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First-Year Engineering Student Perceptions of Creative Opportunities in Design*

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This paper presents the outcomes of a study of first-year engineering student perceptions of creative opportunities in engineering design tasks. The study was guided by three key questions: (1) How do first-year engineering students view creativity and its role in engineering? (2) What opportunities do students see for creativity in their engineering design projects? (3) How do various factors, including the course structure and the instructor, influence student choices to pursue creative opportunities? First-year engineering students participated in four surveys during the semester in which they were working on an engineering design project. Overall, the participants perceived many creative opportunities; however, the opportunities they saw at the beginning of their work were greater and broader, while once into their projects, the scope of their perceptions narrowed. Throughout the design project, the instructor, project constraints, and risks associated with exploring a creative design option influenced the participants' perceptions. The research outcomes can guide how instructors advise student decision-making and structure their design courses to facilitate creativity.

Keywords: creativity; engineering design; design education; first-year engineering

1. Introduction

Creativity is an essential skill in the design of innovations necessary for the sustainability and prosperity of our country and our world. Corporations also emphasize the need for innovation in order to diversify and respond to market challenges [1]. In order for innovative solutions to be achieved by engineers, they must possess creative skills that they can apply in the context of engineering challenges [2–4]. However, engineering students have reported feeling that they have limited creative experiences in engineering, and engineering instructors have reported a lack of creativity in engineering students [5]. Ambiguity seems to exist for both students and faculty in terms of what creativity is in the context of engineering and how it can be supported. Thus, our study focused on: student perceptions of creative opportunities throughout a design project in an introductory engineering course, the impacts of these perceptions on design decisions, and what factors influenced perceptions and decision making. The outcomes of this work provide insight on how design course environments and instructor interactions can support students in recognizing and taking advantage of creative opportunities.

2. Background

Creativity has been defined in a number of ways in various fields. In the context of engineering, Kazerounian and Foley described a creative person as one who tends "to take chances; to have the ability to make unique connections between ideas; to be flexible and imaginative; to question the normative ways of doing things; and to be motivated, intuitive, and inquisitive" [5, p. 762]. Plucker, Beghetto and Dow [6] attributed the ability to be creative as a function of one's skills, the process he or she is using, and the working environment. Scholars have defended that everyone is born with the ability to be creative, but that that creativity is stifled, and possibly destroyed, by external social pressures in the home, school and in the community [5].

In past research, participants rated engineering as one of the least supportive fields with regard to creativity development [5]. If students feel limited in their opportunities to demonstrate and develop their creativity, especially in an educational environment in which risks and consequences are minimal; how can we expect these future professional engineers to respond creatively in environments, in which failures have such high stakes? Decades of research in psychology has demonstrated the role of environment, called "press" in the 4-P model [8], as a key factor in the ability to be creative [9–12]. Kazerounian and Foley [5] claim that traditional engineering design courses require students to follow well-proven design techniques, resulting in students being unchallenged to consider new processes or concepts, thus resulting in few opportunities to explore and develop creativity skills.

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In addition to the classroom environment, opportunities to demonstrate and develop creativity depend on an instructor's goals and vision for the course, and the instructor must lay sufficient groundwork for students to recognize these creative opportunities [4, 13–15]. Some scholars have documented courses with a specific focus on creativity in engineering [e.g., 2, 16]. However, even when opportunities for creativity exist, specifically in the engineering design context, numerous barriers cause students not to pursue them. These barriers include habits, rules and traditions, cultural constraints, fear of the unknown, fear of failure, lack of instruction on how to be creative, emotional responses, and over-certainty [3, 7, 17]. Students have reported that fear of failure holds them back, stating that their instructors want a final design outcome focused on function and not creativity [18].

It is important to understand the aspects of an engineering design task that participants consider open to creative exploration as well as what aspects of the design task, environment, and instructor interactions impact perceptions of creative opportunities and choices to pursue those opportunities in engineering design. In this study, we were not focused on assessing creativity; rather, our goal was to understand how first-year engineering students define creativity, view the role of creativity in engineering, and perceive and pursue opportunities to be creative in their engineering design work.

3. Methods

3.1 Research goals

Our research was guided by the following research questions: (1) How do first-year engineering students view creativity and its role in engineering? (2) What opportunities do students see for creativity in their engineering design projects? (3) How do various factors, including the course structure and the instructor, influence student choices to pursue creative opportunities?

3.2 Participants

Participants were selected from a design-based introduction to engineering course, which had 445 enrolled first-year students divided into nine sections, each focused on a different field of engineering and led by a different instructor. We invited all students to participate in a series of four surveys throughout the semester, offering an incentive of \$50. Forty-three students indicated interest, and 25 student participants were selected. Selection was based on our goal to achieve diversity in course section, gender, and race.

For each survey, participants were emailed the respective survey link. Although participants were reminded to complete surveys, participation declined with each of the four surveys we administered over the course of the semester. The number of students who participated in each survey is shown in Table 1. Each of the survey respondents in a subsequent survey participated in the previous survey, thus we had 17 participants who completed the full longitudinal study.

Table 1. Total Participation per Survey

Survey	Total Participants
1	25
2	22
3	18
4	17

3.3 Instrument development

We developed four survey instruments, and each was constructed to take less than 30 minutes to complete. We collected both qualitative and quantitative data through free response, attitudinal and ordinal scaling, rank ordering, semantic differential scaling, and nominal scaling questions. We used the complement approach to guide our question design and ordering, which means we organized the questions in a hierarchy, with the later questions complementing the previous as well as asking for further depth [19].

Before each survey was distributed to the participants, it was piloted with 10 graduate students. Specifically, the graduate student reviewers were asked to review the surveys for length, question clarity, software user interface, and grammatical errors. From their feedback, we were able to make improvements to the surveys. The survey items were guided by our established primary goal for each survey and were based on research and literature on creativity. After preliminary analysis of the study participants' responses from earlier surveys, additional survey items were added to subsequent surveys in order to gain additional information on questions and topics that emerged.

Table 2 lists each survey along with examples of survey items. *Survey 1: Perception of Creativity in Engineering Design* allowed us to gain insight into participants' definitions of creativity and perceptions of the role of creativity in engineering design at the beginning of their design projects. *Survey 2: Design Project Progress & Decisions Made* asked participants to report on their design progress as well as advice given by their instructors that influenced their decisions. *Survey 3: Design Project Progress & Decisions Made* was similar to survey 2, as participants were asked to report and reflect on their design progress. Additionally, we also asked participants to rank the level of creative opportunities in multiple disciplines, discuss the differences between problem solving and creative problem solving, and provide synonyms for their definitions of creativity; these questions allowed us to gain additional insight on how participants defined creativity and its role in engineering. In *Survey 4: Perception of Risk of Creativity and Final Project Outcome*, the participants evaluated the outcomes of their projects and reflected on their design experiences. In previous survey responses, participants indicated that being creative was risky. This shaped some of the questions developed for Survey 4, in which we asked participants to discuss the risks associated with exploring creative solutions to their design tasks. Also in Survey 4, the participants were asked to reflect on how their instructor supported risk-taking and asked to identify changes to the course which would better support creativity.

3.4 Data collection

The surveys were distributed at the beginning and end of the design project, as well as at two points in between. The link to the first survey was given during the early phases of the design projects in the first-year engineering course. The participants were given nine days to complete the first survey. The following three surveys were sent in the same manner every one and half weeks. The second and third surveys were administered at the approximate midway point of the student's project progress. The fourth survey was administered after the participants had completed their design projects. We sent participants a reminder two days before the survey closed if they had not completed it and a second reminder the day of the survey closing. All survey responses were collected using the Qualtrics Survey Software, which allowed us to monitor participant progress and record survey completion dates and times. Each participant received an email with a personalized survey link once the survey was activated.

3.5 Data analysis

We used multiple approaches to data analysis because we collected both qualitative and quantitative data. For responses to scaling, ordering and attitudinal questions, we used counts and descriptive statistics. Each free-response question was analyzed inductively for patterns [20]. We read responses and categorized them thematically using emergent rounds of coding, synthesizing, and developing categories as appropriate until the categories were distinct from one another, well defined, and supported by multiple pieces of evidence [19–21]. In our coding process, one researcher did a first pass of analysis, and then discussed themes with the second

Table 2. Survey Topics and Example Survey Items

Survey	Example Survey Items
Survey 1: Perception of Creativity in Engineering Design	• How do you define creativity? • Rate the level of creative freedom your instructor encourages for this design project. (Rating: 1–5) • Do you think engineering design can involve creativity? • When does engineering design involve creativity? • When does engineering design not involve creativity? • Will your grade be dependent on the creativity of your project outcome? (Y/N) • Rate your feelings of creative freedom for this project. • Rate the level of creative freedom your instructor encourages for this design project. • How much value do you think your instructor places on the use of creativity in your design project? (Rating: 1–5)
Survey 2: Design Project Progress & Decisions Made	• What are you finding most challenging about your design project? • What were the 3 biggest decisions that you or your team made concerning your design project? • Did your instructor give you advice on this decision? What was the advice? • Please share the specific creative opportunities you still have in your work.
Survey 3: Design Project Progress & Decisions Made	• List 3 words that you consider to be synonymous with your definition of creativity. • Consider the following five disciplines. Rank the extent to which you believe each discipline involves creative opportunities in the regular work of practitioners of that discipline. • How would you describe the difference between problem solving and creative problem solving? • When thinking about your goals for a design task, would you rather develop something that will definitely work or something that is creative, but has a bigger risk of failure? • Which do you think your instructor prefers you to do?
Survey 4: Perception of Risk of Creativity and Final Project Outcome	• What risks are involved in incorporating creativity in engineering course design projects similar to the one you just completed? • How do you think your instructor's advice impacted your creativity? (Rating: 1–5) • In the context of your project, did you want to be creative? (Y/N) • Do you think your instructor supports risk taking? (Y/N) • What changes would support you in being more creative in your engineering design work in your engineering courses?

Table 3. Example Participant Timeline Created for Analysis and Researchers Notes

Participant 6 (P6) Timeline	
Survey 1	Participant 6 defines creativity as the ability to form new ideas. Note that the participant indicates creativity is an ability. The participant believes that a new solution to a problem comes from creativity; however, he states that when a design employs previously created concepts it does not involve creativity. This participant asserts that the limit to creativity is practicality. He feels that there is moderate creative freedom in the project and that the professor encourages the same level of creative freedom but does not know how much value the professor places on the use of creativity. He also indicates that his grade will not be dependent on the creativity of the project outcome.
Survey 2	For decision 2 the professor told the students how to place the motor in order to increase motor efficiency. This seemed to be direct because the professor appeared to give advice that guided the students toward a best practice. This is not necessarily a bad practice on the part of the instructor but it can create a limit on students in terms of exploring for themselves. Participant 6 noted room for creativity in building the design artifact.
Survey 3	The 3 biggest designs made by participant 6's group dealt with the redesign of the project. This participant also attempted to solve the problem several times before consulting the professor. Participant 6 provided different definitions for 'problem solving' (solution is based on what the solver already knows) from 'creative problem solving' (reaching a solution in a different way). This student would rather create something with a "bigger risk of failure" because it "allows you to learn from your mistakes or learn better solutions." This participant expressed a limit to creativity due to time, thus felt it was important to always have a less risky back-up plan when considering a creative option.
Survey 4	Participant 6 thought the project statement was interesting because of the opportunity to develop and build his own design. He would complete the project again if given the chance and would 1) improve design and 2) practice using the final product before the competition. Although there are designs common to his area of design, the participant saw opportunities to do something "different than the norm." This participant stated that there are "a lot of risks with incorporating creativity in this design project." The time available to complete the project was again noted as a key constraint. The student felt his professor supported risk taking but also recommended that students have a backup plan that is feasible and realistic for the time the creative idea will not work. A suggestion for how he would feel supported in being creative: "allow more time to implement creative designs and correct mistakes."

researcher. Then the first researcher would iterate on the coding scheme and discuss again with the second researcher. We repeated this process, as needed, for each coding scheme. Categories were not exclusive, thus if a participant's response fit in multiple categories, we allowed this single response to be grouped multiple times. Upon finalizing the category organization, we counted the frequency of responses in each category, compared themes within and across surveys, and compared individual student perceptions and experiences over time.

In order to look at each student's perceptions and experiences throughout the design project, we created timelines. These included a summary of student responses and notes by the researcher about these responses to guide us in understanding student ideas over time. An example student timeline is shown in Table 3. For the timeline analysis, we chose to only include the data from the 17 participants who completed all survey items. For the independent coding by question, we included all participants who completed that particular survey.

4. Results

4.1 Student conceptions of creativity

Our first research question focused on understanding first-year engineering student conceptions of creativity. In the first survey, we asked participants to define creativity and in Survey 3 we asked them to provide a list of synonyms for creativity, compare problem solving to creative problem solving, and rank their perceptions of opportunities for creativity by discipline. In the following section, we summarize trends in the participants' responses to these questions as well as what the collection of responses revealed about students' conceptions.

4.1.1 Defining creativity

Almost all the participants (20 out of 25) defined creativity as an ability; however, they did not indicate whether they thought this ability was innate or could be developed. Table 4 displays the categories that represent the key features of participant definitions, the number of responses in that category, and an example definition from one of the participants. Categories were not exclusive; we allowed a single response to be grouped multiple times if necessary. Notice that only one student's definition emphasized that creativity related to usefulness. Most participants indicated a creative idea was something novel and different from what had previously existed. They also often noted that the act of producing something creative required "thinking outside the box."

Initially, participants did not indicate in their definitions of creativity that they thought creativity was related to design outcome aesthetics. Later in Survey 3, when participants were asked to provide synonyms for creativity, they included words related to aesthetic value in addition to words similar to their definitions described above. Participants indicated that creativity could relate to something artistic or visual and that made a project more

Table 4. Categories of Participants' Creativity Definitions

Category	Count	Example Student Responses
Creativity is about creating something unique or different.	9	"Creativity includes unique ideas that are different from anything ever before." (P22)
Creativity is an ability to see things in a new way.	8	"Creativity is the ability to imagine, to be able to see things in a new perspective." (P8)
Creativity means thinking outside the box.	6	"The ability to think outside of the box and find unconventional solutions to a problem." (P3)
Creativity is a type of problem solving.	2	"To be able to come up with ones ideas and take action to solve a problem." (P26)
Creativity is how new ideas evolve from previous ones.	1	"Creativity is the evolution of one idea into the next, which will create a final product. (P15)
Creativity yields useful outcomes.	1	"Creativity is the ability to think of, design, or build something unique and useful." (P13)

interesting or exciting. It was not until the third survey that students associated artistic terms with creativity. As discussed in the next section, participants' descriptions of creative opportunities also shifted as the design project progressed, from problem solving and functional creativity to aesthetic components of the solutions. Participants' synonyms also included words like "options" and "decisions", indicating that they thought creative processes included providing enough options for their decision-making.

For further elaboration on student conceptions of creativity, participants were asked to describe the difference between problem solving and creative problem solving. Sixteen of the 18 participants who responded to Survey 3 described problem solving as executing a standard and expected method that is already known as well as implementing pre-existing solutions, and creative problem solving as exploring new approaches and solutions. One student commented that problem solving is the quickest method to solve a problem. This participant's response indicated that the student felt that involving creativity in problem solving would slow progress toward the end goal. While only one student expressed this idea for this particular survey question, in our timeline analysis as well as student discussions of barriers, many of the participants indicated that they could not employ creative options due to time constraints.

4.1.2 Student perceptions of creativity in engineering and other disciplines

In Survey 1, participants were also asked about the role of creativity in engineering. All participants reported that engineering design could involve creativity. Five participants stated that engineering design always involved creativity. Participants explained examples of when they believed engineering design involves creativity (categories shown in Table 5) and when it does not. The participants thought that engineering design did not involve creativity when (respective counts are in parenthesis): solving equations (8), constraints are tight (4), the task is repeating a previous task (4), and the design is simple (3).

Table 5. Responses to "When Does Engineering Design Involve Creativity?"

Category (Engineering Design Involves Creativity . . .)	Count	Example Participant Responses (Participant number is in parentheses)
During innovation	10	"When my team was thinking about our design project, we were trying to come up with new ideas. Creativity is essential in this process." (P1)
When solving new problems, thus creating new solutions	8	"Engineering design involves creativity when problem solving. An example would be when there is no well-defined answer to an issue and when one needs to be made." (P17)
When there is a need, such as the design has requirements in terms of functionality or visual appeal that demand creativity	4	"When engineers design really tall buildings . . . the buildings must be attractive." (P10)
When things are not working as planned or there are unexpected roadblocks	1	"When presented with a problem where typical applications of a formula or process do not work then engineering requires creativity. . . when things do not work in the expected manner. . . [it] requires a great deal of practical knowledge as well as creativity." (P11)
When there are no constraints	1	"Engineering design involves creativity when the constraints of a project are pulled away. When there are no constraints, the engineer can be as creative as possible to solve the problem." (P15)

All participants agreed that creativity in engineering could yield practical solutions. In Survey 3, we asked participants to rate the opportunities for creativity in engineering as a discipline as compared to other disciplines. We provided participants with a list of five disciplines (Humanities, Engineering, Performing Arts, Sciences, and Visual Arts) and asked them to rank the level of creative opportunities of each discipline on a scale of 1–5 (1 = the least opportunities for creativity and 5 = the most opportunities for creativity). The participants were also asked to provide an explanation for their discipline ranking.

We averaged the score for each discipline as rated by each of the 18 survey participants, shown in Fig. 1. Engineering scored in the middle, with the visual and performing arts ranked as having more creative opportunities.

In Kazerounian and Foley's [5] work, participants ranked engineering as the least creative discipline when comparing engineering, science, and humanities and said that engineering had the most room for creative improvement. Our data indicated that participants perceived engineering as having slightly more opportunities for creativity than the sciences and humanities. Kazerounian and Foley included more advanced undergraduate students, thus there is a possibility that first-year students' ideas shift as they take more engineering courses. In order to further explore these ideas, data would need to be collected from a larger group of first-year engineering students.

4.2 Student perceptions of creative opportunities in design

In the following section, we report the data related to our second and third research questions. Throughout their design projects, students' perceptions of creative opportunities were impacted by their instructors, the structure of the design task, and the challenges they faced. We discuss each of these influential factors as well as students' changing perceptions and choices to pursue creative options.

4.2.1 Opportunities and challenges in the design process and learning environments

In Survey 1, students were given a 15-phase engineering design process [22] and asked to indicate which phase(s) had opportunities for creativity. Participants reported the most room for creativity in the stages *generating design alternatives*, *establishing the function of the design*, *establishing how the design will achieve functionality*, and *modeling and analyzing the chosen preliminary design*. Participants saw the fewest opportunities for creativity in *identifying project constraints*, *clarifying assignment objectives*, and *documenting the final design*. Participants did not perceive much room for creativity in areas related to defining or framing the problem; instead their perceptions were focused on creativity in solution exploration.

In Survey 2 and Survey 3, we asked participants to list the creative opportunities they had in their design projects. Survey 2 responses indicated creative opportunities related to design decisions and alternatives, design functions, design improvements, and creating group timelines for task completion while Survey 3 responses focused on the visual aspects of the design (e.g., product aesthetics, developing the project presentation, and completing the final project report). This shift seemed to relate to participants' design progress; students had chosen a solution by Survey 3 and the student timelines also revealed that as participants approached the end of their projects, they prioritized their goals of achieving product functionality and earning a satisfactory grade over their goals of presenting creative solutions and design methods. Thus, their decisions focused on the most efficient way to make their solution work, rather than considering novel ways to build their solution. Participants articulated the decision to develop a

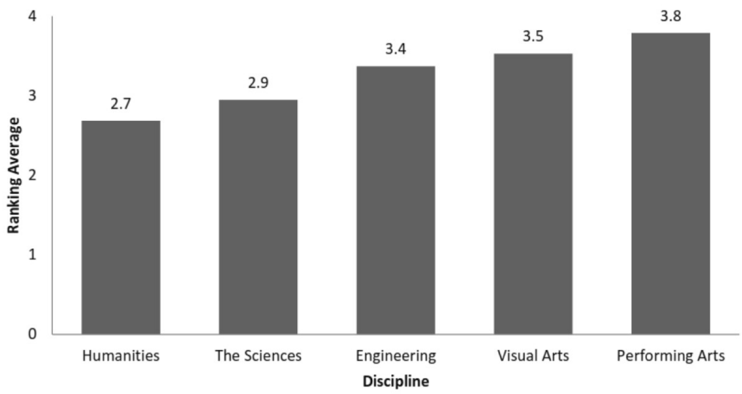

Fig. 1. Student Average Rankings for Creative Opportunities across Disciplines.

working solution and get a good grade in the course. For example:

> *We hope to mainly get an A in our course. We would also like our project to come out as successful. It should be waterproof, stable, sturdy, and scratch-resistant. If we can get at least these things, that will be ok. (P2)*

Participants' perceptions of opportunities for creativity were also impacted by the challenges they encountered in their design work. Early in the engineering design process, many participants reported communication amongst team members as a challenge to creativity. This included difficulty coordinating meeting times, working with difficult personalities, and the inability to make group decisions. Participants also expressed challenges in planning and staying on track during the design process. While students reported team communication and planning as challenges to creativity, these are challenges to achieving any kind of success, creative or not.

Participants also reported being challenged by the time constraints of the semester-long project. They expressed feeling as if they were behind and found it a challenge to do something new with this time pressure. On the other hand, a few participants reported that the time constraint pushed them to do new things. Some participants reported limitations in their creative pursuits due to limited skills or content knowledge and not having enough time to learn the skills needed for project application. Reported challenges also included meeting design project criteria, including criteria set by the instructor and their team, as well as the availability of resources. Table 6 summarizes these challenges and includes example comments from the participants.

On Survey 4, we asked students to list the risks in incorporating creativity into engineering design; they identified risks similar to the challenges listed above; these included failure, loss of direction, cost, a non-functional design outcome, deciding what creative possibilities to pursue, bad grades, running out of time, and not completing the design by the deadline. We also asked them to share suggestions for course improvements that they felt would support them being more creative in their engineering design work. Table 7 summarizes these suggestions.

4.2.2 Instructor and learning environment impact on the pursuit of creative opportunities

Our investigation of student perceptions of creative opportunities included a focus on instructor impact, including grading criteria, instructor priorities, and advice given by the instructor. In Survey 1, participants were asked multiple questions related to their perceptions of the value of creativity in the course. In general, participants thought the problem statement given by their instructors allowed for creativity, and their instructors encouraged and valued creativity. However, 18 of the 25 participants completing the survey indicated that they did not know how creativity would be factored into their grades. We asked about the role of creativity again in the final survey, and the participants reported they would prefer to have a defined way that creativity

Table 6. Challenges Reported by Students

Challenge	Example Participant Responses
Time	"I feel that there is a great deal of pressure to get the project done on time. I feel like we are behind on our project and are not meeting enough or doing enough quickly enough to get this done. It is doable, but I feel rushed to finish. (P2)
	"The most challenging part is the coding and learning to find new ways to accomplish something under a time constraint." (P8)
Meeting Expectations	"The most difficult part of our design was creating a [product] that was fast and aerodynamic but had the ability to turn around fast and efficiently." (P6)
	"He told us to keep in mind the time and budget constraints, and made sure we had room for the interior circuitry." (P20)
	"[The instructor] made sure we knew the constraints we were dealing with and that we were focusing on the ones we should be." (P22)
Availability of Resources	"Finding the right parts that will keep our efficiency high, power high, and costs low [was a challenge.]" (P17)
Limited Content Knowledge	"I simply do not have experience with [programming] and so it often I will miss the nuances which are vital to a successful project." (P11)
Team Coordination and Communication	"Communicating with teammates and trying to maintain a positive atmosphere in the team is the hardest part [of the design process]." (P12)
	"It is often difficult to coordinate the team into creating a thorough and precise design and progression plan; and the team does not seem willing enough to constructively develop an optimum plan." (P16)
Planning	"Keeping track of everything we need to do / distributing work and trusting others to get it done / working with somewhat difficult teammates." (P3)

Table 7. Student Suggestions to Support Creativity

Suggestion	Example Participant Responses
Less focus on grades	"If there wasn't so much of the grade focused on the project working, and more focused on the design of the project, being more creative would be encouraged." (P17)
More time	"If we had more time, I would have expanded the abilities of our synthesizer and transcriber because then it would be less of a risk to try different methods than were given to us." (P5)
Fewer limitations/ restraints	"Having a little more time on the project and less limitations would encourage creativity. We only had about 7 weeks to do our project because many of us had no experience with programming and our instructor had to start from the very beginning in the class." (P23)
Confidence in project functionality & ability to reiterate design process	"I would be more creative in my engineering classes if I knew that with my creative design, the design would work for its designated function. Our design was somewhat creative, but I am positive that it will be very usable." (P13) "Being able to have a second chance if a first and more creative design failed us." (P14)
Sharing ideas	"The engineering course supported creatively very well. For example, at the beginning of the project, every group member presented an individual design to the team. We then took ideas from everyone's design to make our final [solution]." (P8)
Improved team dynamics	"A more well-rounded team." (P4)
Assessment of risk	"Allowing a way to show that we had taken a risk in a good way even if the design fails." (P7)

would be incorporated into their final grades and that because their grades did not depend on creativity, a fear of failure held them back from creative exploration. Participants often opted to create a project that was guaranteed to work, rather than taking a risk, in order to earn an 'A' grade. The participants wanted to meet the requirements set forth by their instructors in the project statements, and since creativity was not explicitly assessed, it was not as high of a priority.

In Survey 2 and Survey 3, participants were asked questions related to their perceptions of their instructors' priorities as compared to their own. The participants' perspectives were divided, with 7 students saying they would prefer an outcome that definitely worked and 6 students preferring a creative outcome with a greater risk of failure. Interestingly, participants reported a stronger belief that their instructors preferred a creative solution. This comparison is shown in Fig. 2.

All Survey 4 participants agreed that their instructors supported risk taking. They did distinguish instructors who encouraged taking risks only to a certain extent, from instructors who encouraged creative risk even if the project was not functional. Participants also stated that their instructors encouraged them to have a back-up plan for when they chose to explore a creative opportunity and it did not work as planned. Example student comments on this topic include:

> *Since less emphasis was placed on how the project worked, it can be seen that the instructor wants us to experiment and be creative to gain experience.* (P15)
>
> *I think taking risks is supported up to the point where the risk could possibly prevent you from finishing your project.* (P17)
>
> *My instructor supported taking risks as long as there was a backup plan to this design that was more feasible and realistic.* (P6)

Our investigation of instructor impact also

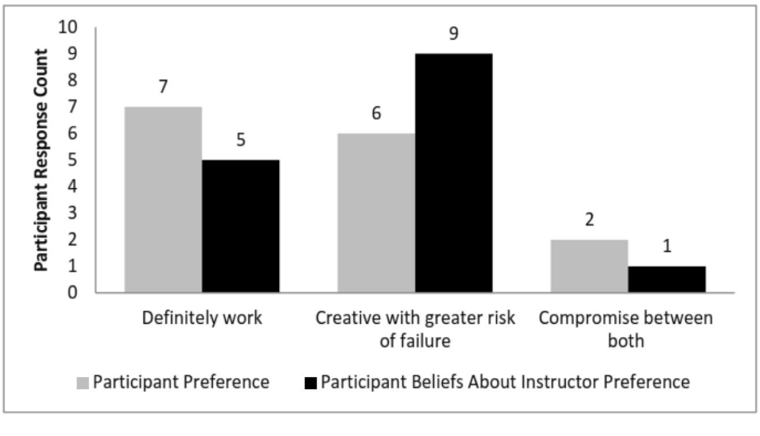

Fig. 2. Comparison of Participant Preference and Participant Beliefs about Instructor Preference.

Table 8. Types of Instructor Advice

Type of Advice Given	Examples of Instructor Advice as Reported by Participants
Direct: Telling the students what decision to make	"The advice was to pop rivet the sheet metal pieces together." (P17) "He told us that with our current battery, we would be actually draining power, as the solar panel was a lower voltage than the battery." (P17)
Convergent: Encouraging prompt decision-making	"That we might want to opt for a less risky design, to avoid repercussions once the ultimate decision was made for a design." (P16) "We were presented with four viable methods to proceed." (P11) "She made sure we knew the constraints we were dealing with and that we were focusing on the ones we should be." (P22)
Divergent: Encouraging exploratory thinking	"She also had us think about problems we might have that we had not thought of." (P22) "Ask[ed] us to think about what's our market." (P12) "He told us that the key to the project is to figure it out amongst ourselves because the best way to learn is by doing. He also offered help if for some reason we were way behind in the future." (P23)

included the types of advice instructors gave to student teams, and how this seemed to influence students' exploration of creative opportunities in their work. On Survey 2 and Survey 3, for each decision participants reported making about their design work, we asked them if they received advice from their instructor and what this advice was. Participants reported varying types of advice, which we categorized with respect to how it impacted student decisions. In some instances, the instructor directed students toward what (s)he considered the best way to solve the problem and explicitly told the participants how to make their decision; we call this direct advice. In other cases, the instructor encouraged students to focus on making decisions and following an established path without telling them explicitly what decision to make (Convergent advice). Other times, the instructor encouraged students to explore possible pathways and design (Divergent advice). Table 8 displays the types of advice given by instructors with examples.

What was most interesting in this analysis was that regardless of the type of advice given by instructors, students most frequently reported following that advice. Thus, if an instructor most often gives direct or convergent advice, students are less likely to engage in exploratory thinking, which is the type of thought associated with creativity [23].

5. Discussion

5.1 Key findings and implications

Participants had common definitions of creativity such as new, novel, unique, and thinking "outside of the box." Only one student included practicality as a component of the definition of creativity. In their original definitions, participants did not relate being creative to being artistic. However, when they listed synonyms to creativity on the third survey, they broadened the way they discussed creativity, by introducing aesthetics as a synonym. This shift was also evident in participants' descriptions of creative opportunities. At the beginning of their design work, participants saw many creative opportunities. Participants also reported a perception that creative opportunities existed in many of the phases of the design process, with most participants citing generating design alternatives as a key design phase to be creative. Initially, the opportunities participants identified focused more on ways to achieve functions and generating multiple solution options; then as the semester progressed, participants reported aesthetics and presentation and report construction as providing creative opportunities. In part, this is likely due to the progress participants made in their design work, but perceived risks (e.g., a bad grade, poor performance of the prototype) also factored into student perceptions.

Throughout the design project, student perceptions of opportunities for creativity and decision-making related to pursuing these opportunities were influenced by how their instructors encouraged creativity (in both word and action). Participants believed their instructors valued creativity but were unsure to what extent. Instructors' advice impacted participants' decision making; they explored creative options less often after receiving direct or convergent advice from their instructors, especially if the participants believed they had been given the "best" solution to their challenge. There were other instances where the instructor directed the students to explore solution ideas or consider multiple aspects of the challenge at hand; this type of advice prompted participants to engage in additional exploration. An important implication from this result is that instructors need to consider how to direct students in their design work. If instructors truly want students to be creative, they have to give advice that directs students to explore ideas.

Student pursuit of creative options was also influenced by project constraints, including time to complete the project, team challenges, and their own skills and knowledge. For example, participants reported being challenged by the time constraints of the semester-long project, expressing that the deadlines did not allow them to take the risks in finding a creative option and making a creative opportunity work. Time can stifle creativity [24], and while instructors cannot change the length of a semester, it is possible to re-evaluate project requirements to consider if there is space for students to explore options that are creative.

Additionally, participants reported team-related challenges, such as scheduling and communication issues. Participants were less likely to focus on the creative aspects of their projects when their team was having issues working together. There are a number of good resources instructors can use to learn how to support better teamwork [25, 26]; however, it is impossible to avoid teaming issues. Instructors can clearly articulate priorities, including goals for creative exploration, and advise them on how to achieve goals that align with these priorities. This can help all teams, even teams who are struggling to work together, to achieve creative goals.

Some participants reported that their lack of foundational content knowledge was a limiting factor in their choice to pursue a creative option. One of our participants strongly believed he could not be creative because he did not have enough foundational content knowledge. As we followed him throughout out the term, this participant consistently reported difficulty learning and applying new knowledge to the design project. As only one of our participants reported significant struggles due to content knowledge, it is unclear how often this challenge arises in the pursuit of creative opportunities. It is important for instructors to recognize the goals of design projects; it could be to help students build content knowledge. It could also be to allow students to pursue creative ideas; however, if this is a true goal, the instructor needs to include instruction related to helping students achieve this. In this participant's situation, it might have been beneficial for the instructor to discuss creativity and what students have the ability to do with the content knowledge they have.

A challenge to participants across all versions of the introductory design course was an unclear understanding of how creativity would be factored into their final grades. Early in the participants' design experience, they indicated that they did not know how they would be assessed. Participants stated that the current assessment of the project did not drive them to pursue creative opportunities. In general, participants wanted to be creative, they believed their instructors encouraged creativity, and they believed that the projects gave room for exploring creative options. However, some students chose not to pursue creative opportunities because they felt it could poorly impact their grades. The lack of a metric by which students would be assessed on the use of creativity in their design process seemed to influence student decisions. They perceived their grade to be primarily dependent on functionality of the final prototype and if a risky, but possibly creative solution could jeopardize the prototype functionality, they chose not to pursue the option. If the project goal and rubric do not focus on creativity, students will not focus on creativity.

Instructors could indicate the importance of creativity by including explicit requirements in their grading rubrics [27]. Those explicit requirements can include specifying a certain number of solution ideas that must generated, creating a grading scheme which includes novelty as a component and specifying how this will be evaluated, and including reflection as part of the design process so that instructors can see what options students are considering and help them figure out how when and how to pursue creative ones. Regardless of the criteria, there should be some discussion between the instructor and participants on how the instructor will assess their process and product with respect to creativity. Additionally, since participants indicated a fear of failure in exploring creative options, instructors should discuss the consequences (positive or negative) of taking a risk in order to develop a creative solution that may not work. Students were also unclear about how much value instructors placed on creativity. As instructors, we need to clearly understand how we value creativity and then ensure that our grading, learning environment and design tasks reflect our creative values. If the instructor, project objective and the grading scheme don't focus on creativity, students will not either.

5.2 Limitations and future work

In our recruiting process, participants self-selected to join the study, thus our participants do not represent a random sample. This group of participants and their respective experiences may not necessarily represent the experiences of the entire engineering first-year cohort. However, we were able to get in-depth information about these students' experiences, thus providing an important foundation for future work on student identification and pursuit of creative opportunities. Additionally, the focus of this research was not to assess creativity. While students reported the perceived level of creativity in their final design, we did not evaluate the accuracy of this perception, and thus did not analyze for correlations between participants' perceptions of creative and the actual novelty and quality of the design outcome. While these limitations exist, our results provided important insights about the student's perceptions of creative opportunities in engineering design projects. Future work includes a better understanding of student risk taking in design courses, the extent different factors influence design decisions that could promote creativity, and the role of the instructor and course structure on facilitating creative exploration by students.

6. Conclusions

Our study objective was to answer three questions: (1) How do first-year engineering participants view creativity and its role in engineering? (2) What opportunities do students see for creativity in their engineering design projects? (3) How do various factors, including the course structure and the instructor, influence student choices to pursue creative opportunities? We explored these questions through student responses to four surveys taken during the student's first semester in the engineering program while they were completing a design task. Our discoveries made clear the importance of the instructor and course structure, including grading policies, in facilitating creative exploration. Our results also indicated that students explored creative opportunities when given direction to pursue to explore. Thus, explicit discussion and structures that allow students to take risks without hurting their grades, as well as placing priority on creativity through grading policies, will support students in deciding to pursue creative options.

In an engineering design course where creativity is a learning objective, students must know that creativity is encouraged and supported. This encouragement and support should align with course assessments, and instruction, discussion, and feedback should help students figure out when and how to explore creative options. This not only prepares students for success in their education, but also prepares them for success in the engineering profession. Creativity is essential to designing solutions to solve complex engineering challenges. As engineering educators, we must find ways within our courses to facilitate this development and growth, so that future engineers can contribute to the betterment of our world.

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