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Engineering Creativity: Toward an Understanding of the Relationship between Perceptions of Creativity in Engineering Design and Creative Performance*

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Few studies have focused on perceptions of engineering students with respect to the importance of creativity in engineering design. Previous researchers have tended to focus on perceptions concerning the degree to which creative thinking is emphasized in the classroom, rather than on whether students value creativity as an important part of the engineering design process. Moreover, the relationship between students' perceptions of the importance of creative thinking in engineering design and their creative performance has not been investigated. The purpose of this study was to identify engineering students' perceptions of creativity during the engineering design process and compare perceptions of students who scored at the extreme ends on a creativity test called the Creative Engineering Design Assessment (CEDA). Of the 42 students that took the CEDA, eight students scored at the extreme ends and were subsequently interviewed. The perceptions that were investigated reflected the two primary influences on a students' motivation to be creative as posited by the expectancy-value theory, namely engineering students' perceptions of the importance of creativity during engineering design and their perceptions of their own ability to be creative in engineering design. The findings of this study support predictions made by applying the expectancy-value theory, which holds that students who value creativity in engineering design and confidently believe they have the ability to be creative are more likely to be creative in various engineering design scenarios.

Keywords: creativity; engineering design; perceptions; expectancy-value theory; mechanical engineering

1. Introduction

Many researchers have focused on developing the most effective pedagogy for enhancing engineering students' creative skills by examining the effectiveness of various learning goals, instructional methods, and assessment practices [1, 2]. However, the effectiveness of these methods has depended on the existence of an already motivated engineering student who is simply waiting for an opportunity to be creative. A prerequisite is an understanding of engineering students' perceptions of creativity and the influence of such perceptions on their motivation to think creatively during engineering design activities. The specific problem addressed in this study was the need to understand engineering students' perceptions of creativity in engineering design and the qualitative relationship between these perceptions and their creative performance.

This study provides insight into the perceptions held by a sample of engineering students' regarding creativity and the value they may place upon creativity within an engineering design context. An understanding of the value students place on creative thinking during the engineering design process is important considering the influence perceptions can have on a student's motivation to think creatively [3, 4]. This study was a first step toward gaining an understanding of the role creativity perceptions plays in determining whether an individual is likely to engage in creative thinking during the engineering design process. Thus, the results of this study should interest engineering educators who may be looking for ways to encourage creative thinking among their students.

2. Background and theoretical framework

Despite numerous calls for more creative engineering curricula, few standard engineering courses require or even encourage creativity. This absence of opportunities to engage in creative thinking can leave students with the perception that creativity is not valued by engineering faculty or perhaps is not important in engineering as a whole [6, 7]. Moreover, despite calls by the NAE that creativity is an important goal of an engineering education, several studies have indicated that creativity is rarely encouraged by faculty, and opportunities to engage in creative thinking in the classroom are often limited [5, 9]. This situation can alter the perceptions of creativity among engineering students.

Many perceptions abound regarding creativity in the classroom, and many creativity researchers believe this stems from a lack of knowledge regard-

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ing how to define, identify, and foster creativity [9]. Some have said such questions are the result of a lack of a precise definition of creativity, leading to poor conceptions regarding its utility to students. For example, some misconceptions about creativity include claims that creativity implies sloppiness, ambiguity, and risk taking, as well as more severe attributes such as deviance and nonconformity [9–11]. Although these may be the traits of some creative individuals, they do not define what it means to be creative.

Within a classroom, there may be a dichotomy between valuing creativity and holding negative perceptions toward creative behaviors and attributes. For example, a number of researchers have reported that teachers hold negative attitudes and little tolerance for behaviors and attributes associated with creativity, despite claiming they generally value it [10, 12–14]. Therefore, some teachers may follow what Alencar referred to as "inhibiting practices" toward the expression of students' creativity and the realization of their creative potential. According to Alencar, the term *inhibiting practices* incorporates the following: (a) emphasis on the correct response, reinforcing the fear of failure; (b) exaggerated emphasis on reproduction of knowledge; (c) low expectations about the students' creative potential; (d) emphasis on the students' obedience and passivity; and (e) little emphasis on fantasy and imagination as important aspects to be taken into account [15, p. 5].

Researchers have shown that the classroom is an important variable for manipulating students' perceptions of creativity as well as for enhancing or reducing their creative performance [16, 17]. Teachers can communicate information concerning the goals of a course, assignment, or project using authority, recognition, and evaluation in various learning situations, thereby influencing learners' beliefs and consequently their motivation to achieve a particular goal or think in a particular manner [18].

Numerous reports have emphasized the need to help engineering students enhance their ability to think creatively during the engineering design process [19–21] Given the apparent need for creative-thinking skills, the National Academy of Engineering (NAE) has recognized creative thinking as a critical attribute deserving of increased attention within undergraduate education for practicing engineers of the future [21]. Therefore, an important outcome for any accredited engineering program would seem to be producing graduates who are capable of creative problem-solving. Given the value placed on creativity in engineering education, and the need for engineers who are capable of thinking creatively during the engineering design process, the question then becomes, do engineering students value creativity in engineering design? As David Cropley suggested, "We can ask our students to embed creativity and innovation in their designs, we can even teach them what this means, but if students do not see the value of creativity and innovation to engineering, then our efforts may be in vain" [1, p. 2].

Simply put, if engineering students do not value creativity in engineering design, their motivation to be creative may be minimal, and hence they may be less likely to engage in creative thinking during engineering design. Expectancy-value theory provides the framework for the notion that perceptions can influence one's motivation to engage in behaviors one considers valuable [18, 22]. Expectancy-value theory, as a theory of motivation, has been useful in helping creativity researcher's account for the various motivational reactions to environmental and personal factors that have been shown to influence creativity [22, 23]. In particular, expectancy-value theorists posit that an individual's choice, persistence, and performance can be explained by his or her beliefs about how well he or she will do on the activity and the extent to which he or she values the activity; these beliefs are often classified as *ability beliefs* and *value beliefs* [22]. Thus, an individual who believes an activity such as attempting to produce creative outcomes during the engineering design process is important (value belief) and who believe they can perform this activity well (ability belief) would be more inclined to engage in creative thinking during the design process than they would be if they thought the activity was unimportant or they would not do well at it.

3. Research design

3.1 Research purpose

The purpose of this study was to identify engineering students' perceptions of creativity with respect to the engineering design process and compare perceptions of students who scored at the extreme ends on a creativity test called the Creative Engineering Design Assessment (CEDA). The perceptions that were investigated reflected the two primary influences on a students' motivation to be creative as posited by the expectancy-value theory, namely engineering students' perceptions of the importance of creativity during engineering design and their perceptions of their own ability to be creative in engineering design. Such comparisons fostered a better understanding of how perceptions of creativity influenced students' creative performance outcomes.

3.2 Research setting and participants

This research study was conducted at a large, public university in the Midwest. Enrollment was 28,771 in the fall 2014 semester. The participants of this study included senior mechanical engineering students within the Department of Mechanical Engineering. The department of mechanical engineering was chosen because it is the largest engineering department at the university and therefore provided a larger pool of students with which to choose from.

Senior students were purposefully chosen for this study because their perceptions were likely to be more descriptive given the reasonable assumption that senior students would have been exposed to at least a modicum of design experiences either through course requirements or co-op experiences. Moreover, the purpose behind choosing students from a single department was to maintain as much uniformity across the students as possible in terms of their courses and professors in an effort to provide as much consistency among students and their responses as possible. Students were sampled from a senior level laboratory course required for all mechanical engineering majors. Of the 100 students who attended the laboratory session, 42 students agreed to participate in the study.

3.3 Data collection methods

Two methods were used to collect data for this study: The Creative Engineering Design Assessment (CEDA) and a student interview protocol. The CEDA represents a domain-specific creativity assessment that is specific to the field of engineering [24]. In particular, this creativity test is a recently validated inventory that provides a quantitative assessment of engineering students' divergent-thinking ability [25, 26]. Note that for the purposes of this study, divergent thinking, as measured by the CEDA, was operationally defined as a measure of an individual's creativity.

The CEDA incorporates three engineering design scenarios to be completed by each student, with a time limit of 10 minutes per scenario. The judges used a scoring sheet to assess each student's test with respect to the four factors that comprise divergent thinking: fluency, flexibility, originality, and usefulness. The CEDA requires participants to sketch designs incorporating one or several three-dimensional objects, list potential users (people) of the design, and perform problem finding (generate alternative uses for their design) and problem solving in response to specific functional goals. These goals are required for each of three engineering design scenarios, and each scenario has a time limit of 10 minutes.

Given the subjective nature of scoring divergent thinking tests, the consensual assessment technique was employed whereby judges with expertise in the domain in question are selected to evaluate the level of creativity involved in the product or process under consideration [27, 28]. The consensual assessment technique is a well-validated method for assessing creativity and is often referred to as the gold standard of creativity assessment techniques. For the purposes of this study, three judges were selected to score the flexibility, originality and usefulness sections of the CEDA, which were the most subjective portions of the test. The judges were selected based upon their experience and expertise in evaluating engineering designs in industrial settings.

The student interview protocol provided the means for capturing students' perceptions of creativity and extracting relevant themes, which then facilitated a comparison of perceptions between students of high and low creativity, as measured by the CEDA. The interviews were semi-structured, lasted approximately an hour, and were audio-recorded.

3.4 Data analysis

One of the primary goals of this study was to understand how perceptions of creativity in engineering design compare between senior mechanical engineering students with high and low creativity scores, as measured by the Creative Engineering Design Assessment. In order to find which students would be placed into the high- and low-creativity groups, mean score and standard deviations were calculated based on the total scores obtained for the students. Data analysis of the student interview data occurred in two phases: within-group analysis and across-group analysis. In other words, students' perceptions were coded and emergent themes synthesized within each group of high- and low-creativity students first, and then themes emerging from each group were compared across the high-creativity and low-creativity groups.

4. Findings

The descriptive statistics are presented in Table 1. The mean, standard deviation, minimum, and maximum scores are presented for each of the four factors and for the students' overall CEDA score.

Table 1. Descriptive Statistics for CEDA Factors and Overall Score (n = 42)

Factor	Minimum	Maximum	Mean	SD
Fluency	7	60	32.59	11.83
Flexibility	5	49	20.86	11.13
Originality	6	29	12.81	5.96
Usefulness	4	24	10.60	4.87
Total Score	42	207	100.26	39.37

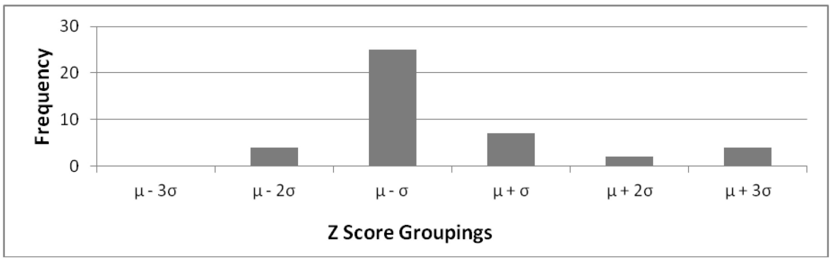

Fig. 1. Z score distribution of CEDA scores.

The mean overall score for male students (n = 34) and female students (n = 8) were 102.48 and 108.61, respectively.

As indicated previously, students with the largest standard deviations (i.e., students whose scores were furthest away from the mean score) were categorized as the most creative and least creative, respectively. To better visualize the categorization, student's total scores were converted to *z* scores. This conversion facilitated grouping of students into highest and lowest creativity categories. Those students whose scores fell into the range that varied the most from the mean score were selected for interviews. The frequency of scores with respect to *z*-score groupings are shown in Fig. 1.

From the distribution of students overall scores on the CEDA, four students scored greater than or equal to 3 standard deviations above the mean score and four students scored less than or equal to 2 standard deviations below the mean score. These eight students represented the extreme scores on the CEDA and were interviewed to obtain their perceptions of creativity in engineering design. The findings of the interviews were compared between students of high-and-low creativity groups, respectively. The students selected for interviews and their respective CEDA scores are shown in Table 2. Note that all names shown in Table 2 are pseudonyms assigned to each student, three are female and five are male.

4.1 Comparison of perceptions of creativity among high- and low-creativity groups

The following section presents a synthesis and comparison of the data collected during the student interviews. The responses were categorized in terms of the perceptions of creativity in engineering design that were of interest in this study, namely engineering students' perceptions of the importance of creativity during engineering design and their perceptions of their own ability to be creative in engineering design

Table 2. CEDA Scores of Students Representing Extreme Scores

High-Creativity Group (M = 194.75; SD = 14.61)		**Low-Scoring Group (M = 47.00; SD = 3.46)**	
Student	**Score**	**Student**	**Score**
Harold	207	Leslie	50
Harry	207	Lance	48
Hannah	187	Liam	48
Herman	178	Leann	42

4.1.1 Perceptions of the importance of creativity in engineering design

Table 3 shows a synthesis of the themes identified for both the high- and low-scoring groups with respect to students' perceptions regarding the importance of creativity during the engineering design process.

Clear differences exist between the high- and low-scoring groups with respect to their perceptions of the importance of creativity in engineering design. The high-scoring group was much more liberal in their perceptions about the importance of creativity in engineering design, believing that it is always important to think creatively when designing, as well as during general problem solving. They viewed creativity as a way of thinking and not just the end result of an engineering design. The low-scoring group, in contrast, was considerably more conservative in their perceptions about the importance of creativity in engineering design, believing that one should be creative only when necessary and that an engineer should not attempt to reinvent the wheel by making radical design changes.

All four students in the high-scoring group believed it is always important to be creative during the engineering design process. Each student

Table 3. Themes for Students' Perceptions of the Importance of Creativity in Engineering Design

High-Scoring Group	**Low-Scoring Group**
• Always important during engineering design	• Important during design, but not always necessary
• Opens up design to more possibilities	• Engineers should not try to reinvent the wheel
• Allows for improvements and betters the engineering profession and society as a whole	• Creativity is valuable only when coupled with logic and reason during design process

in the high-scoring group indicated a perception that creativity is what allows an engineer to think beyond current practice, allowing for technological advancement. Three of the four interviewed in this group spoke of personal advancement as well, mentioning that the ability to think and design creatively allows an engineer to advance professionally more quickly by being able to pitch ideas no one else had thought of. Harold emphasized the importance of creative thinking when designing. He stated:

> Without creativity, the design will end up becoming the same exact design as something else. It won't have any originality, and then of course probably no marketability. I guess I just think being creative opens up the design to more possibilities, things like better efficiency, lower costs, sleeker looking designs, and other things. I think you can only improve something by looking at it a different way than before, and that's what creativity gives you when coming up with an engineering design.

Creative thinking, however, is not just about coming up with engineering designs that are new and different. Several students described how creative people excel during problem solving activities, emphasizing that creative people can come up with solutions to problems quickly. John summed this up when he stated,

> Creative people are idea generators. A creative person will place more ideas on the table; then those ideas might spark other ideas in other people's minds, so creative people cause others to excel. I've seen this happen a lot during my co-op.

Hannah described how even though the decision to come up with a creative new design ultimately depends on the type of firm at which one is employed and what they are designing, creativity can be very useful during problem solving because, in her experience, this is primarily what engineers are called upon to do more than anything else. She described the benefit of being able to think creatively all the time:

> I work in a manufacturing engineering co-op. I don't know how many times engineers are called to put out fires; it seems that that's the only thing engineering does where I work is put out fires that occur in a process, fix problems, and come up with solutions, sometimes immediately, on the spot. Creativity is important in manufacturing settings because without it, we would just continue doing the same things over and over and we would essentially be putting out the same fires every day. I think creativity enables us to find new solutions to reoccurring problems.

Ultimately, all four students in the high-scoring group believed it is always important to be creative, whether this means during engineering design situations or during routine problem solving on the shop floor. They described how a creative mind always gives an engineer an edge up in business. It is "the X factor," as Harold described it "which allows us to make improvements and better the engineering profession and society as a whole". Harold described how engineers are frequently called upon to solve problems where no one else can, often in situations that are very complex.

Although all four students in the low-scoring group also thought creativity was important during engineering design work, however, they each stated they believed it was not always important, and it was this point that each one of them emphasized during the interviews. For example, Liam reinforced the sometimes-negative perception of creativity by suggesting that a creative design can sometimes be too radical, too expensive, and end up costing the firm more money in the long run by increasing production and prototyping costs. Liam stated "creative engineers come up with some crazy ideas, and if they sell people on them and they don't work, I've seen companies go bankrupt because of crazy ideas that were originally thought to be creative, but they were just bad ideas that weren't practical". Lance supported this notion when he stated the old adage "an engineer should not try to reinvent the wheel". Lance had a rather interesting take on whether an engineer should always try to be creative during engineering design activities:

> Think about it, we're in a period in history where there are so many products, designs and methods out there. An engineer can just choose from something already created or thought of and change it or mold it for the task at hand. I don't think this is copying at all; I think it's just being resourceful and using the resources of the modern age. I guess it may not be creative but it's definitely smart. It's smart because it's effective in cutting costs and time. Okay, don't get me wrong, I think being creative is important for the profession, yeah, it's just not always necessary.

Liam brought up the idea of simplicity again, suggesting that the best design is often the simplest one or the one that requires no creativity whatsoever. Liam emphasized the importance of knowing when to be creative and when to do things the way they have always been done in the past. He also emphasized that she had known many creative people who were full of ideas but rarely had the knowledge to implement them. He believed engineering design should rely on a more logical and systematic process rather than on a creative one He stated:

> I think it's important to know when creativity or any kind of change isn't needed though. For instance, when a machine needs a specifically designed part in order to work, don't get all creative and fancy, just design the part to the right specs and get the job done and move on. I feel like it's more important to have a solid idea that's realistic, you know. I feel like creative people have a lot of ideas but no way of getting them done.

> This just wastes time and money. I've seen it so many times at my co-op. Engineering is very logical, step by step, you know, there's a process. Creativity I think sometimes disrupts that process more than makes it better.

When asked about whether creativity is important to the engineering profession, each student felt that creativity is beneficial if it is explicitly needed. Each student described the need for creativity if new technologies are needed or if a company wants to go in a new direction. More ideas on the table are always better than just one, but the primary theme emerging from this group was that creativity is great if and only if it is coupled with logic and reason.

4.1.2 Self-perception of creative abilities

Table 4 shows a synthesis of the themes identified for both the high- and low-scoring groups with respect to students' self-perceptions of their creative abilities.

It was clear that in terms of creative self-perceptions, the high-scoring group felt more confident in their abilities related to creative engineering design. The high-scoring group clearly envisioned themselves as naturally creative and felt confident in their creative abilities, especially in terms of solving mechanical problems such as the ones most often encountered in engineering practice. The low-scoring group clearly felt less confident in this area—two individuals stated they lacked the ability to think creatively during engineering design altogether.

All four students in the high-scoring group classified themselves as creative individuals. Further, students in this group felt they were creative in other areas as well; it was simply a matter of where their interests lay. For example, Hannah stated that she loved both art and engineering, and both elements allowed her to think creatively:

> I would have to say I have always been creative when it comes to art, and I have a love of science as well. You could definitely say I went into engineering to apply my creativity to a scientific field. I constantly come up with new designs, procedures and solutions to problems at my co-op and work, and I love it, I love the challenge.

This idea of creativity and interest came up several times with each student in the high-scoring group. For example, Harold stated:

> I have kind always been creative ever since I was a little kid. My parents always encouraged me to be creative. Man, I tore things apart and put them together again so many times when I was younger, I redesigned so many things to make them better. As a kid, I was the stereotypical future engineering student that constantly was taking things apart and putting them back together. It's funny, my Xbox seemed to be in pieces more often than it was together and my paintball gun was constantly apart on the kitchen table. I know these kinds of things helped develop my creativity. I'm creative primarily when it comes to mechanical type problems though; I guess that's why I went into mechanical engineering.

In terms of the group as a whole, all four students repeatedly stated they had always had confidence in themselves and that they loved thinking outside of the box and trying new things, even if they thought it might result in failure. For example, Herman stated "if I hadn't tinkered with stuff as a kid, I probably would have no imagination right now, I really think tinkering with toys and other stuff as a kid really helped my design skills".

The low-scoring group diverged with respect to their self-perceptions regarding their creative abilities. For example, Liam and Lance felt they were not naturally creative people and often found it difficult to think outside of the box when solving problems, in particular, mechanical engineering problems. Liam elaborated by stating:

> I'm doing a co-op right now, and I'm finding out I'm not really a creative person when it comes to mechanical type stuff. Don't get me wrong, I love engineering and solving problems, but I feel I'm more of a logical type problem solver, not really creative. I love music, and have a real passion for it; I can write my own songs and develop original music. I love engineering, but I guess I don't have a passion for it, I'm not sure, but my brain doesn't think like other really creative mechanical types.

In a similar manner, Lance, although he explicitly stated that he was not a naturally creative person, felt that he was able to overcome this through a systematic approach to problem solving. For example, Lance stated:

> No, I would not consider myself a naturally creative person. I have never been one who was able to come up with ingenious solutions, but I feel like I have developed my creativity to the point that I'm able to, kind of strategically and scientifically attack design problems, and then come up with good, sound, and practical solutions.

Both Leslie and Leann felt they were very creative. For Leslie, however, a lack of confidence and fear of criticism often prevented her natural creativity from coming through. She felt she always had creative ideas, but she feared criticism if she

Table 4. Themes for Students' Self-Perceptions of Their Creative Abilities

High-Scoring Group	Low-Scoring Group
• Confident in their creative abilities • Interest in understanding how things work • Enjoy thinking outside of the box	• Lacked confidence in creative abilities • Prefers a systematic and logical approach to problem solving and design

expressed them. She summarized, "It's a confidence thing, I guess. I hate it, because I have a lot of good ideas". She also stated jokingly that her ideal situation would be to be asked to come up with an idea immediately, with no time to think about potential criticism. For Leann, however, creativity was more of a time issue. She discussed how she felt she had the capability of being very creative but needs a lot of time to dwell on the problem before coming up with a creative solution, time that is not always available.

Thus, two members of the low-scoring group felt they lacked creative abilities but tended to make up for it with a systematic and logical approach to design and problem solving. The other two members felt they were quite capable of creative thinking in engineering design situations, but lacked either confidence or time to be creative and therefore felt they were often perceived as being less creative than they actually were.

5. Discussion

5.1 Key findings and implications from students' perceptions of the importance of creativity in engineering design

The findings for this category suggest that engineering students who are characterized as having high creative ability may tend to value creative thinking as an important part of engineering design and problem solving more so than their less creative counterparts. Furthermore, these findings reinforce predictions made by the expectancy-value theory which posits that an individual's choice, persistence, and performance can be partially explained by the value one places on a particular activity [22]. The high creativity group clearly valued creative thinking throughout the engineering design process more so than the low creativity group, and hence this theory suggests they were more motivated to be creative.

In terms of why the high creativity group valued creativity more so than the low creativity group, a possible explanation resides in the creative personality. Individuals who are categorized as creative tend to have personalities that are conducive to creative thinking such as openness to new experiences and ideas, thinking outside of the box, and always looking for ways to improve upon an existing product or process [10, 29]. These personality characteristics are in contrast with less creative individuals that typically favor feasibility, functionality and simplistic designs over risky, unproven ones [5, 9]. This does not imply that individuals who do not have personality characteristics commonly associated with creative individuals cannot develop the skills necessary to be creative, indeed creativity has been shown to be a skill that can be developed [1, 28]. It merely implies that students who do not possess creative personality characteristics tend to focus on convergent thinking rather than divergent thinking during the engineering design process, in other words, rather than coming up with multiple solutions to a given problem; they try to find the one best solution that solves the problem, which is often the simplest one.

Convergent thinking often involves a logical and systematic approach to engineering design, which explains why this was a clear theme that originated from the low creativity group. Unfortunately, logic and systematic approaches are often viewed as counterproductive to divergent thinking and the production of novelty. That is not to say convergent thinking is necessarily a bad thing; indeed, convergent thinking is useful during any type of analysis activity where one is focused on selecting the one best solution to the problem, and is therefore an important element of creative thinking. The problem is when convergent thinking is overemphasized at the expense of divergent thinking which is contraindicative for creative thinking in the engineering classroom [1, 32].

Unfortunately, unless specifically told to be creative, research suggests many engineers are skeptical of any innovative idea not tied to an extant solution and therefore tend to stay with safer, more traditional designs [1, 9]. While this type of thinking can certainly improve efficiency and the likelihood of developing a design that at least "works," it often limits an individual's willingness to consider new approaches and perspectives. This study suggests that while this may be true of certain engineers, highly creative engineers appear to be more open to new design ideas and a willingness to explore new solutions to old problems.

5.2 Key findings and implications from students' self-perceptions of their creative abilities

It is clear that in terms of creative self-perceptions, the high-creativity group felt more confident in their abilities when it came to creative engineering design. When asked about their perceptions concerning their own creative abilities, each student in the high-creativity group emphatically stated they believed they were creative and had always held this belief about themselves. The low-creativity group clearly had different perceptions when it came to assessing their own creative abilities. Two out of the four members of the low-creativity group felt they were not creative when it came to engineering design. The remaining two members felt they possessed the ability to think creatively but it was often a struggle to get it come through.

Thus, the placement of these students in their respective groups aligns well with predictions posited by the expectancy-value theory. The expectancy-value theory posits that a students' performance in a given situation is related to their expectations of doing well, which is related to the degree to which they are confident in their abilities in the given situation [22]. The high-creativity group expected to do well on a creativity task, given their self-perceptions as creative individuals, and hence they did perform well. Similarly, the low-creativity group perceived themselves as being not very creative, and hence, their performance on the test reinforced their self-perceptions.

It is important to note that, although the number of students interviewed for this study was small (n = 8) and thus prohibits any large-scale generalizations, this study mirrors the findings from other researchers who have suggested an individual's self-perception of his or her creative abilities could have an effect on his or her creative performance [33]. This effect likely occurs because an individual's perception concerning his or her ability to think creatively has a strong influence on motivation and ability to engage in creative thinking and to pursue creative tasks [34]. Bandura cited creative self-perceptions or a belief in one's ability to engage in creative endeavors, as a necessary condition for creative productivity and the discovery of "new knowledge" [34, p. 14].

Some limitations of this study should be noted. First, because of the purposeful nature of the selection criteria used to choose students for interviews and the resulting small sample size, the transferability of the findings to other settings may be limited. It is also important to note that the results obtained in this study were representative of the perceptions of a small sample of engineering students and faculty at a particular instant in time and thus may not reflect a stable and consistent truth, so the findings cannot be generalized to a larger population. These limitations do not lessen the importance or potential implications of this study, however. The design of this study still afforded the researcher an opportunity to identify important themes regarding the relationship between students' perceptions of creativity and their creative performance; they only limited the ability to generalize the findings beyond the sample of students investigated in this study. More research, particularly involving quantitative measures and larger populations, is needed to determine if the findings presented herein are significant.

6. Conclusions

This study utilized a framework based upon expectancy value theory to understand the relationship between students' perceptions of creativity in engineering design and their motivation to be creative within an engineering design context. High-and-low creativity groups were formed to more readily discern differences in terms of perceptions of creativity in engineering design between engineering students with high creative ability and low creative ability as measured by the Creative Engineering Design Assessment (CEDA). The findings of this study aligned with the predictions of the expectancy-value theory. In particular, in the context of the theory, it was found that those students who valued creativity in engineering design and confidently believed they had the ability to be creative were more likely to be creative in various design scenarios.

The relationship between creative performance and perceptions of the importance of creativity in the engineering design process found in this study, in addition to reinforcing outcomes predicted by the expectancy-value theory, has important implications for the engineering classroom given the malleability of an individual's perceptions. Therefore, engineering educators should encourage students to think creatively and provide opportunities for them to do so in the hope that students may begin to see value in this type of thinking and thus recognize the importance of creative thinking during engineering design and problem solving. However, faculty must provide an atmosphere that supports and encourages creative thinking if students are to see value in it. Such an atmosphere can relay to students that not only is creative thinking an important skill to develop, but that engineering educators also value it, and therefore the likelihood of students perceiving creativity as important during the engineering design process also increases.

With respect to the relationship between creative performance and self-perceptions of creative abilities found in this study, it is important to note that while it is common for some engineering students to hold the perception that they are not creative people, this belief does not mean that they cannot be taught to act creatively. Creativity is not an attribute or ability that one either has or does not have; rather, all individuals are capable of exhibiting it in different ways, at different levels, and in differing times and circumstances. Students' creative skills can be developed and fostered, just as practice in any specialized domain can lead to improvements in skills. For example, teachers can improve students' creative skills by aligning course content, instruction, assessments, and the environment towards creativity focused learning goals. In addition, encouragement to be creative on assignments, opportunities to be creative through open-ended projects that encourage teamwork, brainstorming opportunities, and recognition and evaluation of creativity in various learning situations can also have a marked effect on students' development of creative thinking skills.

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