disagree**	**Neutral Response**	**Positive Response: Agree**	**Negative Response: Disagree**	**Neutral Response**	**Positive Response: Agree**
Growth Mindset	**Q1**	I prefer to work on my own through the design process.	22.2%	29.6%	48.1%	19%	19%	61.9%
	Q27	I prefer to work on my own in my other classes.	22.2%	33.3%	44.4%	NA	NA	NA
	Q2	I believe the design review process can be a powerful learning tool for design. *adapted from [1]*	0.0%	14.8%	85.2%	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%	0.0%	100%	0%	0%	100%
	Q5	I appreciate when teachers, coaches, or parents give me feedback on my performance. [6]	0.0%	0.0%	100%	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.	0.0%	3.8%	96.2%	0%	19%	81%
	Q7	I believe that design review helped me make steady progress on the project.	15.4%	0.0%	84.6%	9.5%	4.8%	85.7%
	Q8	I have benefited from reviewing my peer's design.	11.5%	7.7%	80.8%	14.3%	19.0%	66.7%

Appendix C continued.

	Q#	Statement	Negative Response: Disagree	Neutral Response	Positive Response: Agree	Negative Response: Disagree	Neutral Response	Positive Response: Agree
	Q9	I have benefited from peers' reviewing my design. *adapted from [2]*	7.7%	15.4%	76.9%	19%	0%	81%
	Q14	I can recognize changes needed for a design solution to work. *adapted from [7]*	0.0%	23.1%	76.9%	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]*	0.0%	0.0%	100.0%	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*	7.7%	26.9%	65.4%	4.8%	38.1%	51.7%
	Q22	Rate how the design review process impacted your project work. ***Different Likert scale used*	11.5%	7.7%	80.8%	NA	NA	NA
	Q23	My design and CAD skills were strong coming into this course.	11.5%	23.1%	65.4%	NA	NA	NA
	Q24	I feel prepared for senior design after giving and receiving constructive feedback in the design review process.	0.0%	15.4%	84.6%	NA	NA	NA
	Q25	I am prepared to make better engineering designs after experiencing the design review process.	0.0%	3.8%	96.2%	NA	NA	NA
Performance and Competence (Engineering Identity)	**Q11**	I can develop design solutions. *adapted from [7]*	0.0%	15.4%	84.6%	0%	14.3%	85.7%
	Q12	I can effectively communicate my design solutions. *adapted from [7]*	0.0%	19.2%	80.8%	4.8%	9.5%	85.7%
	Q13	I can evaluate a design. *adapted from [7]*	0.0%	19.2%	80.8%	0%	15%	85%

Appendix C continued.

	Q#	Statement	Negative Response: Disagree	Neutral Response	Positive Response: Agree	Negative Response: Disagree	Neutral Response	Positive Response: Agree
	Q15	My peers often ask for my feedback on their design. *adapted from [7]*	0.0%	38.5%	61.4%	23.8%	42.9%	33.3%
Recognition (Engineering Identity)	**Q16**	I feel like an engineer. *based on teaching evaluation comments*	4.0%	32.0%	64.0%	10%	40%	50%
	Q17	My peers recognize me as an engineer. *adopted from [7]*	0.0%	38.5%	57.7%	10%	35%	55%
	Q26	The way I view myself as an engineer has changed after experiencing the design review process.	8.0%	8.0%	84.0%	NA	NA	NA

Open-Ended Survey Questions Q18-20

Q18. Describe how design review impacted your project work with a specific example.

- *I was capable of making multiple design options when thinking of solutions. Particularly, making a strong enough pin that holds the cylinder heads without falling, and allowing rotation. Design review gave multiple ideas that I can use to counter this issue, and ultimately used one of those ideas.*
- *I was able to improve upon things that I couldn't see*
- *The feedback helps improve*
- *Talking to peers that have had experience using 3D printing helped my design a lot. After the first drawings and cardboard model I got good feedback on what works best for (3D) printing.*
- *Allowed for constructive feedback*
- *A design review made me think about how I could make my design more complex while still maintaining the purpose of my design choice and without overly complicating the manufacturing process*
- *Gave me time to reflect and collect feedback from peers and TA's*
- *I never really got impactful feedback.* *(*note: student did not answer Q19 or Q20*)*
- *I was able to improve project 1 by making sure the toy is more grip able.*
- *It allowed me to narrow down what would be a realistic project for the class because I had some ideas that were way too complex to do in the allotted time frame.*
- *Many of my peers emphasized the time constraints of project 1 which ultimately allowed me to be able to complete the project successfully and on time.*
- *Peers noticing I was missing a joint for my fidget design and I had to go back and fix that*
- *Major changes*

Appendix C continued.

● *I was unable to learn how to create a specific joint and I spoke to fellow students and ta for help* ● *Helped point out specific design flaws my drawing/ idea had*
Q19. Describe any improvements you would like to see in the design review process. ● *A lot of students don't consider the real life construction of a piece. So a lot of design reviews from peers were suggestions that is not feasible in real life. Also, I remember getting told by at least 6 separate students my design won't work, it's too complicated, or it won't print. I suggest that it should be taught to students, mainly engineers, to come up with solutions instead of putting others down. That is not review, that is just ignorance. Also, a lot of students don't have a good idea on machinery dynamics, I know that's a ME320 (Machine Design) issue, but isn't that one of the key aspects of mechanical engineers. Students should come into this class with better ideas on how dynamics work when making moving parts.* ● *None* ● *Maybe being required to ask a peer that has used 3-D printing before for feedback.* ● *Maybe more detailed review process* ● *NA* ● *N/a* ● *I feel like we need to be trained on what is good feedback.* ● *A more structured way making sure folks give reasonable feedback, often times I got feedback that was completely useless, maybe don't have the form require 3 things but require a genuine thing wrong.* (Note: The feedback form asks students to list two top priorities for improvement, not three things). ● *I think the process already works well* ● *More points to cover* ● *more checkpoints to keep me accountable during the process* ● *Unsure at the current moment*
Q20. Describe how your design skills developed throughout the class. If they did not change, please explain why. ● *I learned a lot, especially from the SolidWorks textbook. Mainly, importing curves from MATLAB, and creating dynamic simulations. I learned most of this in ME320, however, using it to make real parts I can print and use to this day was a different story. I do wish though, that we were taught more. This is a design class, however we were only taught everything we already learned in ME250. For example, I did not know about the sheet metal add in, or driveworks. I just feel like for a CAD class, we shouldn't move so slowly on the easy topics, and speed through the cool details included in SolidWorks that is useful for design, and future work experience. (I say this because I had no clue there was a sheet metal feature, and I am pretty sure I fumbled my Interview with MAT because of it lol).* ● *I got to experience the mindset of what engineers do unlike my other classes* ● *More steps revising my own work* ● *My skills were challenged with making a working and useable design. I developed a lot of good skills.* ● *I got better at using CAD and other software*

Appendix C continued.

- *I started to think more about different solutions in case something did not work with my initial choice.*
- *I developed a sense of consistent reflection*
- *I was able to understand how to design as the class went by. (Setting objectives, etc)*
- *My design skills changed to adhere to the requirements of the ME 347 lab, I don't usually go the most inefficient route, but it wasn't the route the lab wanted me to go.*
- *I am able to receive a project and complete it on my own now. I am much more confident in my skills as an engineer, and I feel like I can actually apply what I've learned in an industry setting.*
- *I learned different ways to approach a design and new way to improve a design as well as learning that you can always improve the design*
- *Great change able to use solid works*
- *they improved because throughout the design process i was able to help fellow students improve with me*
- *I didn't really have any design skills before. I kind of just winged it a lot of the time before*