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Engineering the Next Generation of Innovators: Analysis of Students' Innovation Habits

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Abstract

Innovation is the cornerstone of high value creation in today's rapidly evolving landscape. Successful innovation education requires an emphasis on lifelong learning, inquisitiveness, and an unwavering commitment to continuous self-improvement. This work is focused on the evaluation and design of a course called "Innovation Mind and Skill Sets for Design and Research," tailored specifically for students in STEM disciplines. The class equips students with a comprehensive innovation-focused skill set, empowering them to synthesize their specialized knowledge within broader societal contexts and, in turn, navigate the complex terrain of breakthrough innovation. This paper delves into the course's framework, which draws inspiration from the vast reservoir of innovation literature and two decades of the instructor's industry experience applying and improving innovation business processes with her teams in a fast-paced, high-tech industry. The core hypothesis of this paper is that innovation is fundamentally a learning process, that personal innovativeness can be cultivated and elevated through the teaching of established principles derived from the realm of learning science. These principles encompass the elevation of metacognition, the deliberate integration of intentionality into the learning process, and the embedding of reflective practices into the students' educational journeys. Additionally, the curriculum integrates pedagogical principles related to systems thinking and Transformative Learning Theory for adults. The coursework is designed to impart practical techniques that serve as scaffolds for students' innovation processes and enhances their metacognition. The journey through this educational framework leads to an ascent through the tiers of Bloom's Taxonomy, guiding students to cultivate enduring habits that are essential for the sustenance of the innovation process. These practical skills are honed through active participation in a team project, revolving around the innovation process, with guidance and feedback from innovation practitioners. The learning experience is further enriched through a deliberate emphasis on reflection, integrated into classroom presentations. These aspects of student progress and improvement are assessed against traditional design curricula using the Innovator Mindset® Assessment. The focus of this paper will be the analysis of four innovation habits (for graduate and undergraduate students) to analyze the impact of this designed course in fostering and amplifying personal innovativeness.

1.0. Introduction

University students play a crucial role in shaping future innovations within organizational settings, as they are poised to become the workforce of the future. Organizations require a workforce capable of adeptly managing unforeseen and unfamiliar challenges to respond to the current landscape where technology is growing in complexity [1] and the rates of technological advancements and disruptions are escalating [2]. Given the constantly changing world and dynamic challenges, students must develop the skills to comprehend and address problems in order to thrive in this dynamic environment—ideally, acquiring these skills before entering the workforce. A fundamental goal of engineering education is to impart students with the necessary innovative skills to overcome challenges and excel in a dynamic environment. This emphasis on fostering innovation should be integral to core engineering education. This work concentrates on instructing students in innovation, testing the question: "To what extent can innovation be taught?" While there is agreement among educators, researchers, and practitioners about its importance, there is still a restricted comprehension of the pedagogical approaches and educational tools that can enhance students' capacity to conceive and implement novel and valuable ideas [3].

Innovation is viewed here as inherently a process of learning, where innovators discern effective and value-creating solutions to problems. Heightening students' awareness of their innovation process, specifically through metacognition, this work aims to study increases in their learning of through conscious application of the innovation process, [4] and as a result improving their pace of innovation. The approach investigated here teaches students to be conscious of their innovation process and provides practical tools to support this journey, with the goal of enhancing their capacity for innovation. Establishing a habit requires repeated practice, and our aim is to aid in the integration of these processes through tools until they become ingrained, unconscious habits. The methodology employed in this work is grounded in the principles of learning science, particularly within the realms of teaching complexity and systems thinking [5, 6], creativity vs. risk [7], intention and reflection [8] and the exploration/exploitation ratio [9]. A more comprehensive exploration of the background literature for this research can be found in [10]. This paper focuses on an examination of four distinct student innovation habits and how the course design facilitates their development.

1.1. Four Habits of Student Innovation

Awareness, or maintaining a clear understanding of the surrounding realities, is an important habit for innovators. This goes beyond mere attentiveness, rather necessitating discipline and a proficiency in *effective* observation [11].

Openness, an innovator is often characterized as an individual capable of making acute observations, conducting experiments, and gathering data with the primary goal of avoiding the repetition of conventional thought patterns. A person's level of openness is shaped by how they respond to the feedback received [11].

Creativity: innovation is the application of creative thinking [12]. When an individual lacks creativity and imagination, they not only struggle to generate new ideas but also face challenges in foreseeing potential issues. Such individuals tend to have a more limited awareness of their surroundings and as a result heavily depend on existing knowledge, causing a resistance to others' ideas as they struggle to envision alternative possibilities [11]. Although *creativity* alone is not sufficient for fostering innovation, it constitutes a crucial element. Numerous studies have explored strategies to enhance creativity within educational environments [13-19].

Bravery, innovating involves experimenting with ideas that may not guarantee success, inherently embracing uncertainty. A novel and useful idea essentially serves as a hypothesis demanding evaluation (Will it succeed? Will it fail? How many attempts are necessary? Who is interested in this product?). Therefore, an innovator must grasp the art of effective experimentation and adeptly navigate associated risks [11]. Embracing the possibility of failure requires courage in the relentless pursuit of turning ideas into reality.

2.0. Curriculum Design: Theoretical Framework

Building on the current literature on innovation practices, a course was designed to encompass the four major commonalities found to be integral to the innovation process. These commonalities shown in Fig. 1 are (1) understanding systems through the use of models, (2) enhancing learning through thoughtful intentions and reflections, (3) quick experimentations that are adaptive and iterative involving the targeted customers, and (4) cultivating a growth mindset that supports improvement, constant learning, and persistence.

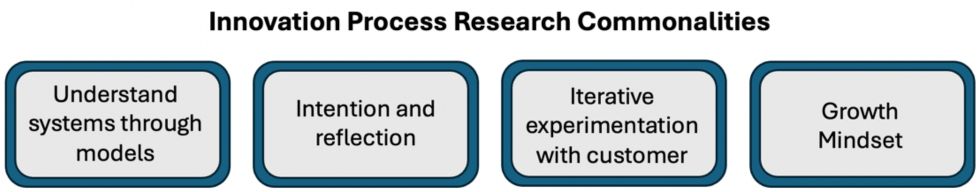

Figure 1. Common findings on successful innovator processes derived from studies on innovation research.

Guided by these principles, the Innovation Mind-and-Skillset educational framework was designed to enhance a student's capacity for profound learning, systematic and experimental thinking, aptitude for identifying and connecting with customers and colleagues, and adaptability to complexity. Cultivating these skills in students through this course is hypothesized here to positively impact their attitude, approach, and performance in pursuit of breakthrough innovations. The framework was also designed to blend teaching system thinking and Transformative Learning Theory for adults. The framework is based on 6 different aspects (1) Engaging with complex systems (2) clarifying key concepts (3) promoting collaboration and discussion (4) developing theories, models, and experiments (5) fostering awareness and critical reflection and (6) benefiting from expert coaching or mentoring. Developing lifelong learners requires a shift from traditional educational approaches [5]. Innovation Mindset and Skillset designs a curriculum for "advanced lifelong learning," a process where engineering students are taught how to maximize learning in all aspects of their work. The Innovation Mindset and Skillset's intended learning outcome can be divided into three categories: (1) developing students' skillsets, (2) cultivating students' mindsets, and (3) combining students' skillsets and mindsets. More information on the framework can be found here [10].

3.0. Study Methodology

An undergraduate and graduate level course named "Innovation Mind and Skill Sets for Design and Research" was developed based on these learning objectives. Although offered within the mechanical engineering department, this course was open to students across all STEM majors. The course's central focus is on a semester-long collaborative group project to devise an innovative product or enhance an existing process. Regular update presentations provide opportunities for peer and instructor feedback. The project facilitates multiple iterations of the build-measure-learn cycle, enabling students to grasp the essence of iterative learning and its role in accelerating technological advancement.

The Innovator Mindset® (IM) instrument [46] was employed to gauge the effectiveness of the classroom framework in enhancing innovative mindset and acquiring innovator skillsets. This assessment, demonstrated to correlate with value creation [41], was administered to students at the program's commencement and conclusion. Each student received personalized results (scores on awareness, bravery, openness, and creativity). Further details on the methodology can be found here [10]. The Innovator Mindset® (IM) instrument generates a score from 0 to 100, with zero representing a strong resistance to innovation and 100 indicating a high receptivity to innovation.

4.0. Results and Discussion

One semester of this course, with 14 undergraduate and 12 graduate students who agreed to participate in the study, is examined here using individual scores for creativity, openness, awareness, and bravery. These assessments were conducted once before the start of the class and once at its conclusion. The box plots (shown in Fig. 2) serve as a visual representation to depict the distribution of the IM score, enabling a comparison between graduate and undergraduate students across all four innovation habits.

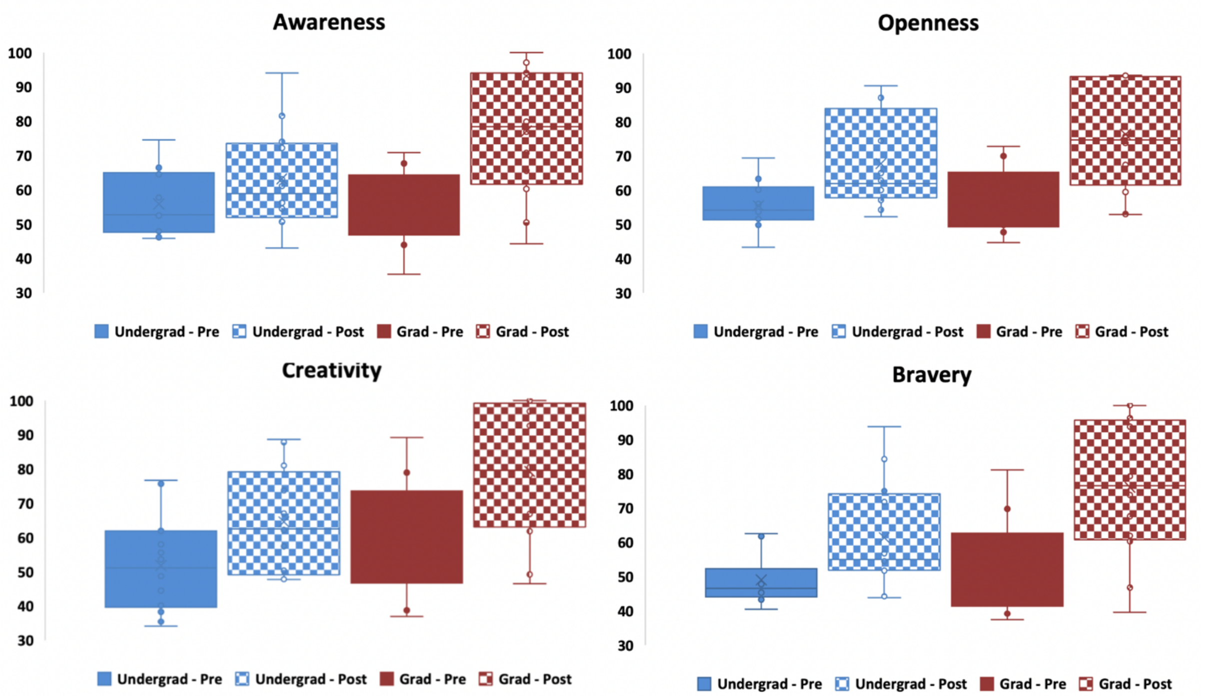

Figure 2. Box plots of pre- and post-IM for awareness, openness, creativity, and bravery assessment scores for undergraduate and graduate students

The *awareness* box plot shows that the median score of undergraduate students' post-assessments is similar to the median of graduate students' pre-assessment. The nature of graduate students' work involves actively seeking feedback, including critical input from processes like journal publication reviews and conferences, fostering a "tougher skin" and a higher acceptance of negative feedback. Additionally, the collaborative and diverse nature of the graduate student environment contributes to an awareness of various perspectives. In contrast, the undergraduate setting tends to provide more straightforward feedback – either affirming correctness or identifying errors. What stands out in these initial findings is that the course's structure has elevated the median awareness scores of undergraduate students to match those of graduate students who haven't taken the course. This could be attributed to the course serving as one of the initial/first experiences for undergraduates where success and failure are seen as relative indicators of progress rather than conclusive judgments. A more thorough analysis is needed to identify specific elements of the course contributing to this effect and determine if this trend holds in a larger sample size.

The box plots depicting *openness* reveals a similar pattern, wherein the median post-IM scores of undergraduates closely align with the median pre-IM scores of graduates. This further reinforces the notion that the course effectively imparts comparable skills to undergraduate students as their graduate counterparts who haven't taken the course. Notably, the box plot illustrates a narrower variation in the openness scores of undergraduate students. This may be attributed to the tendency of undergraduate students entering the course to be more locked into knowledge, influenced by previous courses that may have favored a more rigid mindset. Conversely, graduate students exhibit a more diverse distribution in their openness scores, characterized by a right-skewed pattern. This suggests a broader range of attitudes and perspectives among graduate students, potentially influenced by a variety of experiences and educational backgrounds.

Creativity stands out as the only innovation habit exhibiting a different trend compared to the others. In contrast to the remaining habits, the median post-IM assessments of undergraduates surpass the pre-IM assessments of graduate students significantly. This observation is particularly intriguing as it suggests that the course enhances the creativity of undergraduate students more than their graduate counterparts who have not enrolled in the course. This could be attributed to the course's teaching approach, which empowers students to challenge the status quo through practical tools. Furthermore, a noteworthy discovery emerges from the post-IM assessments of graduate students, where all values in the upper quartile closely approximate 100. This underscores the course's notable success in enhancing creativity among graduate students, emphasizing the effectiveness of the instructional methods in fostering creative thinking and letting go of reliance on existing knowledge alone.

The box plots representing *bravery* scores reveal that approximately 75% of the undergraduate pre-IM assessment scores fall within the lowest quartile of the post-assessment scores for undergraduates. This illustrates the substantial impact of the course in bolstering this habit among undergraduate students. A similar shift in scores is evident between the post and pre-IM scores for graduate students. Additionally, in line with other trends, the median post-IM score for undergraduates aligns with the pre-IM score of graduate students. Another noteworthy observation is the presence of a small number of graduate students scoring lower than their undergraduate counterparts in both post and pre-assessment. Further data is needed to comprehensively understand this pattern. It could be associated with an environment where these graduate students prefer adhering to established procedures and expect others to do the same. This might be influenced by hierarchical structures or advisor expectations that emphasize adherence to established rules and procedures.

These findings are noteworthy as they suggest that the course has the transformative effect of raising the innovation scores of undergraduate students to be on par with those of current graduate students. This transformation is significant, considering that if undergraduate students already possess such elevated innovation scores upon entering graduate programs, it could potentially contribute to a higher level of success. Table 1 facilitates a clear view of the diverse scores and rankings, clearly highlighting which student groups start off the highest or lowest and change the most. The table includes the averages of both pre- and post-assessment scores for the four habits, the percentage increase, and the highest post-assessment score for each category, comparing both undergraduate and graduate students.

Undergraduate students before enrolling in the course exhibited average scores in the order of lowest to highest across the categories (Bravery < Creativity < Openness < Awareness). Graduate students in contrast had average scores ordered from lowest to highest in the categories (Bravery < Awareness < Creativity < Openness). This sequence is interesting, particularly since both undergraduate and graduate students share Bravery as their lowest innovation habit. The highest innovation habit for each group differs, with undergraduates ranking highest in Awareness and graduate students ranking highest in Openness (although the variation between the four categories, as seen in Table 1, is minimal). This is potentially linked to undergraduate students being exposed to a broader range of subjects whereas graduate students have chosen a specific field for advanced study and research making them more specialized, potentially leading to a perception of lower overall awareness. However, the rigors of graduate studies and broader range of available classes may also foster a greater willingness to explore new ideas, challenge assumptions, and embrace different viewpoints, making it more likely for graduate students to have a higher openness. A more extensive sample size is needed for a truly comprehensive analysis.

Table 1. Average pre- and post-scores, percentage differences, and the highest post- Innovator Mindset® (IM) scores for awareness, openness, creativity, and bravery assessments among undergraduate (UG) and graduate (G) students. IM scores are on a scale of 0-100.

	Awareness		**Openness**		**Creativity**		**Bravery**	
	UG	**G**	**UG**	**G**	**UG**	**G**	**UG**	**G**
Pre-IM Average	55.89	56.36	55.48	59.48	51.81	58.65	49.04	53.49
Post-IM Average	63.23	77.18	67.82	76.30	64.63	79.29	61.40	76.11
Average Increase (%)	13.13	36.94	22.24	28.28	24.74	35.19	25.20	42.29
Highest Individual Post-IM Score	94.13	100	90.5	93.55	88.67	100	93.79	100

Upon completing the course, there is a shift in the order of these innovation habits for both graduate and undergraduate students. For undergraduates, scores now follow the order of lowest to highest in the categories (Bravery < Awareness < Creativity < Openness). On the other hand, graduate students exhibit scores in the order of (Bravery < Openness < Awareness < Creativity). The change in the sequence of innovation habits indicates that this course appears to enhance the creativity of both undergraduate and graduate students, as it shifts up one order for both graduates and undergraduates. The sequence of the habits does not necessarily imply that the course is superior in cultivating a specific habit over the other; rather, it is intriguing to observe the diverse shifts in areas where students exhibited improvement. The true analysis of improvement lies in the percentage increase. Notably, graduate students demonstrated a more significant improvement in their innovation habits across all four categories in comparison to undergraduates, as seen in Table 1. Further analysis with a larger sample size is required to test this hypothesis. The highest percentage increases for both undergraduate and graduate students were observed in the bravery habit, possibly because the course, employing practical tools like the Failure Mode and Effects Analysis (FMEA) and consistently emphasizing experimentation and outcome measurement, effectively contributes to students' advancements in the bravery aspect. Creativity also saw a peak in percentage increase for both graduates and undergraduates, emphasizing the course's success with helping students think outside the box by teaching them about the growth mindset. Furthermore, those scores exceeded 70 in all categories *after* both graduate and undergraduate students took the course, a significant finding even at this sample size as scores of 70 and above fall within the top 10%, categorized by Stauffer as "elite innovators" who show a strong correlation with the ability to provide greater value [20].

5.0. Conclusion

Exploring innovation habits among graduate and undergraduate students revealed interesting patterns both before and after the course. Following the completion of the course, there was a noteworthy shift in the order of innovation habits for both groups. This change suggests that the course had a positive impact, particularly enhancing the creativity of both undergraduate and graduate students. Additionally, finding student scores exceeding 70 (out of 100) in all categories post-course is significant as it places the students in the top 10% of "elite innovators," indicating a strong correlation with the ability to deliver substantially greater value. Overall, these findings highlight the positive influence of the course on students' innovation habits and the potential for cultivating elite innovators. This course presents a model that addresses a growing demand for students to become a future workforce capable of adapting to an increasingly challenging and uncertain environment. The course structure is shown here to equip them to tackle complex engineering problems, fostering value creation, and innovation. Subsequent work will expand sample sized to further understand the significance of the presented data and to explore any possible connections between various demographics.

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