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ABSTRACT

As studies have previously shown, creativity is crucial in the engineering design process. While many studies have examined creativity and personality, few studies have looked at the relationship between creativity and other types of individual differences, such as problem-solving styles. This thesis fills that gap by investigating the impact of individual differences, as measured by the Preferences for Creativity Scale (PCS) and Kirton’s Adaption-Innovation (KAI) cognitive style inventory, on the creativity of ideas generated and screened by engineering design students. Specifically, this thesis sought to answer two main research questions: (1) Can the Preferences for Creativity sub-scales be used to predict the creativity, quality, originality, or goodness of ideas generated and screened by engineering design students; and (2) Can cognitive style, as measured through KAI, be used to predict the creativity, quality, originality or goodness of ideas generated and screened by engineering design students? This was accomplished through a pilot study and a full experimental investigation.

The results of the pilot study with 19 engineering students in an introductory engineering design class showed that PCS could predict the creativity of ideas screened by engineering students, but it could not predict the creativity, quality, or originality of ideas generated by students. On the other hand, the results showed that KAI could be used to predict the creativity and quality of the ideas generated by engineering students, as well as the quality of ideas screened. These results informed the design of the full experimental study which looked at the impact of these factors on a larger scale (48 engineering students in the same first-year engineering course). The results of the experimental study, however, provided different evidence on the impact of these factors. Specifically, the results showed that while the PCS sub-scales could significantly predict the originality of ideas developed, it was not able to predict screening behaviors. Additionally, the results showed that KAI was not a significant predictor of ideas generated or screened by students.

The results from this thesis contribute to the field in two main ways. First, this thesis shows that there is a relationship between individual differences as measured through KAI and PCS and the creativity of the ideas screened and generated by individuals. Second, it provides a framework for selecting individuals who can generate and screen for ideas which are rated as creative throughout the engineering design process. Though many questions remain, this thesis builds a solid base for how to continue the research into individual differences, cognitive style, and the relationship these two metrics have with engineering design.
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RELEVANT PUBLICATIONS

CONFERENCE PAPERS


WORK IN PROGRESS

Heininger, K., Chen, H. E., Jablokow, K., & Miller, S. R. The impact of individual differences on creativity of engineering design students during idea generation and concept screening. To be submitted to the Journal of Mechanical Design May 2019.
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There’s a rule when you’re accepting an Oscar about the order in which you’re supposed to thank the ones that helped you get there: first, God; second, your family; third, your agent; and, if there’s time, fourth, your fans. I’m not sure if there’s any similar rule in the acknowledgements section of a thesis, but I do know three things: 1) there was no way I could have done this alone, 2) there’s no maximum length, and 3) there are absolutely going to be people who are not mentioned by name in this section that were pivotal in my success. With that, thank you to all of the below people and many more. I could never have accomplished this without my unbelievable support network.

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INTRODUCTION

According to a study of 1,500 global CEOs, creativity is the most crucial quality a leader can possess [1]. Creative leaders drive innovation because they are “comfortable with ambiguity and experimentation” when solving problems (p. 2) [1]. This comfort with ambiguity also applies to the creative engineering design process, a more structured version of ‘solving problems.’ Creative ideas, defined as ideas that are both novel and appropriate (correct, useful, valuable, meaningful) [2], must flow through the design generation and selection phases to result in the best product [3-5]. This is important because the “availability of creative ideas is a necessary but insufficient condition for innovation” (p. 48) [6]. In other words, creative ideas must be identified and screened during the design process in order to contribute the most value [7, 8]. However, little is known about how individual factors influence how individuals creatively solve problems throughout the engineering design process.

There has been, however, substantial work on the impact of personality attributes on creativity [9] and the novelty of ideas screened by a team [10]. In addition, this prior work has shown that there are other underlying factors implicating concept selection preferences, including a team’s tolerance for ambiguity [10], or situations where outcomes have an unknown probability of occurring [11]. Similarly, recent work [12] has also identified that an individual’s tolerance for risk and ambiguity can impact their creative idea generation and selection preferences. However, these studies were focused on risk taking and ambiguity aversion in the financial domain. While there are many engineering-specific scales that study risk aversion and risk-seeking attitudes, such as the Engineering-Domain-Specific Risk-Taking test, or tests that specifically examine diversionary thinking [13-15], these scales do not capture an individual’s preference towards creative idea selection. While these findings support the notion that there are underlying creative idea generation and selection preferences, they bring to question if there are better methods for
measuring these preferences in the engineering domain. If so, it is unknown whether these measures appropriately predict the outcomes of the idea generation and selection processes.

As a first step towards achieving an understanding of the prediction, Toh and Miller [12] developed and validated the Preferences for Creativity Scale (PCS) in order to identify the underlying factors that impact preferences for creativity in engineering design. The PCS scale breaks down preferences for creativity into four major dimensions including: (1) Team centrality, or the amount of influence a team member possesses; (2) Risk tolerance, or comfort and ambiguity with which an individual is comfortable; (3) Creative confidence/preference, or how an individual prioritizes creativity when moving ideas forward in the design process; and (4) motivation, which measures how motivated an individual is to do a design task. Importantly, the initial work on PCS suggests that Team Centrality may have the largest impact on creative preferences during the design process. Unlike prior methods, the PCS scale provides a means for measuring not only risk-taking preferences specific to the engineering design process, but also the roles of team centrality, creative confidence and preference, and motivation. While the scale has been validated with engineering design students, the role of these PCS factors in idea generation and selection has yet to be investigated.

In addition to the PCS scale, an individual’s problem-solving tendencies or preferences may also impact idea generation and selection. Here, it is important to distinguish carefully between the cognitive style and the cognitive level of the individual. Cognitive style is defined as the “characteristic cognitive preference for seeking and responding to change, including the solution of problems” (pg. 26) [16]. This exists in contrast to cognitive level, which is “an individual’s capacity for problem solving and creative behavior, as assessed through measure of both potential capacity… and manifest capacity” (pg. 26) [16]. A more fundamental understanding of individual traits, informed by deeper consideration of individual problem solving and cognitive styles, may better explain how an individual or team might generate and select one concept over another.

According to Kirton (author of Adaption-Innovation theory), a common misconception is that people who solve problems in a more structured way are not creative [17]. To address this error, he created the Kirton Adaption-Innovation inventory (KAI), which places individuals on a spectrum from highly adaptive (more structured thinkers who may have been traditionally seen as “uncreative”) to highly innovative (less structured thinkers who have traditionally been considered “creative”) [17, 18]. While an individual’s cognitive style does not change over time [19], individuals can learn “coping behaviors” – i.e., behaviors that enable them to act in non-preferred ways [17]. The KAI is important because it recognizes that all people are inherently creative.
problem solvers, regardless of where they fall on the Adaptation-Innovation spectrum. While Kirton [18] cites numerous studies across multiple disciplines that have investigated the impact of cognitive style on idea generation, far less research has been conducted to examine the impact of these cognitive style differences during the concept selection stage of the engineering design process.

The purpose of this thesis was to explore the impact of individual differences, as measured by the Preferences for Creativity Scale and Kirton’s Adaptation-Innovation cognitive style inventory, on the creativity of ideas generated and screened by engineering design students. The results of this study can inform future design studies through examination of how these individual preferences and cognitive styles influence creative problem solving and performance.

1.1 | OBJECTIVES OF THIS THESIS

The purpose of this thesis was to examine individual differences, as measured by the KAI and PCS metrics, and its effect on creativity during the engineering design process for undergraduate engineering students, as well as idea goodness of ideas generated. This was achieved through a pilot study, presented in Chapter 3, and a subsequent full experimental study, presented in Chapter 4. Through these two studies, the following questions were explored:

RQ1: Can the Preferences for Creativity sub-scales be used to predict the creativity, quality, originality, or goodness of ideas generated and screened by engineering design students? The purpose of this research question is to gain insight into the connection (if any) between individual differences, as measured by PCS, and creativity as measured by expert individuals and design team members. This knowledge will help inform selection of individuals for design teams, particularly when looking for an idea that has creativity, quality, or originality specifically.

RQ2: Can cognitive style, as measured through KAI, be used to predict the creativity, quality, originality or goodness of ideas generated and screened by engineering design students? Similar to the previous research question, the purpose of this research question is to gain
further insight into individual differences, as measured by KAI, and creativity in the engineering design process, as measured by expert raters as well as design team members. This knowledge will help inform the selection of individuals to solve design tasks, based on the creativity requirements of the design tasks.

1.2 | CONTRIBUTIONS OF THIS THESIS

This thesis examines the individual differences in cognitive style and the role they play in the engineering design process. While individual differences have been studied in relation to the engineering design process, the majority of these studies have used general personality tests, such as NEO FFI [20] or Myers Briggs Type Indicator [21], as individual difference measurements as opposed to metrics specifically relating to problem solving styles and creativity – i.e., specifically, the Preferences for Creativity Scale (PCS) and the Kirton Adaption-Innovation inventory (KAI).

The results of this thesis contribute to the field in two main ways. First, this thesis shows that there is a relationship between individual differences and the creativity of the ideas screened and generated by individuals. Second, it provides a framework for selecting individuals who can generate and screen for ideas which are rated as creative throughout the engineering design process. Though many questions remain, this thesis builds a solid base for how to continue the research into individual differences, cognitive style, and the relationship these two metrics have with engineering design.

1.3 | DOCUMENT OUTLINE

In order to address the research goals of this thesis, the methodologies, findings, and implications of this thesis are detailed throughout the next five chapters. Chapter 2 of this thesis reviews current literature on the Preferences for Creativity Scale (PCS), the Kirton Adaption-Innovation inventory (KAI), and outside factors that may affect students during the engineering
design process. Chapter 3 details the pilot study. Chapter 4 examines the full experimental study. In addition to answering the research questions from the pilot study, this chapter also examines idea goodness, and also compares the results to those obtained in the pilot study. Finally, Chapter 5 provides a summary of the findings of this thesis and highlights the contributions and implications of this work.
2

RELATED WORK AND HYPOTHESES

Section 2.1 defines creativity, as it will be referred to many times within the next four chapters. Sections 2.2 and 2.3 summarize the underlying constructs of the Preferences for Creativity Scale (PCS) and the Kirton Adaption-Innovation (KAI) cognitive style inventory in an effort to provide a foundation for the studies in this thesis. Section 2.4 examines other underlying factors such as environment that may affect students during introductory engineering design classes, as well as the effects these factors may have on creativity. Finally, Section 2.5 details the hypotheses of this thesis based on the literature reviewed in this chapter.

2.1 | DEFINING CREATIVITY

There are a wide variety of definitions of creativity, even within the engineering design space. For this thesis, the most common definition of creativity in engineering design will be utilized, as defined by Amabile [2]. According to Amabile and the Consensual Assessment Technique, creativity is the combination of quality, originality, and overall creativity [2]. According to this definition, quality is the usability and technical feasibility of a product [22], originality is the novelty of an idea while disregarding feasibility [23], and overall creativity considers both quality and originality of the idea. It is important to note that this definition only holds for design tasks that are not algorithmic, meaning that there is no set path or structure with which to create the final design [2]. This definition of creativity was utilized when rating ideas with the Consensual Assessment Technique.
The Preferences for Creativity Scale (PCS) was developed to measure factors that influence designers’ creative concept selection [24]. The original 116 item PCS scale was based on prior work in psychology, behavioral economics, and cognitive science around three major themes – (a) personal biases and cognitive style [25-27], (b) creative confidence and motivation [28-30], and (c) social effects and the environment [31-33]. Exploratory factor analysis was conducted and resulted in a 23-item scale with four major factors: (1) team centrality and influence, (2) risk tolerance, (3) creative confidence and reference, and (4) motivation [24]. Confirmatory factor analysis in this same work validated the four dimensions with engineering design students.

Team centrality and influence (TCI), or the amount of influence held by an individual team member [32], in the PCS scale includes items such as “I do not feel comfortable presenting my ideas to my team members” [24]. This factor was built on prior work that highlights the importance of an individual’s comfort in expressing opinions [33], their sensitivity to criticism [34], and their fear of failure [35] in a team environment. This factor accounted for the largest variance in the PCS scale. Importantly, team performance has been shown to have a significant positive relationship with team mental models [36]. Given the influence of cognitive and social processes on group creativity [37], an individual’s TCI score may influence their decisions when generating ideas (e.g. self-filtering) as well as selecting ideas (e.g. which ideas will result in the highest grade or group success). However, this effect has yet to be investigated.

The factor that accounted for the second highest variance in the PCS model was risk tolerance (RT), which assesses the influence of risk and ambiguity aversion on creativity throughout the design process. This factor is important because prior work has shown that individuals who have success in taking risks are more likely to take more risks, and vice versa [38, 39]. The underlying constructs of this factor included the importance of making decisions under uncertainty [26] or taking risks to push creative boundaries [40]. This factor includes items such as “I do not like dealing with ambiguous or unknown elements in the design process” [24] and is important in the current discussion, because prior work has shown that some individuals tend to select more feasible ideas in place of more original solutions [28] due to the risk associated with endorsing and investing in novel ideas [28, 41]. Thus, this factor may play an important role in the concept selection process.
The third factor in the PCS model is creative confidence and preference (CC), which focuses on an individual’s prioritization of creative ideas and confidence in moving them forward in the engineering design process. This factor was supported by prior work that showed that an individual’s focus and preference for creativity, as well as their belief in their own creative abilities [28, 29], were essential for creativity in the design process. This factor includes items such as “I do not believe I am a creative individual” [24]. As David and Tom Kelley from IDEO stated, “Creative confidence is about believing in your ability to create change. [Like a muscle], it can be strengthened and nurtured through effort and experience” (p.1-2) [42]. Thus, an individual’s level of creative confidence and preference may impact whether an individual is confident in their own ideas, as well as their confidence level when selecting creative ideas.

Finally, motivation (M) accounted for the least variance of the PCS scale and focused on an individual’s motivation for the task at hand. This factor include items such as “It is hard for me to stay focused on the task at hand during design projects” [24]. This factor is significant, because motivation has been found to significantly impact the quality of team projects [43]. In particular, the evaluation structure of courses and exams may impact a student’s motivation in the course [44]. This suggests that a student may prioritize grades over the quality and creativity of their work when generating and screening concepts.

While prior work has shown that the ability to generate creative ideas does not necessarily correlate with selecting creative concepts [45], we do not know which PCS factors can be used to predict creative idea generation and selection and if, or how, these PCS factors contribute to creative idea generation. In addition, we do not know if the PCS factors impact idea generation and screening differently. This study seeks to provide a first step at filling this research void.

2.3  | KIRTON’S ADAPTATION-INNOVATION INVENTORY (KAI)

In addition to an individual’s preference for creative ideas, it is also important to understand if and how one’s cognitive style impacts their idea generation and selection practices, and if it does so more (or less) than the PCS factors. Cognitive style is defined as one’s stable, characteristic cognitive preference for seeking and responding to change, including the solution of problems [46]. It is independent from cognitive level, which is defined as an individual’s capacity for problem
solving and creative behavior. Cognitive style can be rigorously measured using Kirton’s Adaption-Innovation inventory (KAI) [17, 18] which places an individual’s cognitive style along the continuous spectrum between highly adaptive and highly innovative, with individuals who are more adaptive preferring more structure (with more of it consensually agreed), and individuals who are more innovative preferring less structure (with less concern about consensus) [17]. Kirton created this scale based on the fundamental psychological principle that wanting “to do things better” (adaption) and wanting “to do things differently” (innovation) are equally creative (p. 622) [17], although different amounts of adaption and innovation will be more suitable or desirable depending on the situation.

Through multiple validation studies, Kirton also identified three inter-related sub-scores that correspond to three sub-factors of cognitive style: Sufficiency of Originality (SO), Efficiency (E), and Rule/Group (R/G) Conformity [17]. Sufficiency of Originality (SO) is most readily recognized in idea generation, where adaptors (strictly speaking, more adaptive individuals) tend to generate ideas that iteratively improve upon a given solution, while innovators (strictly speaking, more innovative individuals) tend to generate ideas that are radically different and have more uncertainty. Efficiency (E) refers to how efficient an individual’s problem-solving method is relative to the current paradigm. Adaptors tend to work closely with the current structure to refine and produce more immediately efficient results, while innovators take more paradigm-shifting approaches that may not have short term efficiency, but that may (or may not) be efficient later on. Finally, Rule/Group (R/G) conformity refers to an individual’s preference for interpersonal and personal structure during problem solving. Adaptors prefer to leverage or use rules to develop ideas and tend to abide by group structures for better team cohesion, while innovators tend to “stir the pot” and are more likely to bend or break rules to achieve more radical changes.

During idea generation, innovators are less likely to filter their ideas, more likely to stretch the limits of a problem statement, and place less emphasis on group cohesion, while adaptors will make a greater effort to stay within the constraints of a problem, filter ideas to fit the problem as presented, and work to ensure the group is a cohesive unit [16]. It is important to note that while KAI states that everyone is creative and it is the style of creativity that differs, metrics measuring creativity rarely take this distinction into account. Typically these metrics, such as the Consensual Assessment Technique (CAT), used in this thesis, rank an idea as either creative or not creative, which Kirton would argue is an incorrect way to rank them [2, 17].

While multiple studies have examined cognitive style in idea generation, few studies have related KAI to concept screening. Thus, identifying the effects of both cognitive style and
preferences for creativity will allow us to better understand what impacts one’s behaviors and preferences in idea generation and screening. These results may inform how we train engineering design students to solve problems in individual and team contexts.

2.4 | IMPACTS OF OUTSIDE FACTORS ON INTRODUCTORY ENGINEERING DESIGN CLASSES

Introductory engineering design classes have commonly been used as a proxy for engineers in the workplace, as the behavior exhibited in engineering classes is very similar to that of professional engineers [47-49]. This population is also of interest, as soft and hard skills learned in the engineering design classroom can be transferred to the real world [50, 51].

For these introductory engineering design students, in addition to individual differences having an impact on the creativity of ideas generated and screened, there are many environmental factors which can have an impact on creativity in the engineering design process. One factor is the design prompt itself. Studies have shown that creativity cannot come from nothing, and that there need to be constraints in place, making the selection of the design task critical [52-54]. Additionally, it has been shown that certain design task prompts are going to allow for the generation and selection of more creative ideas, and it is possible that the second prompt chosen was too vague [54]. For these reasons, careful selection of the design prompt is crucial. Even if all other factors were to remain the same but the design prompt changes, it is possible that the results of the study may change entirely.

Another potential factor in creativity in idea generation in engineering design classes is the instructor teaching the class. Even when given a standard syllabus, classes can vary greatly depending on the experience of the professor, material presentation, classroom activities, or even topic enthusiasm [55-57]. Additionally, previous studies have shown that student success can change over time, especially as a teacher’s self-efficacy changes, along with other factors [58]. For this reason, the class taught by the same professor several semesters apart could have changed drastically, even if the general lesson plan and classroom activities stayed the same.

Another factor which could cause differences is the semester in which an engineering design task is assigned, specifically comparing a summer bridge program to a typical fall or spring
semester. Many studies have looked at the difference between at-risk students who enter college through a summer bridge program and the positive effects this can have on their overall college career [59, 60], especially in STEM fields [61]. However, a 2015 study also found that students may be discouraged in the short-term to pursue their goals after a summer bridge program, depending on how the results of their work are presented to them during the program [62]. Therefore, it is important to consider how feedback is presented to students during the course of a summer bridge program, as well as in fall and spring semesters. Studies have also shows that there is a difference between the feedback given by professors versus feedback given by peers [63].

While there was a positive relationship found between peer reviewers and professors, there were also important differences, such as the difference in overall interpretation of criteria due to differences in breadth of experience of peers versus professors [63]. For this reason, assessments done by peers can offer different, valuable insight when combined with the assessments of professors or other experts in the field.

To bridge the gap between in-the-moment assessment of creativity and after-the-fact assessment of creativity, therefore allowing peer feedback to be measured during the engineering design process, idea goodness was developed [64]. Idea goodness, expressed as a percentage, describes the number of team members, excluding the individual who generated the idea, who screened an idea to be moved on in the engineering design process. This metric can be used as a proxy for quality of ideas generated as viewed by peers [64]. While no previous studies have compared idea goodness to KAI and PCS scores, it is expected that those with a more adaptive KAI score are more likely to have ‘good’ ideas compared to their peers who are more innovative, because they are more likely to filter their ideas than their peers that fall on the innovative side of the scale [17]. For example, if students were told to screen an idea that had any merit, an innovative student may have an idea which was quality, but harder to understand without explanation from the student. Conversely, an adaptive student is more likely to have an idea which can be more easily understood, as it is more likely to be derivative or another idea, and therefore more likely to be screened [17]. Additionally, it is expected that PCS does not predict idea goodness of ideas generated, because the PCS metric has not predicted quality of ideas generated in previous work [65].
HYPOTHESES BASED ON RELATED WORK

Based on the related literature in this chapter, there are several hypotheses that can be drawn for the research questions from Chapter 1. These questions and their hypotheses are detailed in this section.

RQ1: Can the Preferences for Creativity sub-scales be used to predict the creativity, quality, originality, or goodness of ideas generated and screened by engineering design students? It is hypothesized that PCS, especially creative confidence, would influence the originality of ideas generated, based on previous work [65]. This is believed to be true because individuals who focus on creativity and therefore have a higher creative confidence are influenced by this intrinsic need to be more creative, therefore producing more creative ideas [65]. However, it is hypothesized that PCS would not influence the overall creativity, quality, or goodness of ideas generated [24, 65]. Additionally, it is hypothesized that engineering design students with higher team centrality and influence would screen for higher quality ideas because the students want to give their team the best chance at being successful and therefore will not risk team success on an idea of poor quality [36]. Finally, it is hypothesized that engineering design students with higher risk tolerance would screen for more creative and original ideas [40, 66] because those who have high risk tolerance tend to be more concerned with the ‘newness’ of an idea, which can be described by both creativity and originality.

RQ2: Can cognitive style, as measured through KAI, be used to predict the creativity, quality, originality or goodness of ideas generated and screened by engineering design students? It is hypothesized that engineering design students who are more innovative would generate solutions that have higher creativity and originality scores, because of the way creativity is defined by the Consensual Assessment Technique [2], while students who are more adaptive would generate higher quality ideas because they are more likely to only write down their ideas they believe to be of high quality [16]. Additionally, it is hypothesized that students who are more adaptive would screen for higher quality ideas, which is a trait of more adaptive
individuals, while students who are more innovative would screen for more original ideas [16]. Finally, it is hypothesized that KAI would be a significant predictor of idea goodness because of how innovators and adaptors are classified on the scale [17]. Specifically, adaptors are more likely to have good ideas because they are more likely to filter their ideas, which would make them more understandable to their team members without requiring additional explanation [16]. Similarly, it is hypothesized that innovators would be less likely to have idea goodness, as they are less likely to filter their ideas, and are more likely to push the boundaries of the problem statement [16].
PILOT STUDY

The previous chapter highlighted the different ways in which individual differences can be understood quantitatively, such as the PCS and KAI scales, which were created to relate specifically to an individual’s creativity [17, 24]. The purpose of this chapter is to introduce a research study which examines the relationship between creativity and the individual differences characterized by the PCS and KAI scales. This was accomplished through the collection of data from idea generation and concept selection portions of an engineering design project. Data was analyzed through statistics that are well-accepted within the field. The results of this study will be used to inform future studies on potential trends and procedure, as well as what can be accomplished in the field of creativity in engineering design by categorizing participants by their individual differences and cognitive styles.
3.1 | METHODOLOGY

As a first step towards answering the research questions of this thesis, a pilot study was conducted that examined two design sessions of an 8-week design project from a first-year introduction to engineering design course (EDSGN100) at Penn State with 30 undergraduate engineering students. This section summarizes the methodology of this study.

3.1.1 | PROCEDURE

The design study presented here was a part of a graded 8-week design course project (see Figure 1 for an overview of the study). Specifically, at the start of the semester, the 30 students were assigned to six 3- and 4-member teams based on prior experience in engineering design (e.g. CAD, sketching, and prototyping skills). Each team was then tasked with designing a low-cost, energy efficient greenhouse seedling rack. After receiving the design problem description, the students performed preliminary research on available solutions to the problem, including market research and patent searches. Following this preliminary data gathering, the current study started during the third week of the project. At this time, an overview of the IRB-approved study was provided and implied consent was obtained by all participants. The study then proceeded over 3 weeks, with one 1-hr-and-50-min design session each week. Finally, prototyping was conducted in the final weeks of the semester. For the purposes of this study, only the individual idea generation and concept screening sessions will be described.

During the first week of the study (idea generation), students were introduced to the importance of creativity in engineering design. Next, they participated in an idea generation session using design heuristic cards [67], where they were instructed to draw and number each of their ideas on separate idea generation sheets. A total of 116 individual ideas were collected and scanned by the course instructor at the end of the session. During the following concept screening session

![Figure 1. Timeline of 8-week design process in engineering design course project. The current study focused on weeks 3-4.](image-url)
of the study, all ideas generated during the first week were returned to the team who originally
generated the ideas. Students were then asked to individually categorize all ideas within their team
into “Consider” and “Do Not Consider” piles using the definitions and procedures outlined by Toh
and Miller [12]. During this process, individuals were instructed to consider an idea if all or any
part of that idea had potential to move forward in the design process. The rest of the design process
was completed in teams and was not examined as part of this study. As a final step, the Preference
for Creativity Scale (PCS) and the Kirton Adaption-Innovation (KAI) Inventory were administered
at the end of the course project; both were paper-based. The results of this study were discussed by
the course instructor in a lecture on biases in design (including PCS and KAI), following
completion of the study and course project.

3.1.2 | PARTICIPANTS

All 30 of the students in the course agreed to participate in the design study. However, only
27 of these students were present for all design sessions, and only 25 of those students completed
both the PCS and KAI instruments. In addition, one student dropped the course mid-semester,
which meant we excluded their team from the analysis. Finally, two students’ KAI results were
discarded due to unreliable results. Thus, a total 19 students (2 females, 17 males), aged 17–20
(M=18.3, SD=0.7), were included in the analysis and were distributed across seven teams.

3.1.3 | METRICS

To measure the impact of the Preferences for Creativity (PCS) and Adaption-Innovation
(KAI) cognitive style on the creativity of the ideas generated and screened by the engineering
design students, several metrics were used. This section provides detailed definitions and
calculations for these metrics.

Consensual Assessment Technique (CAT): To determine the quality, originality, and creativity of
the ideas generated and screened during the study, three quasi-expert raters were recruited
to independently rate all 116 ideas generated on a 6-point Likert scale based on Amabile’s
Consensual Assessment Technique (CAT) [2] using the guidelines found in [68] and [69]. Amabile’s CAT relies on the simple idea that an artifact is creative only to the extent to which experts in the area agree, independently, that it is creative. All raters were familiar with Amabile’s work and had read Amabile’s paper [2] explaining the assessment. Additionally, while we define a creative product as being both novel and useful, this definition was not explicitly given to the reviewers as they were rating the students’ ideas. Finally, raters were not given qualitative descriptions of creative ideas to assist them in assigning scores, as this would have been an incorrect use of Amabile’s CAT.

Before reviewing the engineering design students’ ideas, the raters completed a practice set of ratings to ensure high inter-rater reliability could be reached. Once inter-rater reliability was deemed sufficient (higher than 0.7), the raters went to do their assigned ideas separately. Three ratings were captured for each idea, including: (1) creativity ($C_i$), (2) perceptions of value, logic, utility ($quality, Q_i$), and (3) perceptions of originality and surprise ($originality, O_i$). There was a high level of agreement among the raters ($\alpha > 0.70$) for creativity ($\alpha = 0.809$), quality/usefulness ($\alpha = 0.800$), and originality/uniqueness ($\alpha = 0.871$), which met the threshold of 0.70. Since the full rating scale was used for each variable, and each of the idea scores was normally distributed, the scores were treated as continuous variables in the analyses. Examples of low, medium, and high overall creativity, quality, and originality can be seen in Figure 2.

Once the creativity, quality, and originality scores were calculated for each design idea, the task Creativity (C), Quality (Q) and Originality (O) of each participant’s idea generation was calculated using the method put forward by Toh and Miller [10] as follows:

**Participant Task Creativity, $T_C$:** This metric for idea generation was defined as a participant’s ability to generate ideas that are creative. Thus, this metric was calculated as the average creativity of the idea set that each participant generated:
<table>
<thead>
<tr>
<th>Overall Creativity</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Low Creativity Example" /></td>
<td>use plastic model (frame)</td>
<td><img src="image2.png" alt="Medium Creativity Example" /></td>
<td><img src="image3.png" alt="High Creativity Example" /></td>
</tr>
<tr>
<td>Quality</td>
<td><img src="image4.png" alt="Low Quality Example" /></td>
<td>Not too high and not too short</td>
<td><img src="image5.png" alt="Medium Quality Example" /></td>
</tr>
<tr>
<td>Originality</td>
<td><img src="image6.png" alt="Low Originality Example" /></td>
<td><img src="image7.png" alt="Medium Originality Example" /></td>
<td><img src="image8.png" alt="High Originality Example" /></td>
</tr>
</tbody>
</table>

**Figure 2.** Examples of low, medium, and high overall creativity, quality, and originality for pilot study
where $C_i$ was the creativity an idea and $N$ was the total number of ideas generated by the participant. Participant Task Quality ($T_Q$) and Originality ($T_O$) were calculated using the same method. Because some scholars have questioned the use of average quality or creativity ratings in design research [70] due to the potential negative correlation between idea count and the average score of the idea set (which punishes those who generate a large quantity of ideas), we checked for correlation between idea count and the average creativity, usefulness, and originality scores. We found no significant correlations between these metrics ($p > 0.05$), so we proceeded with the use of the average creativity metrics, as is customary in design research.

**Propensity toward creative concept screening, $P_C$:** In addition to each participant’s idea generation, we were also interested in their tendency to select creative ideas. Thus, the PC metric defined by [12] was used. This metric is used to describe a participant’s tendency toward selecting creative ideas. The purpose of this metric is to normalize the creativity of the ideas screened by participants with the set of ideas that participants could select from within their teams. Additionally, this calculation excluded any ideas that a participant had also generated, to avoid any potential biases towards selecting one’s own ideas [64]. The metric is defined as follows:

\[
P_C = \frac{\sum_{i=1}^{j} (C_i \times S_i)}{j} \times \frac{k}{\sum_{i=1}^{k} C_i}
\]

where $j$ is the number of ideas screened, $S_i = 0$ if the idea is not screened and $S_i = 1$ if the idea is screened, and $k$ is the total number of ideas the participant evaluates. Participant propensity towards quality ($P_Q$) and original ($P_O$) concept screening were calculated using the same general approach. Figure 1 shows the distribution of creativity, quality, and originality of ideas generated and the propensity to select them.
Preferences for Creativity Scale (PCS): The Preferences for Creativity Scale measures each of the four major factors: (1) team centrality and influence (TCI), (2) risk tolerance (RT), (3) creative confidence and preference (CC), and (4) motivation (M), on a continuous scale from 0 to 100 \[24\]. Higher scores in each factor indicate a stronger preference for creativity. The 19 engineering design students participating in this study displayed an approximately normal distribution in each of the four factors. Team centrality and influence scores ranged from 60-97 (M=82.2, SD=9.7); risk tolerance scores ranged from 43-91 (M=64.6, SD=14.3); creative confidence and influence scores ranged from 60-97 (M=81.6, SD=12.1); motivation scores ranged from 60-93 (M=80.0, SD=10.7). It is important to note that the Preferences for Creativity Scale is intended to capture someone’s preferences for creativity over many projects and circumstances; thus, individuals are instructed to respond to the items in a way that would reflect their behavior over a long period of time, as opposed to their behavior for one specific project \[24\].

Kirton Adaption-Innovation (KAI) Inventory: In order to measure the impact of cognitive style on creative idea generation and selection, the KAI inventory was used to assess individual problem-solving style preferences \[17\]. For the purposes of this study, the total KAI score, or the sum of the three inter-related sub-scores, was used in the comparisons. Since the KAI is scored on a continuous scale, style comparisons are relative, with higher scores corresponding to more innovative individuals and lower scores corresponding to more adaptive individuals \[18\]. A certified KAI practitioner scored the participants’ responses, and individuals received feedback on their results. Similar to PCS, KAI is not project-specific; KAI instructions specifically request that individuals answer each of the items considering their behavior in general and over the long term (not just a one-hour design session) \[17\].

The KAI total scores of the 19 engineering design students in this study approximated a normal distribution (W=0.934, p < 0.209), with total scores ranging from 76-121 (M=94, SD=13). For large general populations and across cultures, the distribution of KAI total scores forms a normal curve within the theoretical range of 32–160, with an observed range of 43-149 (M=95, SD=17). The sub-factors are also normally distributed within the following theoretical ranges: SO (13–65), E (7–35), and R/G (12–60) \[16\].
3.2 | RESULTS

During the study, participants generated a total of 116 ideas. On average, individuals screened 11.5 ideas (SD=4.9) of the 16.57 ideas (SD=6.8) developed by their team. The results from the analyses are presented in the subsections below with respect to the research questions. All data were analyzed with a significance level of 0.05 using SPSS Version 25; effect sizes were classified according to Cohen [71].

3.2.1 | CAN THE PCS SUB-SCALES BE USED TO PREDICT THE CREATIVITY, QUALITY, OR ORIGINALITY OF IDEAS GENERATED AND SCREENED BY ENGINEERING DESIGN STUDENTS?

The goal of the first research question was to examine how PCS factors influenced the creativity, quality, or originality of the ideas generated and screened by engineering design students in a course project. To test the first hypothesis, found in Section 2.5, six multivariate regression models were computed to compare the relationship between the PCS factors (independent variables) of team centrality and influence (TCI), risk tolerance (RT), creative confidence (CC), and motivation (M) and the creativity, originality, and quality of the ideas generated and screened by participants (dependent variables). Assumptions were checked prior to building the regression model, and no violations were found.

The first analysis on the influence of PCS factors on idea generation failed to show a significant result for creative idea generation, $F(4,14) = 1.420$, $p < 0.278$, adj. $R^2 = 0.085$; quality idea generation, $F(4,14) = 1.373$, $p < 0.293$, adj. $R^2 = 0.077$; or original idea generation, $F(4,14) = 2.059$, $p < 0.141$, adj. $R^2 = 0.190$. These results support the hypothesis that the PCS factors would not predict an individual’s idea generation behavior.

To test the second hypotheses, found in Section 2.5, a second set of three multivariate regressions were performed. The results showed that the PCS factors explained 74.0% of the variance in participants’ propensity for creative concept screening, $F(4,14) = 9.950$, $p < 0.0005$, adj. $R^2 = 0.665$, with a large effect size [71]. In particular, participants with higher team centrality and influence, $B = 0.003$ (95% CI, 0.002 to 0.004), $p < 0.0005$, and lower risk tolerance, $B = -0.001$ (95% CI, -0.002 to 0.000), $p < 0.021$, were more likely to screen for
creative ideas. However, PCS factors did not predict participants’ propensity for quality, F(4,14) = 2.824, p < 0.066, adj. R² = 0.288 nor original concept screening, F(4,14) = 1.533, p < 0.246, adj. R² = 0.106. These results support the hypothesis that participants with higher team centrality and influence had a significantly higher propensity to select more creative ideas. These results support the original PCS scale development [24], which identified TCI as the largest contributing factor to the scale. Interestingly, individuals with lower risk tolerance screened more creative ideas, which warrants further exploration. In general, the results showed that higher PCS scores predicted participants’ propensity for creative concept screening, but not original (novel) concept screening. This is important, because these results indicate that participants with higher PCS scores screened ideas with higher creativity, which encompassed ideas that were both novel and technically feasible, but not ideas that were only higher in originality (novelty), ignoring technical feasibility. These results are encouraging and support further use of the PCS scale in measuring factors that impact an individuals’ creative concept selection. Additionally, these differences in idea generation and screening results support prior work showing that idea generation and concept selection abilities are not correlated [6, 28].

Table 1. Summary of findings for PCS (TCI, CC, RT, M) with idea generation and concept screening for pilot study. * indicates significance at p < 0.05

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable (DF, DF)</th>
<th>F</th>
<th>Adj. R²</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative Idea Generation</td>
<td>PCS – TCI, CC, RT, M (4, 14)</td>
<td>1.420</td>
<td>0.085</td>
<td>0.278</td>
</tr>
<tr>
<td>Creative Concept Screening</td>
<td>PCS – TCI, CC, RT, M (4, 14)</td>
<td><strong>9.950</strong></td>
<td><strong>0.665</strong></td>
<td><strong>0.0005</strong>*</td>
</tr>
<tr>
<td>Quality Idea Generation</td>
<td>PCS – TCI, CC, RT, M (4, 14)</td>
<td>1.373</td>
<td>0.077</td>
<td>0.293</td>
</tr>
<tr>
<td>Quality Concept Screening</td>
<td>PCS – TCI, CC, RT, M (4, 14)</td>
<td>2.824</td>
<td>0.288</td>
<td>0.066</td>
</tr>
<tr>
<td>Original Idea Generation</td>
<td>PCS – TCI, CC, RT, M (4, 14)</td>
<td>2.059</td>
<td>0.190</td>
<td>0.141</td>
</tr>
<tr>
<td>Original Concept Screening</td>
<td>PCS – TCI, CC, RT, M (4, 14)</td>
<td>1.533</td>
<td>0.106</td>
<td>0.246</td>
</tr>
</tbody>
</table>
3.2.2 CAN COGNITIVE STYLE, AS MEASURED BY KAI, BE USED TO PREDICT THE CREATIVITY, QUALITY, OR ORIGINALITY OF IDEAS GENERATED AND SCREENED BY ENGINEERING DESIGN STUDENTS?

The second research question was developed to understand whether KAI could be used to predict the creativity, originality, or quality of concepts generated and screened by engineering students. Similar to the previous research question, six regression models were produced, where the dependent variables were the *creativity*, *quality*, and *originality* of ideas *generated* and *screened*, while the independent variable was KAI total score (single linear regressions). To test the first hypothesis, found in Section 2.5, three linear regression models were computed. The dependent variables were *creativity*, *originality*, and *quality* of the ideas generated by participants, while the independent variable was the KAI total score. Assumptions were checked prior to building the regression model, and no violations were found. A summary of these findings is found in Table 2.

The results showed that the KAI was able to significantly predict *participant creativity* (F(1, 17) = 6.530, B = 0.035, p < 0.020, adj. R² = 0.235) and *originality* (F(1, 17) = 7.572, B = 0.046, p < 0.014, adj. R² = 0.267) but not *quality*, (F(1, 17) = 2.835, p < 0.111, adj. R² = 0.093). Specifically, each additional point in participants’ KAI scores led to a 0.035 (95% CI, 0.006 to 0.063) increase in creativity and a 0.046 (95% CI, 0.011 to 0.081) increase in participant originality. While these results support the hypothesis that individuals who fall on the more innovative end of the spectrum generated ideas that were rated as more conventionally creative and original [2], these effects were considered small because of the low R² values [71]. In addition, there were no effects of KAI on participants’ ability to generate high quality ideas. This may be due to students displaying coping behavior [17], regardless of their cognitive style, in order to develop technically feasible solutions for their course project.

**Table 2.** Summary of findings for KAI total score with idea generation and concept screening for pilot study. *indicates significance at p < 0.05

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable (DF, DF)</th>
<th>F</th>
<th>Adj. R²</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative Idea Generation</td>
<td>KAI Total Score (1, 17)</td>
<td>6.530</td>
<td>0.235</td>
<td>0.020*</td>
</tr>
<tr>
<td>Creative Concept Screening</td>
<td>KAI Total Score (1, 17)</td>
<td>0.014</td>
<td>-0.058</td>
<td>0.909</td>
</tr>
<tr>
<td>Quality Idea Generation</td>
<td>KAI Total Score (1, 17)</td>
<td>2.835</td>
<td>0.093</td>
<td>0.111</td>
</tr>
<tr>
<td>Quality Concept Screening</td>
<td>KAI Total Score (1, 17)</td>
<td>5.263</td>
<td>0.191</td>
<td>0.035*</td>
</tr>
<tr>
<td>Original Idea Generation</td>
<td>KAI Total Score (1, 17)</td>
<td>7.572</td>
<td>0.267</td>
<td>0.014*</td>
</tr>
<tr>
<td>Original Concept Screening</td>
<td>KAI Total Score (1, 17)</td>
<td>0.105</td>
<td>-0.052</td>
<td>0.750</td>
</tr>
</tbody>
</table>
To test the second hypothesis, found in Section 2.5, three regression analyses were conducted. The results showed that KAI score significantly predicted a participant’s propensity for quality concept screening, \( F(1,17) = 5.263, B = 0.002, p < 0.035, \text{adj.} \ R^2 = 0.191 \); however, the effect was again small [71]. Specifically, each additional point in participants’ KAI total scores led to a 0.002 (95% CI, 0.000 to 0.005) increase in their propensity for quality concept screening. However, KAI scores did not significantly predict the students’ propensity for creative idea screening (\( F(1,17) = 0.014, p < 0.909, \text{adj.} \ R^2 = -0.058 \)) or their propensity for original concept screening (\( F(1,17) = 0.105, p < 0.750, \text{adj.} \ R^2 = -0.052 \)). While the effect was considered small, these results refute the hypothesis that more adaptive individuals would screen for higher quality ideas; instead, it demonstrated that more innovative individuals were more likely to screen for higher quality, technically feasible ideas. Additionally, KAI total score did not predict participants’ propensity to screen for creative or original ideas. Because there was no difference between the propensity to screen for creative or original ideas, Kirton’s belief that all individuals across the adaption and innovation spectrum are creative [17] is supported, and which means that all KAI styles have the ability to screen for creative ideas.

### 3.3 | CHAPTER SUMMARY

The purpose of this pilot study was to examine the relationship between individual traits, creative idea generation, and concept screening preferences of engineering design students throughout the design process. The key findings were as follows: (1) PCS factors could not significantly predict an individual’s creative idea generation behavior, but it could predict the creativity of ideas screened, with a large effect size; (2) Students who scored higher on the PCS factors of team centrality and influence and/or lower on risk tolerance were more likely to select creative ideas; and (3) KAI scores were able to significantly predict participant creativity and originality during idea generation, but the effects were small. Students with higher KAI scores screened higher quality ideas, but there were no cognitive style differences in selecting creative and original ideas.
This results from this chapter will be submitted to the Journal of Mechanical Design in May 2019. This work is multiple-authored. Katie Heininger will be the lead author on the paper. Drs. Scarlett Miller and Kathryn Jablakow helped advise the work.

The previous chapter outlined the pilot study in which individual differences were compared to creative idea generation and concept screening during the engineering design process. This study found that KAI could be used to predict creative and quality idea generation, as well as quality concept screening, and PCS could be used to predict creative concept selection [72]. The previous chapter was used as a pilot study, and as such, the conclusions that could be drawn were limited because of the size of the sample of the study. This chapter aims to close that gap by testing the hypotheses with a larger sample size of students. Another limitation of the previous study was the lack of in-the-moment understanding of the creativity of the ideas generated and screened by the teams. To address this, this chapter adds another metric to use as a proxy of quality of ideas generated, called idea goodness. This was seen as an important addition because the understandings of individual raters outside of the group creating the ideas could be very different from the ideas of the teams creating the ideas [64].

This study was completed through the collection of data in the idea generation and concept selection portions of an introductory engineering design class (EDSGN 100) at Penn State University. Data was analyzed using statistical methods found commonly in the creativity and engineering design field. The results of this study add to the understanding of individual differences and creativity, and encourage the continuation of future work in this field.
4.1 | METHODOLOGY

To answer the research questions of this thesis, a second experimental study was conducted during two design sessions of a 4-week engineering design project in an introductory engineering design class (EDSGN 100) at Penn State University. The two sections of the course taught by the same instructor were studied, each with 24 undergraduate engineering students. Participants consented at the start of the study using the Institutional Review Board guidelines set forth at the university. This section summarizes the differences in methodology compared to the first study in this paper [72].

4.1.1 | PARTICIPANTS

All of the 48 students in the course agreed to participate in the design study. However, only 43 of these students were present for all design sessions. Additionally, two students’ KAI results were discarded due to unreliable results, as determined by a KAI expert. Thus, a total 41 students (9 females, 32 males), aged 17–19 (M=18.0, SD=0.4), were included in the analysis. The 41 students included in the analysis were distributed across twelve teams, with at least three students representing each team.

4.1.2 | PROCEDURE

The design study presented here was a part of a graded 4-week design course project. This project was a portion of a condensed summer course where students met every day for three hours. Students were assigned to take the Preferences for Creativity Scale (PCS) and Kirton Adaption Innovation inventory (KAI) online as a homework assignment. Both the PCS and KAI inventories were administered electronically. During Time Point 2, students researched the design problem given below:

“Across developing countries, there are a host of problems connected to food insecurity and other major agricultural challenges that impede economic and human development. Your team’s challenge is to either select a food insecurity
problem from the list below, or come up with your own as a team, and come up with a solution to remove or reduce the burden imposed on the world’s most vulnerable populations by that specific problem.”

Students were instructed to research the topic by reading news articles and looking at the current market to see what solutions were already in place. During Time Point 3, students participated in the idea generation module, including a presentation focusing on why creativity was important in idea generation. Students were told to individually sketch as many ideas as possible in a 15-minute session. Each idea was put on a separate idea generation sheet, as outlined in Toh and Miller [10]. During Time Point 4, students first individually categorized all of their team’s ideas as either “Consider” or “Do Not Consider” before coming together to discuss the final ideas with which to move forward as a group.

Figure 3. Timeline of 6-week design process in engineering design course project. The current study focused on time points 3-4.

4.1.3 | METRICS

To measure the impact of the Preferences for Creativity (PCS) and Kirton Adaption-Innovation (KAI) cognitive style on the creativity of the ideas generated and screened by the engineering design students, several metrics were used. This section provides detailed definitions and calculations for these metrics.

Consensual Assessment Technique (CAT): The same procedures outlined in Section 3.1.3 were used to determine the quality, originality, and creativity of the ideas generated and screened during the study using the same two quasi-expert raters to rate the 350 ideas on a 6-point Likert scale. There was a high level of agreement among the raters (α > 0.70) for creativity (α = 0.809), quality/ usefulness (α = 0.818), and originality/ uniqueness (α = 0.801), which met the threshold of 0.70. Once inter-rater reliability was deemed sufficient (higher than 0.7), the
raters went to do their assigned ideas separately. Since the full rating scale was used for each variable, and each of the idea scores was normally distributed, the scores were treated as continuous variables in the analyses. Examples of low, medium, and high overall creativity, quality, and originality can be seen in Figure 4.

**Participant Task Creativity (Tc):** The same procedures outlined in Section 3.1.3 were used to rate the 350 individual ideas generated by participants in the study using the same two raters from the pilot study. During this process, 29 of the 350 ideas were considered unratable by the rating team due to either not enough detail to understand the design or ideas developed that did not address the problem statement created by individual teams. Thus, these ideas were excluded from the study, leaving a total of 321 ideas to be used in analysis. From these ratings, Participant Task Creativity (Tc), Quality (Tq) and Originality (To) were calculated.

**Propensity toward Creative concept screening, Pc:** The same procedures outlined in Section 3.1.3 were used to measure Propensity towards Creative (Pc), Quality (Pq), and Original (Po) concepts.

**Idea Goodness, G:** While CAT is a good metric for measuring creativity, quality, and originality after the design task is over, it was important to also use a metric that measured quality during the design task. Thus, the final metric utilized was the idea goodness metric, as defined in Toh, Strohmetz, and Miller [64]. Idea goodness is defined as the quality or effectiveness of an idea as determined by team members [64]. The metric describes how often an idea was screened to be considered by members of the team, expressed as a percentage. The metric ignores the idea generator’s own opinion on whether the idea should be considered in order to remove ownership bias. The metric is defined as follows:

\[
G_i = \frac{\sum_{m=1}^{M} X_m}{M}
\]

Where \(X_m = 1\) if the \(m^{th}\) team member screened in the idea, \(i\), generated by another team member is categorized into the ‘Consider’ group, and \(X_m = 0\) otherwise. \(M\) is the total number
of team members who scored the idea, which excludes the idea generator. An idea goodness score of greater than or equal to 0.5 indicates that at least half the team believed the idea to be viable and classified it as ‘Consider,’ while a score of less than 0.5 indicates that less than half the team classified the idea into the ‘Consider’ group.

Preferences for Creativity Scale (PCS): The Preferences for Creativity Scale was collected similar to the procedure mentioned in Section 3.1.3. For the current study, team centrality and influence scores ranged from 51-100 (M=76.4, SD=10.2); risk tolerance scores ranged from 43-91 (M=68.0, SD=9.6); creative confidence and influence scores ranged from 50-100 (M=77.4, SD=11.2); motivation scores ranged from 53-93 (M=78.4, SD=10.1).

Kirton Adaption-Innovation (KAI) Inventory: KAI results were collected similarly to the procedure mentioned in Section 3.1.3. The KAI total scores of the 41 engineering design students in this study approximated a normal distribution (W=0.961, p < 0.110), with total scores ranging from 63-123 (M=89, SD=12).

In order to validate the results from Chapter 3, which found that PCS could be used to predict the creativity of concepts screened, four multivariate regression models were created, using the PCS factors as the independent variables and the creativity, quality, originality, and goodness of ideas generated by the participants as the dependent variables. In addition, another goal was to identify whether or not the PCS factors could predict the goodness of ideas generated by participants. This metric was seen as an important addition because it measures perceived quality of an idea by the design team members, as opposed to expert raters who were not a part of the design task.
Table 1. Examples of low, medium, and high overall creativity, quality, and originality for full experimental study.

<table>
<thead>
<tr>
<th>Overall Creativity</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Low Creativity" /></td>
<td><img src="image2" alt="Medium Creativity" /></td>
<td><img src="image3" alt="High Creativity" /></td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td><img src="image4" alt="Low Quality" /></td>
<td><img src="image5" alt="Medium Quality" /></td>
<td><img src="image6" alt="High Quality" /></td>
</tr>
<tr>
<td>Originality</td>
<td><img src="image7" alt="Low Originality" /></td>
<td><img src="image8" alt="Medium Originality" /></td>
<td><img src="image9" alt="High Originality" /></td>
</tr>
</tbody>
</table>

**Figure 4.** Examples of low, medium, and high overall creativity, quality, and originality for full experimental study.
4.2 | RESULTS

During the study, a total of 350 ideas were generated by the participants, with 260 ideas rated as ‘good’ ideas by the teams. On average, participants screened 20.09 ideas (SD=4.0) of the 29.17 ideas (SD=6.2) developed by their team. The remainder of this section outlines the results with reference to the research questions of this thesis. All data were analyzed with a significance level of 0.05 using SPSS V. 25.

4.2.1 | CAN THE PCS SUB-SCALES BE USED TO PREDICT THE CREATIVITY, QUALITY, ORIGINALITY, OR GOODNESS OF IDEAS GENERATED AND SCREENED BY ENGINEERING DESIGN STUDENTS?

The goal of this research question was to further examine the results of the pilot study with a larger sample of students. Specifically, this question assesses the influence of PCS factors (team centrality and influence; creative confidence; risk tolerance; motivation) on the creativity, quality, and originality of ideas generated and screened by first-year engineering design students during a course project.

To test the hypotheses outlined in Section 2.5, four multivariate regression models were created, using the PCS factors as the independent variables and the creativity, quality, originality, and goodness of ideas generated by the participants as the dependent variables. Prior to building the model, assumptions were checked, with no violations found. The summary of this analysis can be found in Table 3.

Table 3. Summary of findings for PCS (TCI, CC, RT, M) with idea generation and concept screening for full experimental study. * indicates significance at p < 0.05

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable (DF, DF)</th>
<th>F</th>
<th>Adj. R²</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative Idea Generation</td>
<td>PCS – TCI, CC, RT, M (4, 43)</td>
<td>1.402</td>
<td>0.033</td>
<td>0.249</td>
</tr>
<tr>
<td>Creative Concept Screening</td>
<td>PCS – TCI, CC, RT, M (4, 43)</td>
<td>0.718</td>
<td>-0.028</td>
<td>0.585</td>
</tr>
<tr>
<td>Quality Idea Generation</td>
<td>PCS – TCI, CC, RT, M (4, 43)</td>
<td>1.596</td>
<td>0.048</td>
<td>0.193</td>
</tr>
<tr>
<td>Quality Concept Screening</td>
<td>PCS – TCI, CC, RT, M (4, 43)</td>
<td>0.932</td>
<td>-0.006</td>
<td>0.456</td>
</tr>
<tr>
<td>Original Idea Generation</td>
<td>PCS – TCI, CC, RT, M (4, 43)</td>
<td>2.990</td>
<td>0.145</td>
<td>0.029*</td>
</tr>
<tr>
<td>Original Concept Screening</td>
<td>PCS – TCI, CC, RT, M (4, 43)</td>
<td>0.597</td>
<td>-0.040</td>
<td>0.667</td>
</tr>
<tr>
<td>Idea Goodness</td>
<td>PCS – TCI, CC, RT, M (4, 43)</td>
<td>1.804</td>
<td>0.064</td>
<td>0.145</td>
</tr>
</tbody>
</table>
The regression analyses related to idea generation showed that the PCS sub-factors could be used to predict originality \((F(4,43) = 2.990, p < 0.029, \text{adj. } R^2 = 0.145)\) of ideas generated. Specifically, both risk tolerance \((B = -0.028, 95\% \text{ CI -0.050 to -0.007})\) and creative confidence \((B = 0.024, 95\% \text{ CI 0.004 to 0.043})\) significantly contributed to the originality model, indicating that participants with lower risk tolerance and higher creative confidence were more likely to generate original ideas. Interestingly, the pilot study found that lower risk tolerance could be used to screen for more creative ideas, as opposed to original ideas, as found in this study. This warrants further investigation into why lower risk tolerance would be a predictor in these cases.

However, the PCS factors were not able significantly predict the creativity \((F(4,43) = 1.402, p < 0.249, \text{adj. } R^2 = 0.033)\), quality \((F(4,43) = 1.596, p < 0.193, \text{adj. } R^2 = 0.048)\), or goodness \((F(4,43) = 1.804, p < 0.145, \text{adj. } R^2 = 0.064)\) of ideas generated. These results supported the results of the pilot study, which found that idea generation behaviors could not be predicted by PCS factors. This also supports previous work done about PCS, which stated that only originality in idea generation could be predicted by PCS [65].

The second set of regression analyses were related to concept screening. To test these hypotheses, three multivariate regressions were created, with PCS factors as the independent variables and the propensity for screening creativity, quality, and originality by the participants as the dependent variables. The results showed that PCS factors could not predict participants propensity for: creative concept screening \((F(4,38) = 0.718, p < 0.585, \text{adj. } R^2 = -0.028)\), quality concept screening \((F(4,38) = 0.932, p < 0.456, \text{adj. } R^2 = -0.006)\), or original concept screening \((F(4,38,)= 0.597, p < 0.667, \text{adj. } R^2 = -0.040)\). These results refute the pilot study results, which stated that PCS could predict screened originality [72]. Additionally, the results refute other prior work, which stated that PCS factors could be used to predict originality and quality of ideas screened [65]. This discrepancy requires further examination.

**Table 4.** Summary of findings for KAI total score with idea generation and concept screening for full experimental study. *indicates significance at \(p < 0.05\)

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable (DF, DF)</th>
<th>F</th>
<th>Adj. (R^2)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative Idea Generation</td>
<td>KAI Total Score (1, 46)</td>
<td>0.286</td>
<td>-0.015</td>
<td>0.595</td>
</tr>
<tr>
<td>Creative Concept Screening</td>
<td>KAI Total Score (1, 46)</td>
<td>0.206</td>
<td>-0.019</td>
<td>0.625</td>
</tr>
<tr>
<td>Quality Idea Generation</td>
<td>KAI Total Score (1, 46)</td>
<td>2.333</td>
<td>0.028</td>
<td>0.134</td>
</tr>
<tr>
<td>Quality Concept Screening</td>
<td>KAI Total Score (1, 46)</td>
<td>2.008</td>
<td>0.023</td>
<td>0.164</td>
</tr>
<tr>
<td>Original Idea Generation</td>
<td>KAI Total Score (1, 46)</td>
<td>2.377</td>
<td>0.028</td>
<td>0.130</td>
</tr>
<tr>
<td>Original Concept Screening</td>
<td>KAI Total Score (1, 46)</td>
<td>1.317</td>
<td>0.009</td>
<td>0.248</td>
</tr>
<tr>
<td>Idea Goodness</td>
<td>KAI Total Score (1,46)</td>
<td>1.594</td>
<td>0.012</td>
<td>0.213</td>
</tr>
</tbody>
</table>
4.2.2 | CAN COGNITIVE STYLE, AS MEASURED BY KAI, BE USED TO PREDICT THE CREATIVITY, QUALITY, ORIGINALITY, OR GOODNESS OF IDEAS GENERATED AND SCREENED BY ENGINEERING DESIGN STUDENTS?

The second research question examined the influence of cognitive style, as measured by KAI, on the creativity, quality, originality, and goodness of ideas generated and screened by engineering design students during a course project. To test the hypotheses listed in Section 2.5, four multivariate linear regressions were created, using KAI as the independent variable and creativity, quality, originality, and goodness as the dependent variables. Prior to building the models, assumptions were checked with no violations found. The summary of the analysis can be found in Table 4.

The four regressions of KAI were not able to significantly predict the creativity ($F(1,46) = 0.286, p < 0.595, \text{adj. } R^2 = -0.015$), quality ($F(1,46) = 2.333, p < 0.134, \text{adj. } R^2 = 0.028$), originality ($F(1,46) = 2.377, p < 0.130, \text{adj. } R^2 = 0.028$), or goodness ($F(1,46) = 1.594, p < 0.213, \text{adj. } R^2 = 0.012$) of ideas generated by participants. These results refuted prior work, which found that KAI could be used to predict idea generation creativity metrics [72]. Additionally, these results refuted the hypothesis that KAI could be used to predict idea goodness.

The second regression analyses, focused on concept screening, found that KAI was not a significant predictor of any measure of concept screening: propensity for creativity ($F(1,41) = 0.206, p < 0.652, \text{adj. } R^2 = -0.019$), quality ($F(1,41) = 2.08, p < 0.164, \text{adj. } R^2 = 0.023$), or originality ($F(1,41) = 1.371, p < 0.248, \text{adj. } R^2 = 0.009$). These results refute the findings of the pilot study, which found that KAI could be used to predict certain concept screening behaviors [72].

4.3 | CHAPTER SUMMARY

The purpose of this full experimental study was to expand on the work completed in the pilot study, specifically addressing the main limitation, which was sample size, and whether the previous findings could be used for a larger population. The expectation was to find results similar to that of the pilot study, where KAI was a predictor of creativity and originality in the idea generation part of the process, and quality in the concept screening part of the process; and PCS was a predictor of creativity in the concept screening part of the process [72]. However, when the new data was
analyzed, it was found that (1) none of the previous measures were significant, and instead found that (2) PCS was a significant predictor of original idea generation. In addition, (3) idea goodness, which was a new metric in this study, was not found to be significant for PCS or KAI. Importantly, there were differences between the pilot and full experimental study that could have caused the stark difference in results (semester, teacher experience, design prompt). For this reason, KAI and PCS should continue to be studied in concurrence with creativity in the engineering design process, with factors such as class population, school semester, and design prompt as controlled variables.
The purpose of this thesis was to examine individual differences, as measured by the KAI and PCS metrics, and its effect on creativity during the engineering design process for undergraduate engineering students, as well as idea goodness of ideas generated. It was hypothesized that these creativity metrics would be able to predict creativity in the engineering design process, specifically in idea generation and concept screening. During the pilot study, the hypothesis was tested on 19 undergraduate engineering students, and it was found that certain creativity metrics could be predicted by the KAI and PCS scores of the students. However, during the full experimental study with 44 undergraduate engineering design students, it was found that different metrics could be predicted than were found in the pilot study. These results are summarized in Figure 5. Idea goodness, which was not studied in the pilot study, was not found to be significant in the full experimental study.

<table>
<thead>
<tr>
<th></th>
<th>Idea Generation</th>
<th>Concept Screening</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Creative</td>
<td>Original</td>
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<tr>
<td>Pilot Study</td>
<td>PCS Sub-scores</td>
<td></td>
</tr>
<tr>
<td></td>
<td>KAI Scores</td>
<td></td>
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<tr>
<td>Experimental Study</td>
<td>PCS Sub-scores</td>
<td></td>
</tr>
<tr>
<td></td>
<td>KAI Scores</td>
<td></td>
</tr>
</tbody>
</table>

*filled box indicates significance at p < 0.05*
5.1 | CAN THE PCS SUB-SCALES BE USED TO PREDICT THE CREATIVITY, QUALITY, ORIGINALITY, OR GOODNESS OF IDEAS GENERATED AND SCREENED BY ENGINEERING DESIGN STUDENTS?

According to the results from the pilot study, PCS sub-scores cannot be used to predict any idea generation metrics, but can be used to predict creative concept screening. However, this result contradicted previous work, which found that PCS sub-scores could be used to predict originality of ideas generated, and originality and quality of ideas screened [65]. The results of the full experimental study, which had a larger sample size, showed a relationship between original idea generation, which supported other studies, but not the pilot study [65, 72]. However, the full experimental study also found that there was no relationship between PCS sub-scores and creative, original, or quality concept screening, which did not agree with the pilot study, nor other studies [65, 72]. While it was hoped that there would be clear-cut relationships between PCS sub-scores and creativity, originality, quality, and idea goodness in idea generation and concept screening, at this time, no concrete conclusions can be made. However, because of the number of contradicting claims, it is important to continue to understand which creativity metrics, if any, PCS can predict, and under which circumstances.

5.2 | CAN COGNITIVE STYLE BE USED TO PREDICT THE CREATIVITY, QUALITY, ORIGINALITY, OR GOODNESS OF IDEAS GENERATED AND SCREENED BY ENGINEERING DESIGN STUDENTS?

According to the results of the pilot study, KAI can be used to predict creative and quality idea generation, and quality concept selection [72]. More specifically, students with higher (more innovative) KAI scores screened for more quality ideas, but there was no difference in KAI scores when selecting creative and original ideas [72]. However, the full experimental study found that no creativity metrics were significant in either idea generation or concept screening. In addition, the full experimental study found that KAI was not a predictor of idea goodness in the idea generation part.
of the engineering design process. This is important, because while three different metrics were found to be significant in the pilot study, the effect size of all three significant metrics was found to be small. Unfortunately, no concrete conclusions can be drawn from these two studies, and we cannot conclude whether KAI can be used to predict creativity, quality, originality, or goodness of ideas generated and screened.

5.3  LIMITATIONS AND FUTURE WORK

While the pilot study, seen in Chapter 3, showed there was a significant relationship between individual problem solving and creative preferences and the ideas generated and screened by engineering design students, there were several important limitations. First, the relationship between Kirton's Adaption-Innovation spectrum and the creativity metrics used to evaluate the ideas in this study is complex and potentially problematic. In particular, ideas that fall more on the innovative side of the KAI spectrum (risky, boundary breaking, unusual) are typically rated more highly (i.e., as “more creative”) using the consensual assessment technique due to the traditional definition of creativity, which is biased toward Kirton’s more innovative characteristics. Yet, Kirton’s model is built on the underlying tenet that all locations on the KAI spectrum are equally creative – they simply represent different styles of creativity. It is important to note that the creativity, quality, and originality of ideas used in this paper are defined by Amabile’s method [2]. Thus, the definition and evaluation of “creative ideas” should be further explored. In addition, cognitive level, which was not explored in this thesis, is another important construct to consider when understanding the individual differences that impact creative problem solving.

There were also several other limitations to the pilot study that should be explored in future work. First, in order to understand whether perceived roles and actual roles in teams are related, future work should also examine the perceived role a student takes on a team, as measured by the team centrality and influence sub-score of the PCS metric and compare this to the actual role the student takes in a team. Next, this work was also limited to engineering students in their first year; future work should look at the generalizability of these findings to a larger base of engineering students or industry practitioners. Finally, the sample size was limited due to the small number of participants who completed the entire study. Future research should be conducted to analyze the relationship between PCS, KAI, team performance, and problem-solving abilities with larger sample sizes. This limitation was addressed in the full experimental study, seen in Chapter 4.
While the full experimental study addressed what was believed to have the largest impact on the pilot study (sample size), several other factors were present, which may have inadvertently caused the difference in results between the two studies.

One reason the results of the full experimental study could have been so drastically different than the pilot study results was because the design prompt changed between the two semesters. While the pilot study had a well-defined problem of building a low-cost greenhouse, the full experimental study was much more open-ended, and allowed students to have more freedom with the problem they decided to solve, allowing them to choose the country as well as the food shortage problem they wanted to solve. This aligns with previous research, which shows that design prompt selection is critical [52-54]. Additionally, certain prompts are going to allow for the generation and selection of more creative ideas, and it is possible that the second prompt chosen was too vague [54].

An additional reason for the differences in the pilot and experimental studies could have been related to the classroom environment: instructor, classroom activities, etc. While the instructor was the same for the pilot study and the follow-up study, the studies occurred almost two years apart, in which time the instructor taught the class three more times, which could have led to changes in self-efficacy of the professor, and therefore changes to student experience [58]. Additionally, while the modules presented were the same, if slides were updated or different examples were given, this could have affected the outcomes of this study as well [55].

Another possible difference is the difference in student population involved with the second study compared to the first study. There have been many studies about the impact of at-risk students attending a summer semester of college, and how this positively impacts the success of these students later on in their college careers [59, 60], especially in STEM fields [61]. According to the Penn State, where this study took place, many of the students who attend the 6-week summer session were admitted to the university only if they first attended the summer session, as opposed to starting in the fall [73]. The option to attend the summer session is offered as an alternative to attending a local university (“branch”) campus before transferring to the main university campus after one or two years [74]. Because these students are considered to be ‘at-risk,’ the population is not the same as the pilot study, which was the general freshman engineering population. These differences should be a focus of future work.
5.4 | IMPLICATIONS

The two studies included in this thesis were among the first to study the difference between individual differences, specifically cognitive style, and creativity in the engineering design process. While neither research question had a definitive answer, this thesis lays the groundwork to continue this research and extend the questions asked and the limitations found into future work. Both PCS and KAI are extremely useful tools in the field for which they were originally designed, and with the right research, can be equally useful in the field of creativity in the engineering design process.
References


[65] Toh, C. M., Scarlett, 2018, "Does the Preferences for Creativity Scale (PCS) Predict an Engineering Students’ Ability to Generate and Select Creative Design Alternatives?," Journal of Mechanical Design.


