Differences and Similarities in Student, Instructor, and Professional Perceptions of ”Good Engineering Design” through Adaptive Comparative Judgment

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Abstract
This project details the results from first-year undergraduate engineering students, engineering instructors, and industry professionals collaborating to assess student design projects. Each group (students, instructors, and industry professionals) used adaptive comparative judgment to rank the final projects from a first-year engineering course designed to engage students in the process of design and analysis in engineering at a public land-grant institution. The similarities and difference in the resulting rank orders of the student design projects, as well as the accompanying rationale statements from the assessors, were used to identify the assessment values and perceptions of quality of each group. A better understanding of these similarities and differences can help inform education practice and may assist educators in ensuring alignment between current practice and industry-needs towards future student success.

Introduction
Adequately preparing students for future careers, learning, and civic opportunities is at the forefront of discussions around best practices for education (Sharples et al., 2016). However, despite an emphasis on this preparation, research shows there is not always alignment between student, instructor, and industry perceptions of skills, traits, and competencies necessary for this preparation (Adecco, 2014; Deloitte, 2015). Further, much of this preparation revolves around difficult-to-assess-and-teach 21st century skills such as critical thinking, problem-solving, creativity, innovative thinking, and collaboration (NRC, 2012). In spite of the challenges associated with these issues, the adequate preparation of students for future success is paramount (Partnership, 2017). Therefore, this research will investigate the use of a relatively-new form of assessment, Adaptive Comparative Judgment, as a tool for not only improving the assessment practices of educators in open-ended situations (Bartholomew, 2017), but also as a method for identifying the potential disconnects between student, instructor, and industry perceptions of quality.

Problem Statement
As society continues to progress through a host of technological advances and innovations, skills such as creativity, problem solving, collaboration, critical thinking, and communication are consistently lauded as a necessity for student success in school and the workplace (Partnership, 2017). Student’s ability to not only interact with, but also shape, influence, and catalyze, innovative forces has led to calls for emphasis on design thinking and design skills in students (Goldman, Kabayadondo, Royalty, Carroll & Roth, 2014), with a specific emphasis on engineering design (Grubbs & Strimel, 2015; NRC, 2009). The emphasis on engineering design is not restricted to the United States but extends globally as designing is
considered a fundamental component of education worldwide (Banks & Williams, 2013; Barlex, 2006; Gattie & Wicklein, 2007; Leahy & Phelan, 2014; Sheppard, 2003; Wakefield & Owen-Jackson, 2013).

Notwithstanding the increased emphasis on engineering design, the actual implementation has been disjointed as several different engineering design processes and procedures have been developed, endorsed, and implemented in classroom learning environments (Grubbs & Strimel, 2015; Reeve, 2016). Though many of these engineering design process models have similarities, components exemplified in one model, may be excluded in another (Flowers, 2010; Reeve, 2016). Other recent findings demonstrated that these engineering design processes, may not be an accurate reflection of the practices used in industry and technical fields (Reeve, 2016). Accordingly, we investigated the perceptions of students, instructors, and practicing engineers through the assessment of a collection of student work from a first-year engineering course.

Research Questions

To investigate the potential similarities and differences in the values related to engineering design between students, instructors, and practicing engineers the following questions guided our study:

RQ1: What correlation, if any exists, between the perceptions of first-year engineering education students, their instructors, and practicing engineers when assessing student design projects through adaptive comparative judgment?

RQ2: What design values, if any, can be identified through the collected comments from adaptive comparative judgments of students, instructors, and practicing engineers?

First-Year Engineering

Undergraduate students beginning their post-secondary engineering studies often enroll in a first-year engineering program prior to entering their discipline-specific major, such as chemical, electrical, or biomedical engineering. Through first-year programs, students typically share a common set of coursework with other engineering majors of a similar level of academic achievement (Strimel et al., 2018). The purpose of these programs can often be viewed as providing students with the information necessary to ensure the proper selection of an engineering discipline-specific major and the knowledge and skills necessary for success in their selected major. The first-year engineering curriculum is often designed to reinforce basic science and mathematics concepts while developing a student’s engineering design capabilities. According to Strimel et al. (2018), the typical core requirements during a student’s first year includes physics, chemistry, multiple levels of calculus, and writing/composition as well as an engineering orientation seminar and multiple engineering courses focused on design/problem solving. While the orientation seminars often include an exploration of each engineering discipline, the first-year engineering coursework typically focuses on fundamental knowledge and skills that are considered necessary across all engineering disciplines (i.e. engineering design, project management, teamwork, technical writing, data analysis). These courses typically engage students in problem-and team-based activities to teach engineering design methods and tools and develop their skills in logical thinking, problem-solving, design, computational thinking, collaboration, project management, and technical communication. Therefore, the first-
year engineering coursework can provide a great platform to study the perceptions, teaching, learning, assessment, and valuation of engineering design practices and capabilities.

**Engineering Design**

Project-based learning and design-based learning pedagogies are widely used in first-year engineering design courses (Dym, Agogino, Eris, Frey, & Leifer, 2005). An emphasis on teaching design and utilizing design-based pedagogies was noted specifically by Dym et al. (2005) who specifically highlighted this trend of introducing project-based learning through design in first-year engineering courses. Often engineering design revolves a process-based approach which typically involves problem scoping, need analysis, solutions generating, prototyping, test and evaluation, presenting, and continuous improvement. Specifically, Dym, et al. (2005) defined engineering design as:

> A systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints. (p.104)

While emphasizing and teaching engineering design to students is seen as a positive and useful endeavor, assessing engineering design project remains a challenge for educators due to the open-ended nature of many engineering design problems (Bartholomew, 2017). Chiu & Salustri (2010) suggested peer evaluation and introducing experts to evaluate creativity in student design projects, while Dym et al. (2005) reported the use of holistic judgment, rubrics, and combinations to assess the quality of project solutions. Further, Platanitis & Pop-Iliev (2010) suggested to use rubrics to evaluate engineering projects but raised important question around how to establish criteria for grading.

In addition to challenges with assessment research on students working in engineering design contexts has revealed differences in students of different grade-level and practicing engineers. Specifically, Atman, Chimka, Bursic, & Nachtmann (1997, 1999) found that students who are new to engineering design tend to spend less time defining a problem and gathering information than more senior engineering students and practicing engineers.

**Adaptive Comparative Judgment**

Adaptive Comparative Judgment (ACJ), is a relatively new assessment approach which uses a comparison-based approach for decision-making and is based on research originally done by Thurstone (1927). Thurstone (1927), and later Pollitt (2004, 2012) argued that human beings are inherently better at making comparative judgments than rubric-based assessments. This claim has been validated repeatedly, in a variety of settings (Bartholomew et al., 2017; Hartell & Skogh, 2016; Kimbell, 2007, 2012; Pollitt, 2004, 2007), and has contributed to a large increase in research and implementation of ACJ in educational settings (Bartholomew & Yoshikawa, 2017). ACJ has consistently produced higher levels of reliability than traditional assessment methods (Bartholomew et al., 2017; Hartell & Skogh, 2016; Kimbell, 2007, 2012; Pollitt, 2004, 2007) as well as validity (Bartholomew, Strimel, & Jackson, 2018; Bartholomew, Strimel, & Yoshikawa, In Press). The process is iterative with multiple judges viewing sets of items; as different pairings of items are compared, the reliability of the resulting rank order increases (the highest-ranking item is the item which is consistently chosen as “better” during the judgments).
After each judgment is made, the judge can also be prompted to provide comments justifying their choice and revealing their thought-process during the judgment.

The process of choosing one item over another is holistic—judges are not asked to provide a grade for each piece of work but rather asked to holistically decide which student artifact is better based on their own professional opinion or an identified directive. Significantly, researchers (Bartholomew, Hartell, & Strimel, 2017) have recently used ACJ to identify similarities and differences in design values amongst diverse groups with success demonstrating the potential for this application of ACJ.

**Methods**

Considering the challenges raised around assessment open-ended engineering design problems, and, recognizing differences in students and practicing engineers we sought to investigate the identified research questions around perceptions and design-values for different groups in the freshman engineering process. This study took place in a first-year engineering course focused on engaging students in innovative thinking across the engineering disciplines and providing experiences for practicing the processes of engineering design and analysis at one large public land-grant institution. Following an approved protocol from the Institutional Review Board, 110 first-year undergraduate engineering students were enrolled in this study. The student participants were divided into 29 groups of three to four students each and given an industry-driven, open-ended engineering design challenge in which to solve. Prior to working on the open-ended design challenge, the students participated in an ACJ session to evaluate prior student design project presentations from the previous offering of the course to provide them with insights to the design scenario. All students viewed pairs of design presentations, collected from the previous semester offering of the course, and completed at least 5 comparative judgements as part of their initial brainstorming process to inform their own design. During this process the students simply chose, from the two presentations displayed, which presentation they thought was better. Following each paired comparison the students were shown a new pair of items and made another judgment.

Following the introduction, the design challenge and the initial ACJ session, students worked in their teams to solve the industry-driven challenge. The challenge, provided in Figure 1, revolved around the task of designing a new trash receptacle that separates used paper towels from other waste to help facilitate the recycling of the discarded paper products. The student groups submitted their final solutions for evaluation in the form of a video presentation which detailed both their process and their design concept.
First-Year Engineering Design Challenge
A local manufacturing needs an economical solution for efficiently separating used paper towels from other contaminants in order to easily enable the collection and recycling of the paper towel waste. The solution should remove the most contaminants from the used paper towels as possible, require limited human interaction for separating the paper towels from other waste, be easy to implement in the restrooms of crowded venues, and not necessitate the alteration of the user’s typical behavior.

Example Student Solutions

Once all 29 of the group presentations were collected, these video presentations were uploaded to an ACJ system called CompareAssess for evaluation in three separate judgment sessions—one session (N=104) for the students to serve as judges/assessors, one session (N=7) for the instructors to serve as judges/assessors, and one session (N=8) for the practicing engineers to serve as judges/assessors. The instructors for these students were all recruited for this study (n = 6) and invitations were sent to three local engineering firms soliciting
participation by practicing engineers; these invitations resulted in eight practicing engineers being recruited for participation. Following recruitment, each group of judges/assessors was trained on the ACJ tool (CompareAssess) and provided with an identical ACJ session—each containing all 29 of the project videos. Each group of judges/assessors then completed their ACJ session by participating in multiple rounds of comparisons between pairs of group presentations and selecting the better project based on their own expertise. In addition, each judge/assessor, whether student, instructor, or practicing engineer, provided comments in the ACJ system to justify their decision in each comparison. As a result, the output of these ACJ sessions included a rank order of the student design projects generated from each judgement group (student, instructor, and practicing engineer) and a series of comments rationalizing each person’s judgement decision. The rank-order from each judgement group was conditioned and prepared for analysis using standard correlational statistical procedures to determine any potential relationships between groups. In addition, with each judgment made the assessors (students, instructors, and practicing engineers) were allowed to provide a comment, or justification, for their judgment decision. These comments, which were collected through the CompareAssess software, for later qualitative analysis to investigate our second research question around the ideas, concepts, skills, or traits that were valued by the various judgment groups.

Findings
Following data collection, all data were conditioned and analyzed in line with the guiding research questions. The findings, from both the quantitative and qualitative data were separated by research question and will be presented here.

RQ1: What correlation, if any exists, between the perceptions of first-year engineering education students, their instructors, and practicing engineers when assessing student design projects through adaptive comparative judgment?

For this research question, we sought to identify what relationship, if any exists, between the rank-order produced through the ACJ sessions for each group (the students, teachers, and practicing engineers). A Spearman correlation between the final rank-order of student work from the final project produced by each group revealed significant correlations between the ranks produced by students and instructor (r = .56, p < .001) and the ranks produced by students and practicing engineers (r = .66, p < .001). However, the correlation between the ranks produced by practicing engineers and instructors was not significant (r = .33, p = .08).

These findings suggest that the students and practicing engineers had the closest perceptions of quality for the assigned design project. Further the students also produced a rank which was significantly correlated with the rank produced by the instructors suggesting students’ perceptions aligned well with the teachers in terms of comparative quality. However, the lack of a significant correlation between the rank produced by the instructors and that produced by the practicing engineers is perhaps the most illuminating as it suggests that the design skills, traits, and qualities perceived positively by practicing engineers were not the same as those identified by instructors. This significant relationship, while inconclusive on its own, suggests a potential difference in design values that can perhaps help to inform better design practices in industry or engineering preparation. Perhaps, idealistic methods may not be retained by students as they move into the workplace and become practicing engineers or classroom environments may need additional support to authentically mimic the engineering workplace.
For further analysis we took the final rank order received from each group of judges and summed these ranks to achieve an overall ranking for each item. These overall rankings were compared with the rankings assigned in each session of judges to ascertain potentially large differences in the perceptions of each group (see Figures 2-5).
Figure 2. Overall Rankings for Student Portfolios and Rankings by Students and Instructors
Figure 3. Overall Rankings for Student Portfolios and Rankings by Students and Practicing Engineers
Figure 4. Overall Rankings for Student Portfolios and Rankings by Instructors and Practicing Engineers
Figure 5. Overall Rankings for Student Portfolios and Rankings by Students, Instructors, and Practicing Engineers
Notably, group 5’s work was ranked #1 by practicing engineers and #2 by students but did not make the top-ten for instructors while group 6’s work was ranked very similarly by all three groups. Group 19 was ranked #1 by the instructors, #3 by the students, but did not make the top-ten for industry members while group 18 was ranked almost identically by all three groups. These similarities and stark differences in perceptions of comparative quality highlight areas on consensus and other possible disconnects between students, instructors, and practicing engineers. Further analysis of these similarities and differences will be address in conjunction with the next research question.

**RQ2: What design values, if any, can be identified through the collected comments from adaptive comparative judgments of students, instructors, and practicing engineers?**

A preliminary analysis, which focused on selected portfolios demonstrated wide differences in judge-group ranking and has provided a general direction for further efforts. We theorized that beginning with a select group of portfolios, which were ranked very differently by the different groups, would be provocative in terms of potentially revealing stark contrasts in the values of the individuals within each of the judging groups.

We began our analysis with Team 28. Team 28 was ranked 10th best by the instructors but fell in the bottom 10 of the rankings for both practicing engineers and students. An analysis of the comments suggested that students and practicing engineers valued feasibility in ideas while the instructors emphasized creativity in the solution. For example, instructor comments associated with Team 28’s portfolio included the following:

“...[Team 28] had the more innovative solution and supplemented their test results with helpful charts.”

“...[Team 28] did a better job of evaluating the test data.”

“[Team 28’s] idea is very novel adding magnetic material into the paper towel.”

While the instructors’ comments seemed to emphasize an instructor-value towards creativity, the students appeared to take a more practically-driven approach which centered on the feasibility of the proposed idea. A few of the student comments, which were representative of the comments in general, included phrases such as:

“Great presentation and idea, but it does not seem reasonable for [sponsoring company] to change the way they make their paper towels.”

“their idea of using magnetic will attract other magnetic trash. Furthermore, they assumed that the contamination rate will be almost 0% which I think is too ambitious.”

“Solution depends on the paper towels being magnetic, which is not possible everywhere.”

“Is magnetic paper towels actually an idea that is feasible, and how exactly are you going to be implementing the "magnets" in paper towels?”
Conclusion

While assessing student work through ACJ it appeared that students and practicing engineers focused on “technical feasibility” and “practicality” while the instructors focused on “novelty” and “creativity.” The significant relationship between students and practicing engineers in the assessment of design projects and the insignificant relationship between engineering instructors and practicing engineers found in this study, while inconclusive on its own, suggests a potential difference in design values between these groups of individuals. Understanding these value similarities and dissimilarities may help to identify and inform better design practices in industry or engineering preparation. For example, a further investigation may illuminate that idealistic design methods may not be retained by students as they move into the workplace and become practicing engineers. Alternatively, it may be possible that classroom environments need additional support to authentically mimic the engineering workplace and more closely align with industry perceptions and expectations. It is also possible that the instructors’ evaluations may have been influenced by factors beyond the artifact such as the team’s work ethic and other insights the instructors may be privy to about the team as a result of their interactions and observations in class. In this vein it may not be surprising that the instructor’s expectations would be beyond simply the performance of the prototype; elements that may be reflected in their evaluation of the prototype. Regardless, we believe the ACJ process/system can be a valuable research tool to study and better inform the practices and processes of education related to engineering design.

Further exploration around the similarities and differences in student, instructor, and practicing professionals through ACJ may yield meaningful findings related to best-practices for pedagogy. Therefore, it is recommended to expand upon this work to better understand the values in design amongst diverse groups of individuals to enhance the teaching and learning of engineering design and establish potential assessment indicators for determining competence in solving open-ended design tasks. Consideration of other related constraints and factors such as time, space, teacher training, and other personnel requirements should all be included in additional analysis around the potential for integrating ACJ into research around engineering design education.
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