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Student Persistence Through Uncertainty Toward Successful Creative Practice

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Student Persistence Through Uncertainty
Toward Successful Creative Practice

Abstract: To increase creative practice among students in engineering and other disciplines, an interdisciplinary instructor team developed a cross-college undergraduate course aimed at open ideation and creative inquiry. One skill in the development of creative practice is identifying and addressing uncertainty avoidance behaviors, which are high in engineering students. We leverage research grounded in professional identity and cognitive design processes to study impacts of curriculum designed to address student persistence through, or indifference toward, uncertainty in creative practice. Questions we seek to explore are: What role does uncertainty avoidance play in developing creative practice, especially in interdisciplinary teams? What strategies can be used to overcome that uncertainty? To explore the role of uncertainty avoidance in the course, we analyze observational data of classroom activities, including ideation workshops, public critiques, team discussions, and artifacts of student work. Findings are used to draw conclusions about processes that are teachable in engineering and interdisciplinary learning environments, in terms of uncertainty avoidance and creativity. To this end, we offer initial directions and questions for future work that would contribute to a pedagogical model that helps engineering students succeed in interdisciplinary contexts.

Introduction and Background

In cross-cultural psychology, uncertainty avoidance is a construct that is based on how an individual responds to uncertainty and ambiguity. For example, instruments such as Hofstede's cultural dimensions survey measure tolerance for uncertainty at the societal level, indicating how members of a society either embrace or attempt to minimize uncertainty.[1] Importantly, uncertainty and risk are distinct concepts: risk can be defined while uncertainty cannot.[2] That is, "risk tolerance" involves gauging variables and probabilities and adjusting decision-making accordingly; managing uncertainty, on the other hand, involves the discomfort of working with "unknowns" and is a skill that can support critical and creative thinking.[3] For example, the concept of design thinking intentionally incorporates uncertainty in the creative process:

> The uncertainty of design is both the frustration and the joy that designers get from their activity: they have learned to live with the fact that design proposals may remain ambiguous and uncertain until quite late in the process. Designers will generate early tentative solutions, but also leave many options open for as long as possible; they are prepared to regard solution concepts as temporarily imprecise and often inconclusive.[4, p. 12]

In undergraduate course settings that incorporate uncertainty, students face a number of challenges, and they often try to perform in ways that satisfy traditional learning contexts governed by well-designed problems and grade-driven incentives. Like most undergraduates, engineering students often have expectations from learning in their home discipline, in which "the most commonly encountered problems are well-structured with known, correct solutions"[5a, p. 38, 5b]. In building teaching and learning environments for improving creative practice, we seek to incorporate strategies to address uncertainty by immersing students in a design thinking environment. Our strategies emphasize reflective practice in which not only are problems

complex and ill-structured, but emphasis is placed on both problem-solving and on problem framing[6]. This entails an iterative process of sustaining multiple possibilities and dealing with the necessity to "pivot", and the value shifts to problem shaping: "Identifying, framing, and reframing the problem to be solved are as important in this process as solving the problem or finding an appropriate solution"[7, p. 44].

In our cross-college undergraduate course aimed at open ideation and creative inquiry, we work with student groups that include engineering, science, design, and humanities majors. To increase creative practice, we focus on identifying and addressing uncertainty avoidance behaviors, which are often high in engineering students,[8] and using design thinking strategies to support students' ability to continue working throughout the loosely structured curriculum. In these settings, it is critical to provide students with the permission they need to explore ambiguous spaces, and to offer support and guidance on how to overcome perceived failure[9]. As instructors in our own interdisciplinary team, we used an auto-ethnographic practice to examine our own "attitudes and dispositions" in an effort to remain sensitive, open-minded, and tolerant of a certain level of ambiguity in how we structured and supported the class[3, p. 9, 10, p. 17]. Through transparent modeling by instructors, the students received the permission they needed to question, struggle, fail, and regroup numerous times, which contributed to multiple levels of behaviors related to uncertainty avoidance.

Throughout the design and implementation of the course, we used our observations as recorded in the auto-ethnography and embedded assessment tools such as student reflections and group activities to both enact and study student persistence through uncertainty in creative practice. This paper reports on our initial findings in addressing the following research questions:

- What role does uncertainty avoidance play in developing creative practice especially in interdisciplinary teams?
- What strategies can be used to overcome that uncertainty?

Methods

Participants

The participants (n=15) were students enrolled in an undergraduate honors course titled *CREATE!*. The undergraduate students represented freshman through fifth year seniors from a variety of disciplines, including 4 students enrolled in engineering majors, 3 design/architecture majors, 2 art majors, 3 science majors, 1 math major, and 2 business majors. The course was electively taken to fulfill three hours of 21 credits required to receive an honors degree. Each of the 15 students enrolled in the course signed Institutional Review Board (IRB) documents providing written consent to participate in the research, including class participation and submission of class artifacts. Of the 15 participants, 4 were male and 11 were female.

Setting

The course is designed to encourage the development of competencies in several areas, including critical and creative thinking, collaboration and communication, and identifying and proposing innovative ideas. Recognizing that the main objectives of the course involved collaborative work

and communication, it was critical these skills were modeled to the students. Thus, the course was co-taught by two instructors. The instructor-of-record, a professor in engineering education, taught the course for the first time. The secondary instructor, a research professor in instructional design, had designed and taught the course for five previous semesters. In addition, a graduate student in human-centered design was present in each of the classes as well as in planning sessions with the instructors to observe and offer additional support. As the course also aimed to get students to engage in cross-disciplinary discussions, it was critical to offer a variety of perspectives and areas of expertise. As such, the instructors created a list of guest speakers to periodically visit class. These guests included representation from industry (strategy planning, user experience, design, marketing) as well as other departments (industrial design, business, library science).

To help move through the design process, students participated in three studio-based critique sessions during which they presented their work and received critique from an invited panel of experts. The goal for these critiques was to provide at least one content-area expert for each different project idea, as well as industry and academic representation. From each critique, students were expected to analyze and consider all feedback in order to make progress on their projects.

Data Collection and Analysis

The activities throughout the course were designed to provide students a safe environment to question, explore, take risks, and fail with the intention of teaching them how to work through continual iteration and negotiation with their teams. We used a course-embedded assessment approach to ensure flexibility in teaching and learning styles while still measuring the quality of student work. We also designed our instructional activities to be linked to authentic learning outcomes that would serve the students in their experiences beyond the classroom[11]. Thus we structured the course to include instructional methods such as presentation of problem spaces, team forming exercises, multiple critiques, completion of reflections and final projects, and a co-creation activity conducted at the end of the semester. The data collected from these activities throughout the semester served as both assessment data and data that informs our research. In this paper, we specifically draw on data from students' reflective writings, their participation in a co-creation activity, their critiques and instructors' ratings of critiques, as well as observations from the aforementioned collaborative auto-ethnography conducted by the instructors, in which they concurrently reflected on how student progress aligned with course objectives.

> **Student reflections.** Students completed reflections in which they responded to open-ended prompts from the instructors throughout the course. Reflections were typically brief (~75-150 words), with a longer final reflection (~500-800 words). As assignments, students received credit for completing these reflections and the instructors wrote feedback based on criteria that included students' abilities to 1) integrate ideas from class into real-world experiences, 2) critically analyze conceptions of innovation, 3) clearly articulate their ideas, and 4) progressively incorporate multiple perspectives into a personal, holistic viewpoint of innovation.
>
> **Critiques.** At three points in the semester, student groups prepared a brief, 10-minute presentation of their project. Students were prompted to present several elements of their

project, including their problem statement, background research and market analysis, user testing results, and solution. These presentations were to evolve throughout the semester as the students engaged in multiple phases of the design process. At each critique, the instructors as well as outside visitors used a rubric to gauge the process and progress of each group. The rubric does not measure right or wrong answers but rather leads the reviewers to focus on certain aspects of the presentation and engage in a semester-long comparative to judge progress. Each group received approximately 15 minutes of verbal feedback from peers and instructors during the critique session, and the course instructors kept track of the feedback. During the class sessions following each critique, instructors provided more targeted feedback based on the critique, giving students the opportunity to ask clarifying questions and share their responses. At the second and third critiques, reviewers used feedback from each prior critique to identify points of progress. If changes or improvements were not made, students were asked to provide justification for their decision to dismiss the feedback. At the final critique, students were judged primarily based on the quality of their progress throughout the semester and the quality of their decision justifications, and the instructors directed feedback and final grades accordingly.

Collaborative auto-ethnography. Inspired by the work of Sochacka, Guyotte and Walthers on STEAM education[12], the instructors exchanged reflections in order to more deeply explore uncertainty avoidance in relation to learning objectives as the course progressed. The instructors took notes during class periods, guided by rubric criteria and course objectives, primarily noting indications of student responses to uncertainty and collaborative behaviors. Examples of student behaviors that we noted included students' questions and concerns, engagement in group activities, and group conflicts. Within the week following the class period, the instructors would reflect on their notes and post summaries in a collaborative web-based document that included observations from the class meetings as well as their own responses as instructors to the progression of the course. They also responded to each other's posts and took turns on who would lead first in that week's discussion. Finally, the graduate student instructor would periodically (approximately every 3 weeks) synthesize the trajectory of the instructors' posts, pointing out patterns and pain points that she observed in the narrative and as a participant in the course.

As research data, the reflections, the critiques and critique feedback, and the collaborative auto-ethnography were analyzed using a thematic coding process for identifying patterns both within each data set and across data sets. While informed by research on uncertainty avoidance, the instructors approached the thematic analysis primarily from iterative, inductive readings of the data[13], focusing on the research question of student uncertainty avoidance (analysis of instructor uncertainty avoidance will be reported elsewhere). The purpose of this thematic analytic approach was to get more familiar with the data and identify broad patterns that all three researchers agreed upon. The results took the form of trajectories of each group throughout the semester as they formed and reformed ideas, interacted in teams, and eventually concluded the semester with a summative formulation of their work.

Co-Creation Activity. The co-creation activity was offered during a class meeting one week before final presentations. Co-creation is a broad term that indicates any collective act of creation. In human-centered design, it can be seen as a "disruptive" approach that reflects the evolving role of the user as subject vs. the user as partner, and in relation to product/service development led by design vs. research[14]. The co-creation activity that we used, proposed by the graduate student instructor, led students to collectively construct comprehensive diagrams about innovation. Before students came to the class session, each was tasked with choosing one image that expressed his/her answer to the questions: *What is innovation today? How can design contribute to change?* In groups, the students used whiteboards and poster materials in the following activities:

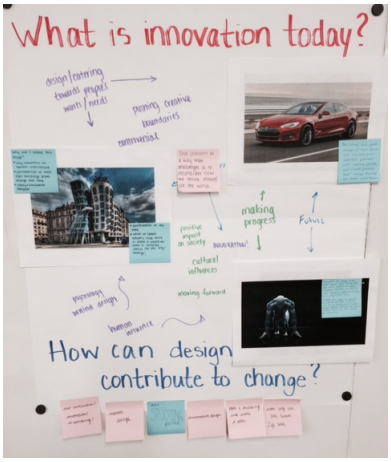

Figure 1: Co-creation student concept map

Stage 1: Each student wrote down his/her ideas and definition about innovation, identifying key words.

Stage 2: Groups worked together with their images and keywords to build a visual map, which they presented and explained to the whole group, leading to discussion about emerging themes.

Stage 3: Each group was asked to reflect on and discuss a third question, "*Based on the ideas you presented, how is your group developing a project addressing innovation?"* The groups added their reflections to their posters and shared their ideas with the whole group again. Figures 1-4 show examples of the students' work in this stage.

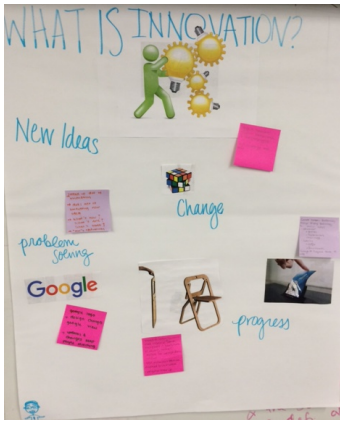

Figure 2: Co-creation student concept map

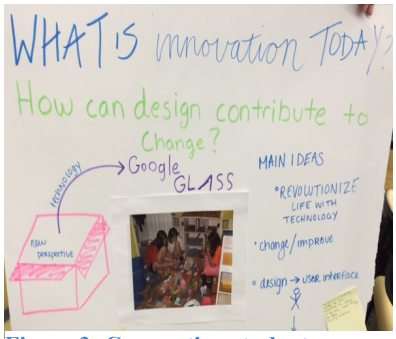

Figure 3: Co-creation student concept map

After the class session, all of the resulting data (concept maps, presentation of ideas, and class discussion) were transcribed and analyzed using thematic analysis to organize data in clusters of meaning. Initially, all the information was transcribed as literal, generating a list of approximately 80 entries. The entries were roughly grouped by meaning and possible applied connections. In the final stage of analysis and reporting, the language was slightly adapted, leveled, and a classification was applied. This generated 10 general themes answering the main question and two additional boxes registering aspects raised about the second and third questions. The results are represented in Figure 5.

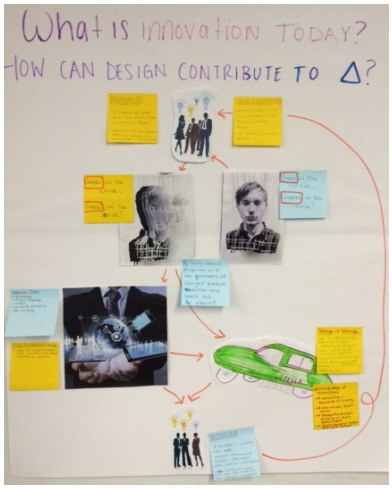

Figure 4: Co-creation student concept map

As a teaching tool, the activity was designed to encourage the development of competencies that are critical to a design mindset and managing uncertainty avoidance. In addition, this activity is a participatory mode of innovation and research, which is less controlled by an instructor or outside researcher[15]. The objectives of the co-creation activity were to promote students':

- Collaboration and affinity for teamwork and collective thinking, nurturing a culture of creativity, shared vision and communication;
- Ability to visualize and propose graphic/visual representations that synthesize ideas;
- Various cognitive processes and ability to make changes in their perspectives of current works;
- Reflection-in-action, or ability to use design as a reflexive conversation with the situation, which helps them to deal with situations of uncertainty, instability and uniqueness.[6]

Limitations

The sample size of 15 is too small to make any broad generalizations, and the gender representation is significantly different than in typical engineering curricula. Therefore, the small number of engineering students does not enable us to broadly construe our findings as representative of "engineering" as a discipline. These are typical limitations associated with qualitative research and with early phases of research in settings with small samples, but we do not believe that they diminish the value of this study, which comes from student and instructor insights about student transformations in terms of teamwork and tolerance for ambiguity. The qualitative information provided here offers value in the form of context-mapping, and some of the distilled lessons from the study were made possible because of the small sample size enabling the researchers to know the teams in more depth, and those lessons are still quite useful regardless of context.

Findings

This course was strategically designed to move students from a level of uncertainty through to a point where their comfort level with uncertainty was not a limiting factor in progress, and the course culminated with activities that helped emphasize this message to students and help them self-identify their personal stance on uncertainty avoidance. Through artifacts from these activities we are able to clearly identify key moments and characteristics within each group of students as they relate to overcoming uncertainty avoidance. In the discussion below, we first provide a description of the co-creation design activity aimed to promote reflection and awareness about the nature of the innovation each group was proposing. Second, we provide a brief summary of each project team in regards to their performance during the final presentation session (and also their trajectory along the design process). We identify their major areas of struggle, and how they emerged from the course at the end of the semester. Following these summaries, we include a discussion of patterns we recognized in individual student final reflection documents. These reflections provide even further insight to key moments throughout the semester where both individual students and whole groups overcame points of struggle and recognized how to persist through these challenges.

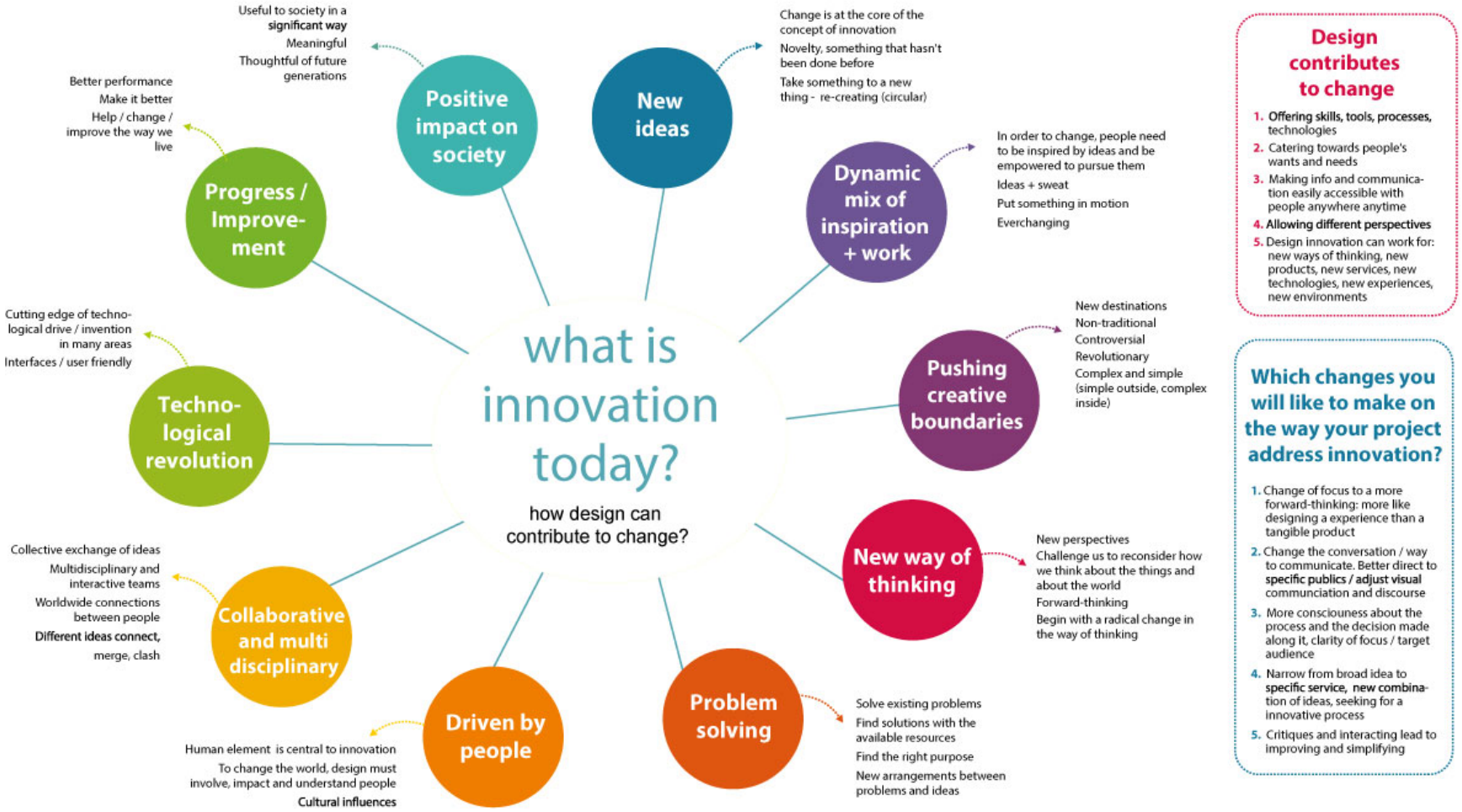

Figure 5: Synthesis of visual maps and group discussion from the co-creation activity (Organized by Najla Mouchrek, 2016)

Co-Creation Design Activity

Each stage of the co-creation design activity resulted in enthusiastic discussion among students and instructors. Since the groups had learned about the critique process throughout the semester, they were willing and able to connect what was discussed in the co-creation activity with a review and critique of their semester-long project. Using the insights about design and innovation from the activity described above in the Methods section, each group proposed worthy insights and even changes of perspective on their approaches to their semester-long project. This was an exciting yet unexpected outcome from the co-creation activity.

Some aspects raised by the students in this activity are directly connected to the link between innovation and uncertainty, and the students appeared to explore this link in a positive way, highlighting aspects of uncertainty such as change and evolution (see Figure 5). Overall, students described innovation in clusters around five aspects:

- **Progress, improvement, technological revolution.** Innovation as a way to make things better, to improve the way we live, particularly through invention and technological drive.
- **New ideas / Problem solving.** Innovation as something that has not been done before; novelty; including creation and re-creation and new perspectives for products, services and experiences, and also new ways of framing and solving problems.
- **New ways of thinking / Pushing creative boundaries.** Innovation as challenging ourselves to reconsider how we think about things and about the world, i.e., radical change in ways of thinking. Innovation as new destinations; non-traditional, controversial and revolutionary processes.
- **Collaborative, multidisciplinary and driven by people.** Innovation as product of collective exchange of ideas and convergent work of multidisciplinary, interactive and sometimes world-wide connected teams. The human element is considered central to innovation; importance of understanding people's needs and point of views and cultural influences.
- **Positive impact on society.** Innovation should be useful to society in a meaningful way, including being thoughtful of impacts on and needs of future generations.

The students considered design to have a relevant role to contribute to innovation and change, offering skills, tools, processes and technologies, facilitating innovation processes and fostering new ways of thinking and developing new products, services, experiences, and environments.

Patterns from Student Presentations and Final Reflections

The following results section describes patterns we observed in work that students completed at the end of the semester. We describe each team as a case study, incorporating our observations of their progress throughout the semester and how that progress culminated in their final projects. We also include data from their written reflections to provide examples of their perspectives.

Group 1: *Fournir* was a group of five students representing mostly hard sciences, but included one student enrolled in the fine arts program. The topic of their project was in response to their struggles, as students living off campus, to change their living situations each year. The major issue they identified was having the ability and resources to move large furniture and other

household items to a new apartment after their lease was up. They also recognized that many students held 9-month leases and didn't have a place to store or move their furniture until their new lease began. This team had a very strong idea from the very beginning of the class and was very successful in the early stages. However, as they received consistent feedback from both experts and their peers on ways to pivot and improve, they remained fixed on their original idea with very little movement. This group was the least successful in terms of progress on innovation, but several of the students were able to reflect on specific points of personal growth and identify what was learned through this experience. Through what we gathered in personal reflections, this group was, perhaps, the most successful in terms of identification of their own uncertainty. For example, after the co-creation activity, this group declared that they wanted to change their focus, understanding that they aimed to design an innovative experience to users, instead of a new product or service.

For example, one of the students who came to the class with a set idea later reflected that, at the conclusion of the course, "I realize how limited our scope for ideation and learning was because we started off with such a concrete idea." Another student, who self-identified as "exclusively a worker," reflected that "our research lacked depth and our overall growth as a product was rather mediocre." The group's weakness was in being unable to identify how to move through that uncertainty. Because they got stuck in a pattern of shared leadership with difficulty making decisions and encouraging progress, there was little that could be done to help them. The instructor team offered the same type and amount of feedback to this group as they did to other groups. What they did with it, however, was a little surprising in the sense that although they appeared very receptive and bold during discussions with the larger group, it was evident they became dangerously reserved when they returned to working in their smaller group. The danger in this was that other group members were hesitant to share their ideas, which created a detrimental point of paralysis for the whole project. One team member, however, reflected at the end of the semester that

> as we progressed I was more comfortable with my teammates along with understanding the problem with furniture as well as collecting more information during the interviewing process. This made me realize I can grow as an individual within a group of total strangers, which is an important feat for my future.

As expressed in their final reflections, each team member recognized this reluctance to share and change ideas, so the hope is this experience and recognition will help them work through future situations of uncertainty and discomfort.

Group 2: *IntoIt* was a group of three students, two engineering and one enrolled in studio art. At the start of the semester, this trio of students had extreme difficulty deciding what idea they wanted to pursue. During week four, the class session in which all students had to decide what idea to pursue and form semester-long teams, each of these three students wavered from group to group, idea to idea, and we watched them swim around in their own uncertainty. Out of default, mainly because other groups were at full capacity, they were forced to be together. As a group, however, they recognized a variety of issues within our public education system in regard to building career awareness for students. They struggled to find a specific problem space, but knew they wanted to address a more effective system for getting a larger percentage of middle

and high school students interested in exploring career pathways. Due to their continuing struggles, by week five these students were prepared to drop the course because each of them was failing to solidify a connection to the problem space and to each other. The group leader's reflection frankly stated, "I think our group did a great job of NEVER GIVING UP because at the BEGINNING I definitely wanted to." At the end of the discussion of the co-creation activity, this group presented their perception that they were more conscious about their own innovation process and the decisions made along the way and that they felt they were benefitting from an emerging clarity of focus, particularly regarding the target audience. Instead of pivoting, at that point they reaffirmed their trajectory.

The instructors and one of our guests from industry met with these students early in the process and talked through their questions and uncertainties. It was during this time that it was apparent that while this was a group struggling to find identity, they were very dedicated and would work hard to succeed. Throughout the semester the instructors saw a significant shift in the students' ability to look beyond their own perspective of things, to listen, and to incorporate peer and professional feedback in their thinking. The students were self-aware of this shift; in fact, one of these students suggested that a way to improve the course would be to require more customer discovery activities. They pivoted several times and, in the end, were the most successful in terms of progress on innovation. Their final reflections revealed that though the course was initially uncomfortable for them, they were all able to cite self-improvement and significant progress. For example, one student noted, "I was extremely proud of where we ended up with our final project especially because we had a lot of trouble at the beginning and throughout our process." Another student stated that they had to learn that "everyone needs to take initiative and be actively engaged for the group to function." The team's persistence was evident, and they were recognized by peers and instructors as being highly successful.

Group 3: The *Pick-Click-Play* group included four students, each representing different disciplines and bringing strong and bold personalities to the project. The instructors immediately saw a challenge. The students, however, seemed to see nothing but an exciting opportunity to do something big. With so many big personalities, they pivoted repeatedly and dealt with inner group conflict and many different ideas being entertained. They had to take several steps back for every step forward and had to learn how to really listen to each other, their peers, the instructors, and their potential customers. For example, one of the students attributed the group's success to "our ability to pivot so smoothly, but that was only possible because we came to value each other's opinions and thoughts." As a group, they chose to tackle an issue presented to the class by one of the industry partners. The issue identified our state park system's struggle to attract visitors and maintain activity in the state parks. The state park system was exploring programs to develop to attract more diverse audiences as well as incentive programs for exploring the state parks. The challenge for this group was to develop suggestions or plans for the state park system to explore.

Within the discussion on the co-creation activity, the group explained that they had chosen to change the way to communicate with their audiences ("change the conversation") and that they were adjusting their discourse and visual communication to specifically address parents and students. Their final presentation idea was very different from where they began, and they even moved well beyond the initial design challenge presented to them. In a final reflection, one of the

students recognized that "ideas don't have to be the 'right' ideas. Rather, they are just a stepping-stone and often a sense of inspiration for others." As they transitioned, they never lost sight of their internal value proposition,[16] which became a home base for them throughout all of their struggles.

This group was successful in the ideation process and remained vocal about areas of struggle and uncertainty, another student reflecting that "everyone proved to have a different outlook on every situation," that "things were a bit rocky" and they "struggled to communicate at first." At times this created issues within the group, but they were continually encouraged to keep moving, which they did. One member characterized this as "feeling stuck and at a loss of what to do [... but then learning] to push forward and continue to think out of the box and do so as a group." The final presentation, including a video that humorously depicted the group as a family on a fun weekend outing, was a clear reflection of how they overcame the struggles and began to operate respectfully and of the same mind. They eventually reached a point where each of them was a significant contributor, and they were very proud of their work.

Group 4: *Study Solutions* was a group of three students, two of whom were majoring in architecture+design. This group was jokingly labeled as the *silent attackers* in the instructor reflections because they progressed almost imperceptibly throughout most of the semester but surprised everyone with a breakthrough at the end. The students in this group were primarily concerned with making valuable use of space on our campus to design learning environments for students to use as study spaces. They explored a variety of options – from plans for a brand new building to the renovation of existing classroom and study spaces that were deemed highly ineffective for learning and collaboration.

Throughout the entire semester, it was very clear that they remained uncomfortable with uncertainty. For example, they characterized the class as "an emotional roller coaster," "a risk," and "a long and daunting process." They also struggled with multiple group issues, including a reluctant leader, one student dealing with a serious illness, and another struggling to balance workload across different responsibilities.

The instructors worried that the group would never understand the purpose of critique and pivoting ideas. While they appeared overly submissive and receptive, their work and presentations did not reflect this because they stubbornly stuck with one initial idea, despite consistent feedback by instructors and peers to consider other options. One student acknowledged this, admitting "in the beginning of the semester, I would hold onto my ideas much tighter than I do now."

However, as one student noted at the end, they "ended up with an almost completely different, yet practical proposal." In collectively looking at multiple activities throughout the semester, this final pivot can easily be attributed to the co-creation activity, described above. During this time, the members of this group finally took the open opportunity and permission to internally reflect on the concept of innovation and identify the missing link in all of their work. It was through this time of reflection that they moved to a much broader concept of innovation and finally embraced change. No one in the audience was prepared for their final presentation in which they clearly

overcame all of their personal and group challenges and pulled it together to offer a stellar presentation and idea.

Discussion

The course was designed to increase student awareness of uncertainty and its potential link to increasing creative practice, and this paper focuses on instructor observations and student work as they worked through complex, open-ended problem spaces. Specifically, the instructor team integrated design thinking as a strategy for teaching and learning to help students increase their comfort with uncertainty[17]. Throughout the course, the instructor team drew from participatory design strategies with the intent of immersing students in collaborative and often ambiguous problem spaces that were also "safe" in terms of minimal grade-based consequences. For instance, although the instructors provided students with diverse and constant feedback, they did not provide them with well-structured problems. In fact, the feedback the students received usually presented even more potential avenues for framing their problem spaces. The instructors stated their goal was to provide opportunities for them to work through and reflect on the ways they manage uncertainty. However, they also provided strategies for them to use, including tools such as the business model canvas[18], ideation techniques[19] and co-creation activities.

At the core of the participatory instructional methods, there is a range of activities of *co-creation in design*. This phrase describes a way of progressing through a problem or design scenario that allows the participation of various actors, working together in the development process[14]. Co-creation activities stimulate systemic thinking, encourage people to be active participants, reveal new ways and possibilities of doing things, empower people to engage as active citizens, and seem to strengthen the sense of trust, an essential ingredient for bringing about any real change[20]. Activities of co-creation in educational settings constitute promising initiatives to develop contexts for change and to foster a culture of innovation, in which the central reference is the participation of the students, their contributions and their own references.

Participating in co-creation activities such as those described above and included throughout the course can address many levels of creativity: inspiration, appropriation, making, and productivity[14]. One way that co-creation and collective construction of knowledge help students to deal with uncertainty is the fact that they enhance the processes of *appropriation*, which strengthens their understanding of the context and enhances their ability to influence it. In the particular case of this course, students creatively appropriated the concept and the landscape of innovation; while making it their own, they became able to critique and change their own approaches to the projects. Another important feature linked to managing uncertainty is that co-creation activities provide opportunities for experimentation in which students can explore the possibility of creating solutions their own resources and motivations for action, while creating possibilities of developing concrete and action-oriented projects[21].

In the next iteration of this course, co-creation activities will be integrated earlier, from the beginning, and developed three times throughout the semester, including scaffolding according to the students' projects development phases. These activities promote ownership of the process by the students and also allow the instructors to invite students to revise their decisions and courses of action within the projects, *based on their own ideas and reflections* about the subject

(as seen in Stage 3 of the Co-creation Activity, on page 5). The proposed plan to integrate co-creation activities throughout the course includes:

- ***First iteration, at the beginning*** of the course (2nd/3rd week), aiming to facilitate groups in context-mapping and first approximation with their object of study and their project;

- ***Second iteration, in the middle*** of the course (6th/7th week), aiming to support students in understanding how well their initial decisions within the project are addressing the main underlying questions and to what extent the project development is aligned with the premises chosen by them in the beginning;

- ***Third iteration, close to the end*** of the course (12th/13th week), aiming to promote reflection about the nature of Innovation and different approaches to that; and inviting students to change how their projects are addressing innovation, if needed (similar to what happened in the original iteration, reported in the present paper).

Within these activities, some concepts and dynamics of systemic thinking will be presented and modeled for the students. Applying systems thinking into design processes, through the use of tools such as concept maps and systemic maps, the instructors will prepare students for dealing with complex situations, visualizing individual components and their relationships with the whole to propose solutions[22] Beyond developing technical skills and abilities of analysis and realization, learning to conduct research and project also promotes self-esteem, autonomy and empowerment among students[23]. The relationships among different disciplines and the nature *of Innovation as a point of convergence* for ideas, modes of research and development coming from these multiple areas will be also highlighted in the co-creation activities throughout the course.

To summarize, uncertainty is critical in creative practice, and both instructors and students need to learn to manage our uncertainty (tolerance for ambiguity). In this course, students experienced multiple levels of uncertainty and instructors offered permission as part of the course design to *safely* take risks, fail, and move forward. As a result, final products were much more innovative and creative in nature than ideas presented at the beginning of the class. Students recognized the importance of the challenges they faced (group dynamics, work dynamics, distaste for the course design and overwhelming amount of group work, etc.) in moving through the creative design process.

With that in mind, we look to student reflections, specifically those of the engineering students, to identify strategies that contribute to creative practice and to help students overcome uncertainty. If we look specifically at the four engineering students enrolled in the course, they were consistently the more reserved members of their group. However, in reading their individual reflections, it was clear they experienced a considerable amount of uncertainty but were still able to make contributions, gain confidence, and recognize the value in the course design in contrast with their other courses. Beyond developing technical skills and abilities of analysis and realization, learning to conduct research and project also promotes self-esteem, autonomy and empowerment among students[21.]

Each of the students had several responses that spoke to the team aspect of the course. One states that,

> I have been on teams where we have solved challenges and created things but in those situations we have been so product driven and obsessed with having something that works that we have often skipped over crucial steps in this ideation process. […] I had also never tried to solve a customer driven problem and I found the customer discovery process to be incredibly fascinating.

Another student reflected on their personal role within groups and stated, "This class provided me the opportunity to get a good look of how I work in groups. It made me truly realize that everyone needs to take initiative and be actively engaged for the group to function."

One student reflected on the role s/he played as well as mistakes made in regards to group participation and interaction. The student reflects,

> I learned a lot about and improved my ability to work within a group, fulfill a role within a group, and to identify problems and formulate solutions for those problems. The longevity of the projects assigned in the class far exceed most projects students take on, meaning that a healthy group dynamic is essential and the fact that we're all working under a common goal is key to the project's success. I should seek to improve my dynamic within groups to be more impactful rather than falling in one of two roles. My communication and eagerness to work, especially in group settings, also saw minimal improvement. These are skills and qualities that really need to be embraced for group success.

In addition, the engineering students acknowledged both their own strengths and the strengths of others, identifying areas of nexus as opportunities to learn that they either exploited or missed. For example, two students shared positive self-assessments about the value of working with others. One student reflects, "I have also learned a lot from just being around people that have greater skills than I do." Another student states:

> Also, I realized when people pitch ideas, they don't pitch them as final ideas and actually hope to get feedback. So, if I'm not actively engaged, not only am I not contributing ideas, but the ideas that are pitched by my partners are incomplete since I wouldn't be giving proper feedback.

Engineering students recognized that by playing a more assertive role, even in an area outside of their comfort zone, they could have improved the team's product by improving the team's process. Another student admitted,

> In retrospect, I wish I took a role in optimizing our presentation and providing more depth to the final project. My assumption was that those in charge of the design of the product would be able to best represent it. However, it would have been important for us to mutually understand the product and develop presentations that were better formulated and that we were more passionate about.

Students from other majors also reflected on the value of being flexible enough to change directions and learn from students in other disciplines, but the engineering students were often the ones furthest from their comfort zones.

Future Direction and Questions

In this paper we have reviewed the concept of managing uncertainty avoidance, particularly in connection with design thinking and increasing creativity in interdisciplinary teams that include engineering students. This data analysis has provided initial directions for addressing our research questions. To begin answering the question of how uncertainty avoidance plays a role in developing creative practice especially in interdisciplinary teams, we have observed that students often experience significant discomfort when working with ill-structured problem spaces. While engineering students may be more likely to be averse to uncertainty and risk, it is important to ensure that all undergraduates increase their ability to work with complex, open-ended problems—the types of problems that are likely to involve ambiguity and uncertainty.

Also, participation in interdisciplinary teams presents a common objective for all students: in these settings they need to embrace their own budding expertise while expanding their perspectives to other fields. These types of collaborations thus inherently involve ambiguities that can lead to uncertainty. Drawing on the notion that tolerance for ambiguity and design creativity are closely intertwined, we have explored the experiences of students in an interdisciplinary course that purposely embeds ambiguous problem spaces and introduces strategies to help students be more aware of and more comfortable with uncertainty.

In terms of the question of strategies for overcoming uncertainty avoidance, the design and teaching of this course has led us down several paths of coming to better understand uncertainty avoidance both in instructors and students. The instructors experienced discomfort with uncertainty as well, finding it difficult to allow students to struggle and progress at different rates. For students, it is not clear what lasting impact this single course experience will have on transfer to other coursework and professional situations. However, we have identified a few areas for future exploration that will help us identify broader and longitudinal impact.

First, as the course is slightly unstructured, we recognize that this lack of clear structure contributes to uncertainty. If the goal were to minimize uncertainty, the course should be more structured. However, a major purpose of the course is to give students opportunities to identify areas in which they feel most uncertain and give them the support and permission to work through that. Strategies included coursework that challenged students to work across disciplines, to entertain multiple approaches in open-ended, complex problem spaces, and to respond to critiques and continue "pivoting" throughout the semester. The course activities also included reflective practice, both in individual writing prompts and interactive co-creation activities.

The student accomplishments and reflections reported here indicate that student conceptions of uncertainty and success shifted throughout the semester; even in cases where students were not satisfied with their projects, both students and instructors recognized growth and increased awareness of the interrelationship between uncertainty and creativity in the interdisciplinary, collaborative design process. Thanks to the reviewers of this paper, we are also considering pedagogical improvements. For example, a potential learning opportunity would be to have the

groups share summative evaluations and lessons learned. Increasing inter-group learning was also suggested by several of the students in course evaluations. We are also planning to incorporate tools for teamwork evaluation, both pre- and post-experience, that would be used by both students and instructors to improve collaborative learning. If the course were to be successful, students could transfer ways in which they worked through their uncertainty in a loosely structured and supported way to other coursework and professional situations, regardless of structure. We will continue to explore points of transfer and work to identify more rigorous methods of measuring what activities contribute to that transfer.

In addition, as we reflect on the design of the course, we take into consideration a number of questions. One question involves exploring what elements of the course are specifically designed to help students overcome barriers to uncertainty avoidance. Is it the low-risk environment or the encouragement to fail? Do the studio-based critique sessions give students the space and time they need to recover from failure and move through uncertainty? How critical is it that instructors serve as models in illustrating multiple ways to arrive at a solution or answer? Does reflection and open dialogue truly contribute to student progress?

Finally, we recognize that a single point of exposure (i.e. a single course) may not have the lasting impact we desire, especially for engineering students. Also, we note that the context is somewhat exceptional: honors students in a classroom with a 1:5 (3:15) instructor to student ratio, bolstered by expert guest speakers and panel of knowledgeable professions to give feedback. However, the lessons learned from this course can be modified and adapted for other, less exceptional contexts. As such, we are linking a series of courses designed to improve management of uncertainty avoidance and increase creative practice. We are currently in the process of designing the structure for a scaled general education minor in innovation, which would require students to take a series of courses aimed at addressing multiple facets of innovation. The first course explores the history and critical perspectives of innovation and innovators. The second course, that which is described throughout this paper, focuses on giving students practical experience in design for innovation. The third course provides an increased emphasis on market feasibility and a customer-based approach to innovation, giving students the opportunity to work with real clients and move toward market actualization. The final course is a capstone experience to be designed through the student's home department to tie all elements of the minor together in a way that illustrates the impact of the series of courses on student creative practice. We believe the longitudinal picture of student experiences that we can build through this minor will provide insight to the questions we pose above to understand the critical elements for helping students move through points of uncertainty within a variety of contexts.

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