Effects of Cornerstone Design Experience on Innovative Behavior and Perceptions in engineering for First-Year Engineering Students*

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***Abstract* - This Work-In-Progress paper on innovative practices evaluated the effects of a blended cornerstone design course which was offered to first-year engineering students. In particular the changes of students' individual innovative behavior and their various perceptions in engineering are studied and discussed. Recent studies indicated that cornerstone design courses have the potentials to develop innovative minds' of students, integrating their engineering knowledge to solve real-world, interdisciplinary problems. A first year engineering course, First Year Cornerstone Engineering Design Project Course (ENGG1100), was designed based on a collaborative problem-based learning environment which supports students to explore different disciplines of engineering, apply new concepts acquired through online modules, design engineering artifacts, in this case an 'airship', and test and modify their artifact in an iterative design process cycle. Pre- and post- self-reported surveys were administered to measure the effects of this course. Results were analyzed and discussed. Our analysis shows that the students' innovative behavior and their engineering design self-efficacy changed positively after students went through the cornerstone design experience. The results from this trial have led to inspiring insights in future studies on approaches to fostering innovation mindsets.**

Keywords - first year engineering; cornerstone design; blended experiential learning, innovative behavior

I. INTRODUCTION

Design capability is central to the development of 21st century engineering competencies. However, within the constraints of inflexible curricula in engineering education, a highly technical oriented specialty, nurturing design capability for innovation becomes a great challenge. Traditional engineering curricula have been based on an engineering-science model [1]. Students in first and second years take science and mathematics foundation courses. After selecting their engineering major, students move on to discipline-specific and specialized subjects. Students work on a capstone project or final-year project to apply what they have learned to solve a real, or close to real world problem. "…The resulting engineering graduates were perceived by industry and academia as being unable to practice in industry because of the change of focus from the practical to the theoretical." [1]. At the Hong Kong University of Science and Technology (HKUST), first-year engineering students experience a hands-on introduction to engineering through an interdisciplinary projects course [2], [3]. The First Year Cornerstone Engineering Design Project Course (course code: ENGG1100) aimed to provide a multi-disciplinary introduction of what engineering design is and provides first-year students with the opportunity to innovate and practice the engineering design process cycle in a systematic manner.

This work started in the form of a summer recruitment program. The program revolved around a competition based event where participants had to build prototype airships within a short period of time. Participants competed with each other's designs by performing specific task maneuvers with their airships. It was first translated into a pilot course and later expanded into a regular semester long course. The steering group of this project kept the elements of staging a fun, engaging and constructive learning experience, emphasized the value of appreciating each other's accomplishments in the process. Additional components were incorporated into the course, including team-based learning, application of blended learning, and emphasis in student innovations. The objective is to stimulate students' innovative thinking and to increase their interest in engineering. The work presented in this paper will be an initial step towards answering the overarching research question: What are the effects of this cornerstone design experience on students' innovative behavior and perceptions in engineering?

This paper presents the preliminary results obtained from student self-reported questionnaires. Statistical significance was found in some constructs of individual innovative behavior, engineering design self-efficacy and intrinsic attainment values in engineering. These findings will help to extend future qualitative studies that will identify the elements contributing to these changes. Through this Work-in-Progress format, we hope to gain added insights into our course development and good practices in cultivating students' innovation mind-sets.

II. LITERATURE REVIEW

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The introduction of cornerstone design courses in early engineering curricula could promote the practicality and novelty of engineering. Previous studies had shown that it is an effective way to enhance students' innovativeness, motivation and retention in engineering [1], [4], [5]. Cornerstone design courses help students to gain an understanding of what engineering is and to realize that solving an engineering problem can be an enjoyable process. In particular, projects that are open-ended, interdisciplinary and team-based (e.g. [5], [6]) encourage innovative solutions and increase students' interests in engineering. Cornerstone design courses have been recommended as a suitable means to revamp the traditional first year engineering curricula, integrating hands-on experiences with textbooks content [7].

As emphasized by the Innovation and Technology Bureau of Hong Kong Special Administrative Region (HKSAR), Hong Kong aims to develop a culture that encourages innovation, discovery, technology breakthroughs and risk-taking. To shift from a homogeneous financial centered economy to a diversified knowledge-based economy, becoming an innovation hub for technology in the region. Knowledge-based development is becoming the new economic culture, whereas the extent of societal growth relies on the community's innovative state of mind and culture [8]. Furthering this concept to the engineering education, mastering textbook knowledge is no longer sufficient, students' abilities to design and innovate play an essential role in this rapidly changing era.

In comparison with traditional engineering courses, the idea of promoting innovative behaviors involves a broad area while it is without a concrete set of textbooks nor definite teaching materials. The undertaken design tasks should relate directly to preparing students for industrial, practical demands [9]. A study by Korea Advanced Institute of Science and Technology (KAIST) [5] measured innovation in student design projects by proxies for innovation such as patents and publications. It had a balanced emphasis on both engineering and entrepreneurship education. A key indicator in understanding what motivates and fosters innovations can be through assessing students' innovative behavior. Kleysen & Street [10] categorized five constructs that associates with individual innovative behavior: opportunity exploration, generativity, formative investigation, championing and application.

One's behavior and actions are highly determined by one's values and believes. Schunk, Meece and Pintrich [11] used self-efficacy theory to explain how students' self-efficacy is influenced by task-specific self-concepts including motivation, outcome expectancy, and anxiety or self-doubt toward a certain task. Engineering design self-efficacy refers to ones' perception of their engineering design capability to produce a given level of attainment [12]. This can be elaborated in the context of cornerstone design courses due to the frequent uses of design tasks as part of an engineering learning experience [13]. These design tasks are often represented in a cyclic and iterative engineering design process [14-16]. Massachusetts Department of Education [16] proposed eight steps of the engineering design process: identify a design need, research a design need, develop design solutions, select the best possible design, construct a prototype, test and evaluate a design, communicate a design, and redesign. For each step of the process, students' self-conceptions and ability to apply engineering content and skills govern their performance in engineering design [16].

Besides promoting engineering design self-efficacy, a core purpose of a first year cornerstone design course is to arouse students' interest in the early stage of their engineering studies. Examining students' intrinsic interest value and attainment value would adequately fit this purpose. Engineering intrinsic interest value and engineering attainment value are explained by expectancy-value theory [17]. These two values refer to the importance of how well students perform in engineering in terms of their core personal values [18]. The theory predicts that the levels of interest value and attainment value have a sustained and direct influence to students' performance.

The importance of nurturing innovation can be found in much recent literature in K-12 and final year studies of higher education. However, not much research has been done in first year engineering. Within the limited literature on cornerstone design courses, no research study was found on investigating how students' innovative behavior would affect or be interdependent with engineering intrinsic interest value and engineering attainment value. The above literature review indicates students' perceptions may directly affect behaviors and actions, which suggests possible effects to students' innovative behavior. This work is the first step to investigate if the First Year Cornerstone Engineering Design Project Course can develop students' innovative behavior, engineering design self-efficacy and their interests in engineering. The research questions of this study are as follows:

- Do changes in students' innovative behavior show statistical significance between pre-test and post-test?
- Do changes in engineering design self-efficacy show statistical significance between pre-test and post-test?
- Do changes in engineering intrinsic interest value and engineering attainment value show statistical significance between pre-test and post-test?

III. COURSE STRUCTURE AND ELEMENTS

First Year Cornerstone Engineering Design Project Course (ENGG1100) started as a pilot in a non-regular term setting in Winter 2017 and it was well received by faculty and students. It was then translated into a standard 13-week first-year engineering course with 34 students enrolled.

In typical engineering project courses, students are given the pre-requisite engineering theories and principles, then are asked to complete a project which could apply what they have acquired. The assessment is often focused on the understanding of those theories and the correctness and precision of the presented data and calculations. Alternatively, this course adopted a multi-phase blended experiential learning approach. Much emphasis was addressed on students' creativity and innovativeness, from pedagogical teaching methods to idea-oriented assessments [19]. The physical criteria of the project was to build an airship that uses helium balloons for lift, has motors and propellers for propulsion and control, and is controlled remotely using an Android device. The detail specifications of the airship were kept as minimal as possible. Throughout the semester, instructors reminded students that there is no standardized design nor correct answer to their final products, and students would be incentivized by proposing and testing new ideas.

Instead of coming into classes physically, students took away standard sets of electronic components. These components were identical, basic parts such as batteries, wires, motors and electronic breakout boards. Students were asked to learn how to wire up the electronics and write an application that could control a rotating propeller via a cell phone. This was conducted through online modules during the first few weeks. These in-house modules were developed by faculty in HKUST and introduced on an edx[2] based platform named HKMOOC[3]. Each disciplinary area had instructional videos and guiding exercises to facilitate a self-regulated learning environment. This platform provided multiple advantages. Since the pre-tertiary education background of first year engineering students may vary significantly, they could learn according to their own pace and schedule. Students could always refer to the online materials in later stages of the course. This also served as the key to potentially scaling up in the future.

Onto phase two, students attained a certain level of understanding on how the electronic components work, then the rest of the course took place in a makerspace. Students were assigned into teams of four to five, diversifying the teams into mixed gender and nationality. Students learned to use different design tools and skills for rapid prototyping. They were instructed to apply what they have learned previously and design an airship prototype as their first build. In this process, students exchanged ideas through drawings and discussions. A budget of HKD350 was given to each team to purchase their desired building materials. The first build was an important milestone for the teams to translate what was conceptual into real-life products. The assessment involves demonstration of basic maneuvers (take-off, transverse, turn and land). The demonstrations were done in front of the class, students and instructors could raise questions or provide suggestions to the demonstrating teams.

The final phase involved a competition. After multiple iterations of the engineering design process (plan – create – test – improve), students deployed their mobile app controlled airship to demonstrate the uniqueness and innovation of their engineering designs and strive for the best performance. The competition includes several short contests: a race to knock-off tall blocks, a race to land on the safe zone, and a rescue mission to retrieve objects from afar. Although the objectives of the contests were laid out as the common goals, the ways to meet these goals were not restricted. This instructional approach facilitated radical innovations in students' designs such as choice of body materials and structural design, take-off and landing mechanism, pick-up mechanism, app control interface, etc. Credits were also given to incremental innovations, which refers to successful designs using reduced number of propellers or helium balloons in the airships. While competitive tasks form part of their course assessments, a sharing session was organized at the end of the competitions to let students present their own design as well as appreciating others'.

IV. METHODOLOGY

The survey in this work was adapted based on three validated instruments [10], [13], [19]. The survey consisted of 30 questions. Fourteen Likert scale questions and one open-ended question were asked on innovative behavior [10], nine rating (0-10) questions on engineering design self-efficacy [13], and five Likert scale questions and one open-ended question on engineering intrinsic interest value and engineering attainment values [19].

Among fourteen questions on innovative behavior, it comprised five constructs. Three questions referred to *opportunity exploration*; two questions on *generativity*; three on *formative investigation*; three on *championing*; and three on *application*. These fourteen items suggested by Kleysen and Street [10] can be combined into a single measure of innovative behavior with verified construct validity.

The nine rating (0-10) questions on engineering design self-efficacy can be separated into two parts. The first item asked students to rate their self-conception toward conducting engineering design. The following eight items referred to the steps in the engineering design process: identify a design need, research a design need, develop design solutions, select the best possible design, construct a prototype, test and evaluate a design, communicate a design, and redesign [13]. The mean ratings of these nine items were averaged to represent the students' *engineering design self-efficacy* scores.

Five Likert scale questions on engineering intrinsic interest value and engineering attainment values were originated by Wigfield and Eccles [19], which included two intrinsic interest value items and three attainment value items. These items were also adapted in a study on motivation constructs with first-year engineering students at Virginia Tech [18].

The survey was administered in the first and last session of the class. Each survey took approximately ten minutes to complete. For the purpose of mapping respondents' results, each survey was coded for both pre- and post- test. Results from the survey were compiled and further analyzed. SPSS was used to evaluate correlations and reliability coefficients, and paired t-tests. Internal reliability was examined by Cronbach's alpha for each of the seven constructs. All internal consistency test scores were estimated to be over 0.7, which is considered standard in social science research [20].

[2] edX is a massive open online course (MOOC) provider. https://www.edx.org/

[3] HKMOOC refers to Hong Kong Massive Open Online Courses. https://learn.hkmooc.hk/

V. PRELIMINARY RESULTS

The class had 34 students enrolled, among that 34 completed the pre-test and 26 completed the post-test. Statistical significance ($p<0.05$) was determined through paired sample t-tests. The survey results is summarized in Table I with means and standard deviations for each construct.

Students indicated higher level of innovative behavior in four out of five constructs, namely opportunity exploration, formative investigation, championing and application, except generativity. For generativity, both groups rated this high. Results are encouraging as they meet one of the core objectives of this course, cultivating students' innovation mind-sets. Through the iterative design process, students looked for opportunities to innovate, making enhancements in both mechanical and programming aspects. They formulated and experimented ideas through building concept and feasibility prototypes. The frequent interactions between teams and the final competition promoted championing and risk-taking. They learn that discovering innovations is a regular part of any engineering projects.

Students' engineering design self-efficacy was reported statistically higher. This is not surprising as engineering design self-efficacy is highly dependent on engineering experiences [13]. Although this study was conducted in the second regular semester, many first year students had yet experienced any hands-on engineering projects. By guiding students through the engineering design process, students develop confidence in executing complex design tasks. However, it is surprising to see almost no changes in the reported engineering attainment value and engineering intrinsic interest value. There maybe three possible reasons. First, students may already have certain perceptions in engineering anchored during the first few months in the university. It is expected to find larger differences in students' values and perceptions when they are adjusting to learning engineering, thus further investigation is needed. Second, students enrolled in this project course by their own choice, they may have chosen this course with specific reasons, and these reasons may represent particular student characteristics which differs them from the rest of the student population. Third is that students simply could not gain interests and sense of attainment through this course.

Furthermore, due to the small matched sample size, it is possible to result in type II error. Statistical tests to infer correlations between factors was not carried out due to insufficient samples in this study. From this experience, it is possible to scale up the next class to around 60 students in terms of teaching resources. Also, qualitative research methods, e.g. focus groups, shall be used to follow-up, complement and verify the quantitative results as this work progresses. Lastly, students are enrolled into other engineering courses simultaneous to this course, and therefore the reported effects may not be uniquely contributed by the cornerstone design experience. Comparing students' perceptions in engineering with and without taking this course should be further investigated.

There is no conclusion yet to whether including more instructional elements to promote innovative behavior would positively affect students' interest and attainment values in engineering; and conversely if students with higher interest and attainment values in engineering would facilitate their innovative behaviors. Understanding these relationships would inspire practical insights to the cornerstone design course development.

VI. CONCLUSION AND FUTURE WORK

This study examined the changes of students' individual innovative behavior, engineering design self-efficacy, engineering intrinsic interest value and engineering attainment value before and after the cornerstone design experience. Incorporating interdisciplinary design projects into first year engineering curriculum provides students an opportunity to explore their interests in engineering in the aid of choosing their major discipline to pursue in upper years. A common drawback of project-based courses is that it is resource demanding, no matter on the space, tools and teaching support. Scaling up is commonly the major challenge for this type of course.

As for the survey instrument, since the items were adapted from three independent studies, the response scale appears different from one and another. If further research is to examine the correlations between these factors, the items have to be redesigned and validated in a consistent scale, or a new instrument is to be developed.

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TABLE I

PRE- AND POST- TEST RESULTS WITH COMPARISON

Construct	Scale	Pre- test (N = 34)		Post- test (N = 26)		
		Mean	S.D.	Mean	S.D.	Diff.
Opportunity exploration*	1-6	3.77	0.94	4.05	0.66	0.28
Generativity		3.88	0.92	3.96	0.62	0.08
Formative investigation*		3.69	1.15	4.09	0.81	0.40
Championing*		3.42	1.15	3.96	0.62	0.54
Application*		3.76	1.15	4.09	0.68	0.33
Engineering design self-efficacy*	0-10	6.00	1.51	6.56	1.11	0.56
Engineering attainment value	1-7	5.06	1.23	5.10	1.07	0.04
Engineering intrinsic interest value		5.29	1.07	5.48	1.17	0.19

$p<0.05$ are designed with *

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