Work in Progress: Mind and Skill Sets for Innovation: Preparation for a Rapidly Changing World

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Abstract*— How innovative are you? High levels of innovativeness are correlated with high-value creation, and today's rapid pace of change requires new skills for lifelong learning, curiosity, innovation, and continuous improvement. To what level can personal innovativeness be improved through curricular innovations and how do we improve students' practical skills for ongoing discovery? Innovation Mind and Skill Sets for Design and Research is a new course that focuses on providing STEM students the broader mind and skill sets that will help them connect their specialized work to the larger system and the society it impacts and effectively experiment, discover, and create value in the highly dynamic and uncertain environment of breakthrough innovation. This paper will discuss the development of the course which Hipwell based on both innovation literature and her own two decades of experience applying and improving innovation business processes with her teams in a fast-paced, high-tech industry. An educational class structure and learning outcomes are developed based upon the theory that innovation is itself a learning process and can be improved through the known learning science concepts of improvement of student metacognition about their innovation process and incorporation of intention and reflection in their learning cycles. Further, the model incorporates literature on teaching system thinking and Transformative Learning Theory for adults. Content is developed that teaches the students practical techniques that scaffold their innovation process and increase their metacognition. Movement up levels of Bloom's Taxonomy and long-term habits are developed through the practice of the innovation process in a team project with expert feedback from an experienced innovation practitioner. Learning is increased through reflection on the process during class presentations. Measurement of student improvement results compared to control design curricula using the Innovator Mindset® Assessment is also discussed.

Keywords*—*innovation, metacognition, mindset

I. Introduction

Technology is becoming increasingly complex [1] and the pace of technological change and disruption is accelerating [2]. Organizations need employees who can effectively handle unexpected and unfamiliar challenges. As a result, innovation has been identified as a crucial element in the survival and success of organizations within the workplace [3, 4]. University students are a significant contributor to future innovations in organizational contexts, as they will become the workforce of tomorrow. Consequently, one of the objectives of engineering education should be to equip those students with the skills related to innovation that are essential for surmounting such problems and for thriving in this dynamic environment. Despite the urgent need for innovation mind- and skill-set development, many university programs have not successfully incorporated it into engineering education [5, 6]. Although there is a consensus among educators, researchers, and practitioners regarding its significance, the understanding of the pedagogical methods and learning tools that can improve students' ability to generate and implement new and useful ideas remains limited [7]. Our belief is that innovation is in itself a learning process – an innovator is learning what is an effective or value-creating solution to a problem – and by making students more aware of their innovation process (metacognition), we can also increase their innovation process learning [8] and therefore improve the speed of innovation. Our hypothesis is that if we teach students to be mindful of their innovation process and equip them with practical tools that scaffold this process, we can increase their innovativeness. Repeated practice is necessary for the formation of a habit, and our objective is to assist in the implementation of these processes through these tools until they become unconscious habits.

II. Literature Review

As noted by Pisano [9] in a recent Harvard Business Review, innovation culture is often thought of as freewheeling and unstructured. On the contrary, innovation researchers have found in the most effective organizations that the process of effective experimentation in complex and uncertain environments is actually highly disciplined. In the 21st century, innovation has been heavily researched [2, 10-18]. Effective methods, processes, and approaches have been characterized

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and can be applied to improve the effectiveness and impact of experimentation and research. Engineering curricula usually prioritize technical courses to teach established solutions and known knowledge in their field. This is with good reason, as noted by Leslie [1] since new ideas are often old ideas combined together in new ways or applied in a different context. The "expert's" subconscious mind makes long-term memory connections, so those with deep and broad knowledge can be considered fertile for new ideas. However, the innovation process is not merely the application of known knowledge, but the discovery of new knowledge and may involve different skills and processes from those that help students acquire and master known information.

To explore how innovation can be integrated into education, we need to recognize that thus far there are established techniques to enhance the creative thinking process [19-21]. A plethora of literature exists that delves into the realm of augmenting creativity within educational settings [22-25]. Researchers and educators alike have recognized the significance of fostering a creative learning environment and have devoted considerable attention to this area of study. According to Daly et al., educators can offer students diverse types of assistance in developing their creative skills [6]. Another study suggests that integrating interdisciplinary teaching and providing instruction in creativity techniques can effectively stimulate divergent thinking abilities [26]. Nussbaum et al. propose an alternative approach, contending that enhancing creativity can be achieved by eliminating obstacles to creative thinking [27]. Although there are significant theoretical contributions, it has been noted that the lack of observational research on the creative process poses a significant challenge in devising practical recommendations for fostering creativity in educational contexts [28].

Innovation encompasses the *application* of creativity. It is crucial to note this definition entails additional steps beyond generating creative ideas. Consequently, teaching innovation requires educators to incorporate not just techniques for promoting creative thinking, but also methods for implementing novel ideas in a valuable way and being able to assess impact. Acar and Tuncdogan propose that an open and discovery-oriented inquiry-based approach that involves teamwork could effectively encourage innovative behavior among students [29]. There are studies that investigate the effectiveness of problem-based learning in cultivating both discipline-specific and transferable skills required for innovation [25, 30-32]. Martin et al. explore the practical implications of fostering innovation in the higher education context [3]. The majority of this research mainly focuses on theoretical concepts, with minimal attention to classroom-based studies or teacher-student interactions. On the value side, the National Science Foundation has created the Innovation Corps™ Program that helps researchers understand customer and market needs and value propositions for their discoveries [33]. Both the focus on generation of creative ideas and the understanding of customers, markets and value propositions are extremely valuable skills for students to learn. To generate new products and impacts effectively, however, one must possess proficiency in the entire innovation cycle: ideation, implementation, measurement, and reflection on observations. Curricular offerings and pedagogical approaches for developing skills in application of the *complete cycle of innovation*, which encompasses creative ideation, application, value measurement and reflection, is still insufficient. Without addressing this disconnect through comprehensive changes to engineering education, we run the risk of graduating engineers who lack the necessary skills to confront the challenges that arise from the swift changes occurring in society.

Although there are many efforts underway to enhance engineering programs' effectiveness in preparing students for value-generating, industry-focused careers, a full framework is still lacking. The course instructor has a depth of experience in industrial practice where she has experienced anecdotally that innovation process skills can be developed in her team members and development of these skills does increase performance in the breakthrough innovation space. She has now piloted a first iteration of explicitly teaching what she learned leading, teaching, and mentoring innovative teams in the industry to senior undergraduate and graduate students. The content of the initial pilot course was based on research about the knowledge, skills, and attributes of successful innovators and innovative organizations. The approach is based on learning science in the areas of teaching complexity, systems thinking [35, 36], and creativity vs. risk [37], as well as intention and reflection [38] and the exploration/exploitation ratio [39]. The intended first step of this work is to use the feedback from this pilot program to tune the approaches while gathering the evidence that will motivate more interest from both students and faculty members to ensure the skills presented are more explicitly and effectively taught in all programs for engineers.

III. Theoretical Framework

Stauffer [40] identifies the four dimensions of innovativeness as creativity, bravery, awareness, and openness and identifies the cyclical process of observation, reflection, creation, and action. In [41] Stauffer studies the relationship between these habits and value creation in entrepreneurs. His analysis showed a statistically significant relationship between an entrepreneurs' Innovator Mindset® assessment score and performance indicators of their ventures, such as revenue, profit, and the number of jobs created [41]. Based on this identification, a course was developed and below are the learning outcomes:

The intended learning outcomes for the course are:

1) Cultivate expertise that is crucial for pioneering innovators.

a) Recognize the four facets of innovativeness and employ strategies to enhance both innovativeness and behaviors.
b) Identify the Innovation and Status Quo cycles, and select the most suitable cycle for a specific task. Execute entire

cycle and engage in iterative processes to enhance learning and advancement.

c) Utilize intention and introspection to enhance the application of the scientific method and the innovation cycle. Implement the Observe-Reflect-Create-Act cycle.

2) Actively cultivate the mindsets commonly found in serial innovators.

a) Recognize both growth and fixed mindset approaches, and employ a growth mindset when assessing, improving, learning, and dealing with failures.

b) Explain and utilize methods to enhance cognitive curiosity and the formation of ideational connections within the brain.

c) Recognize operational mental models and underlying assumptions, assess their influence, and explore methods to validate their accuracy.

3) Apply a blend of innovator skillsets and mindset in practical innovation challenges.

a) Implement the Serial Innovators' approach by formulating research inquiries to enhance fundamental comprehension and identify high-impact problems. Engage in an iterative process that encompasses technology, customer, and market feasibility assessment.

b) Recognize minimum viable products that facilitate rapid learning and integrate them into iterative build-measure-learn sequences.

c) Quantify R&D progress through learning measurement

d) Utilize Failure Modes and Effects Analysis (FMEA) to guide experimentation.

e) Recognize essential inquiries and the necessary knowledge required for decision-making.

f) Application of management techniques for team improvement

g) Utilize leading measures to improve innovation impact

IV. Methodology

Using these learning outcomes as a foundation, the primary principal investigator developed a course titled "Innovation Mind and Skill Sets for Design and Research". While this course falls under the mechanical engineering department, it was accessible to students from all majors. The focal point of this course revolved around a group project that spanned the entire term, where students collaborated to create a novel product or enhanced an existing process through innovation. Critical to the course pedagogy is the application of these innovation methods in a research and technology development team project. Many of these concepts sound simple in theory, but in practice are often tricky and nuanced to implement. Students received practice, guidance, and coaching from an expert innovator practitioner as they wrestled with concepts, such as "What do I really need to learn?" "How do I set up my experiment for maximum learning?" "What are the assumptions upon which success of my project most depends?" and "How do I test those assumptions?" Students presented their work regularly and received additional feedback from peers. The team project allowed for multiple build-measure-learn cycles to be completed so that the students experienced the nature of iterative learning and how it can be used to accelerate technological progress. The effectiveness of the program in innovative mindset improvement and innovator skillset acquisition was assessed using the Innovator Mindset® instrument [46]. Innovativeness, as measured by this assessment has been shown to correlate to value creation [41]. The students took the assessment at the beginning and end of the program. Each student received their results and had the opportunity for an individual meeting with an instructor certified in the instrument so they could get feedback on their current mindset snapshot, including areas of strength and opportunities for improvement. Additionally, students from two different design classes also took the assessment to serve as a control group.

V. Results and Discussion

Figure 1 illustrates the pre and post-IM assessment scores of the control and treatment groups as box plots. It shows the summary statistics, such as mean, standard deviation, quartiles 1 and 3, and the minimum and maximum, of the pre-and post-IM assessment scores for the control and treatment groups

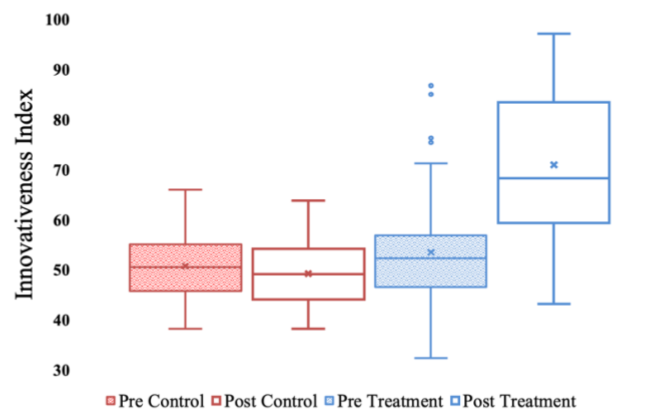

Fig. 1. *Box plots of pre and post-IM assessment scores of control and treatment groups*

The results were also evaluated using a one-way ANOVA tests at a 95% confidence level ($\alpha = 0.05$) between the pre and post-IM assessment scores of the control and treatment groups. The control group is comprised of 18 engineering students who were exposed to other design courses, such as Bio-Inspired Engineering Design, Introduction to Mechanical Engineering Design, and Advanced Product Design within the mechanical department at Texas A&M University offered to undergraduate (400 level) and graduate (600 level) students. The treatment group is composed of 83 students who have previously taken the "Innovation Mind and Skill Sets for Design and Research" course. Figure 1 illustrates the results of the three ANOVA tests conducted for the data. The comparison between the pre-control and treatment groups yielded a p-value of 0.28, indicating a statistically comparable level of innovativeness among both student groups at the semester's *commencement*. A clear distinction between the two groups lies in the data spread: the pre-treatment group exhibits a significantly broader range than the pre-control group. This discrepancy can be attributed to the larger sample size of the treatment group (83) compared to the control (18) group. The pre- and post-control group resulted in a p-value of 0.53, suggesting the innovative capabilities of the control group remained the same despite participating in other engineering courses. The control students' capability to innovate was even lowered, as the average innovative index dropped from 50 to 49 and the data spread also reduced. These reductions at the end of the control groups' exposure to traditional design courses may hint at the possibility of the current curricula reinforcing the application of the known (Status Quo cycle) rather than discovery of the unknown (innovation cycle), which is crucial in the finding of new and novel products/processes. The pre- vs post-treatment groups resulted in a p-value of 0.00, confirming a statistically significant difference in the innovativeness index between the treatment students *after participating in the course*. The average innovativeness index pre-treatment was 53, while post-treatment increased to 71. This increase of 35% in innovativeness can be attributed to the students exposure to the treatment curriculum mentioned above. Furthermore, it is worth noting that over 50% of all treatment students achieved an innovativeness index higher than 70, with the highest score recorded at a 97. These findings are notable because innovative index scores of 70 and above are the top 10% of scores, what Stauffer refers to as "elite innovators," with a strong correlation to provide *much greater value* [41].

VI. CONCLUSION

The work presented here has shown that we can scaffold innovation process with the tools outlined in the theoretical framework. The results demonstrate there is a statistically significant improvement of 35% in a student's innovativeness when exposed to a curriculum that teaches them metacognitive skills & processes, encourages students to embrace curiosity and explore the unknown. This course serves as an example of a course that facilitates the increasing need for students, the worlds future work force, that can adapt in an increasingly demanding and uncertain world and solve complex engineering problems to provide value and innovation. Future work will focus on taking a deeper dive into the data demonstrated to investigate the relationships between the demographics of the control and treatment groups. Furthermore, alternative metrics will be investigated, such as Selznick and Mayhew's metric that evaluates students' innovative abilities as a higher education outcome, apart from traditional innovation metrics [47].

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