Pop-up Makerspace Module in Undergraduate Studies Inculcating Entrepreneurial Mindset

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***Abstract*— *This innovative practice work-in-progress study focuses on creating low-cost makerspace module for an undergraduate engineering course.* Makerspace aims at creating a cohesive environment where participants learn while being creative. Additionally, it accomplishes twenty-first century and entrepreneurial mindset learning objectives such as critical thinking, communication, collaboration, curiosity and creating value. Undergraduate STEM education is the most relevant field where makerspace can enhance learning process. However, makerspace is considered as a high investment project which can limit its implementation to a very small population of undergraduate students. With proper planning and creativity, educators can expose their students to makerspace without inflating the budget. In this study, a pop-up makerspace module was created for an undergraduate engineering course with a limited budget of $100. The students worked in groups to design, fabricate and verify the product functionality for a tissue engineering application. The module consisted of multiple stages which included brainstorming session, searching the market, design under constraints, select a design using a selection matrix, 3D print and verify the functionality of the product. The results obtained from student survey showed statistically significant improvement in technical, entrepreneurial mindset and 21st century skills. The open responses indicated students were engaged throughout the module and worked as a group to create a successful product. The first iteration of this module was successfully implemented and it is expected to extend such pop-up makerspace modules in other engineering courses as well.**

Keywords—Makerspace, STEM, Entrepreneurial mindset, active learning

I. INTRODUCTION

The concept of makerspace started developing in late 90s and between 2000-2010 in United States [1]. One of the first makerspace was built in 1998 at Massachusetts Institute of Technology called Fab Labs (fabrication laboratory) [2]. Fab Labs was derived from a course and the space consisted of multiple computer aided fabrication equipment. While makerspace can seem like a conventional engineering laboratory or a machine shop, it is more than a facility. It is a collaborative environment where group of people engage in solving complex problems while actively creating a tangible product and testing the hypothesis. With focus being shifted to experiential and problem-based learning in education, makerspace has the potential to be embedded into K-12 as well as engineering classroom [3]. Additionally, it is an attractive way to engage under-represented and female population in STEM (Science Technology Engineering Mathematics) [4-6]. This active learning tool can help in improving technical skills as well as 21st century skills such as critical thinking, creativity, communication and collaboration [7]. Along with these, the makerspace can also be embedded with entrepreneurial mindset (EM) that has become an integral part of STEM education to prepare students for global challenges. A study by Van Holm shows positive correlation between the impact of product designing, critical thinking and collaboration on creation of opportunities and market for new competitive products [8]. Typically, setting up a makerspace incurs a cost associated with space, multiple computer aided fabrication equipment, trained personal and maintenance [9]. This requires an initial investment as well as an annual maintenance budget [10]. Generally, smaller STEM institutes struggle in creating such facilities due to lack of funding which deprives their students from makerspace experience. There is a need for educators to use the existing technology in their school to create classroom makerspace modules that can enhance student experiential learning.

This work focuses on creating a pop-up makerspace module for an engineering course in a limited budget of $100 for a class of 20 students. Technical, 21st century and entrepreneurial mindset skills were assessed. The students were exposed to an active learning environment where they collectively solved an engineering problem by designing, fabricating and testing the device in the class. Student responses were collected to evaluate the success of the module for implementation in future engineering classes.

II. MODULE EXECUTION

The makerspace module was developed for a sequence elective course titled 'Cell and Tissue Engineering' at Western New England University, a teaching focused private institute in Massachusetts, United States. This course is offered for seniors as well as junior level students who are primarily interested in tissue engineering or want to widen their knowledge regarding the fields of biomedical engineering. The course covers topics such as scaffold design and development, cellular interaction with engineering structures (scaffolds), bioreactor design and tissue engineering applications.

The module focused on design, development and verification of tissue engineered scaffold in a makerspace environment. Initially, the students were given a lecture regarding scaffolds in tissue engineering, fabrication techniques and target specifications needed while designing the scaffolds. The lecture and affiliated discussion helped in strengthening the basic concepts needed by design engineers. The students were presented with a scenario where they were part of a research team who had created a new 3D printable biomaterial and were tasked to create a tissue engineered porous scaffold appropriate for their new material. The module was divided into 5 stages: (1) assess the market and find a suitable application, (2) create a model of the scaffold using craft supplies, (3) design in computer aided design (CAD) software and fabricate the prototype, (4) select appropriate design based on eleven selection criteria, and (5) verify the working of the prototype. The scaffold design was limited by constrains such as final dimensions and porosity (measurable parameters for final testing).

A. Stage 1

The class was divided into five groups with four students/group. The instructor formed the groups to ensure maximum participation by matching complementary skillset, and equal representation of senior and junior students in each group. A detailed module instruction handout was given to the students to streamline the execution. Before the second stage, each group completed a homework on the market research and product application. In this assignment, students were supposed to look for a tissue engineering application such as bone, nerve, cardiac or skin which could benefit from the biomaterial developed by their company. After that, they were asked to search for atleast five commercially available scaffolds for their specific application which would serve as gold standard during scaffold development. This created curiosity in the students with respect to the next stage of the module.

B. Stage 2

This stage was an in-class session comprising of brainstorming in which the class was provided with supplies such as play-doh, beads, wires, tooth-picks and wire screens to create a model of the projected scaffold. The play doh model had to represent the final product with respect to shape and design details (Fig. 1 A). Students used play-doh as their main biomaterial and used accessories such as wires and beads to represent pores in their structure. Initially, some students were hesitant since it was their first in-class makerspace experience. Once they were involved, each group came up with well-engineered design concepts. Since students used play-doh, they were able to give shape to multiple ideas before coming up with their final model.

C. Stage 3

In the second class, each team was asked to create atleast two CAD designs that nearly mimicked their play-doh model. At this stage, multiple design constraints were introduced as part of user needs and manufacturing technology limitations. Following criteria were considered during designing: each scaffold should have an overall external dimension of 20×20×20 mm^3, be housed in 1mm thick wall casing on all sides with inlet and outlet ports to allow porosity measurement, have atleast 80% porosity, minimum pore size of 200 µm and mostly interconnected pores. Students were engaged during CAD session and asked valuable questions from the instructor to get better idea about the progress of their design. Specially, juniors took senior's help in learning new CAD techniques to replicate their play-doh model which indicated collaboration. Since porosity and interconnected pores were critical design aspects, students came up with innovative ideas to create pores while preventing free standing structures which would have caused design failure during 3D printing stage. In addition to class hour, students were given two more days to complete their CAD models.

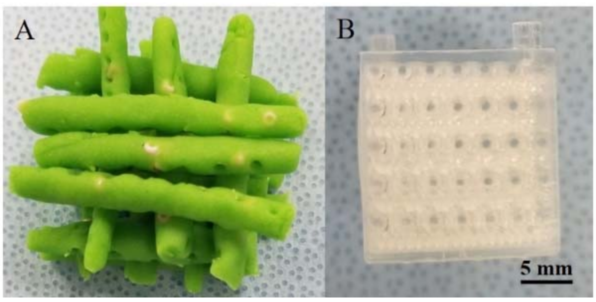

Fig. 1: Student work from makerspace module. (A) Play doh mixed with beads (depicting finer design details) represented the model of the final design of a tissue engineered scaffold. (B)The design was modelled using CAD software and 3D printed for testing.

D. Stage 4

In the third in-class session, the final design was chosen based on a design selection worksheet with atleast 11 design criteria such as percentage porosity, overall size, interconnectivity, inlet and outlet position and size, novelty of the concept, implanting ability, manufacturability, durability and cost. All the group members were asked to discuss and come to consensus while working on selection matrix. Each criterion was scored on a scale of 1-10 (10: highest and 1: lowest). The design that was scored significantly higher was chosen for printing and further testing. The final designs were 3D printed using stereolithography (FormLabs Form 3) by a trained laboratory assistant, undergraduate student worker (Fig. 1B). After a week, the scaffolds were ready for testing. Out of 5 designs, one design failed to print the target porosity percentage and was printed as a solid block. This example was used to talk about how good concepts might not translate into a product due to manufacturing limitations. This scaffold had a complicated CAD design which looked promising during design stage but failed manufacturing. The failure could be attributed to neglecting the resolution of the 3D printer. Some designs also had minor errors but were passed for final testing stage. Students were asked to take a note of the design errors which could be fixed if the module had design iteration stage.

E. Stage 5

In the last in-class session, two critical user needs (overall dimensions and minimum 80% porosity) were verified. Even though interconnectivity is an important criterion for a successful tissue engineered scaffold, this parameter was not quantified as it would have increased the module budget. Interconnectivity was qualitatively evaluated during porosity test. Each group was asked to measure the external dimensions of the scaffolds using a caliper. For porosity testing, a simple syringe pump set-up (Fig. 2 A) was used to fill the scaffolds with low surface tension liquid (70% cleaning alcohol) mixed with food color. A 5ml syringe with a hypodermic needle was fitted into the inlet. The syringe pump was turned off once the scaffold was completely filled and a liquid droplet appeared at the outlet. The volume of the liquid that filled the scaffold (Fig. 2B) was compared with the theoretical pore volume, calculated

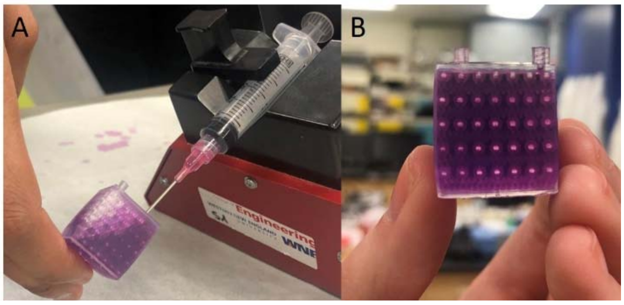

Fig. 2: (A) Device testing in the class using a syringe pump and food color. A mathematical formula was used to assess the success of the design. (B) Student holding their 3D printed scaffold after completion of the test.

from CAD design, to quantify the actual porosity of the scaffolds. The design that met atleast 80% porosity was considered as successful product.

F. Final report

To bring all the pieces together, students were asked to submit a 2-page report to their company supervisor describing the target application, market analysis, final scaffold and testing results. Students were also asked to assess societal and economic benefits of their product if it was commercialized. In conclusion, students gave suggestions to improve their designs for successive iterations.

G. Cost Analysis

The total average cost incurred towards the whole module was \$100±10. The cost included craft supplies, 3D printing cost and estimated service cost (~\$16/scaffold). Detailed cost analysis is given in Table 1. Most of the cost was incurred towards supplies for play doh activity and 3D printing. It took approximately 10 hrs to print five scaffolds with no iterations. The final product tests were designed to prevent usage of any expensive or specialized equipment which would have added cost to the module. Supplies such as syringe pump was borrowed from the biomedical engineering laboratory.

III. Assessment

The effectiveness of the module was assessed using a pre and post survey. The surveys were approved by IRB prior to their use. The confidentiality of the participants was maintained by using a random number that was used to match the pre and post surveys. The survey consisted of two technical questions related to knowledge about scaffold materials and critical design specification needed for scaffolds. In addition, it also included 5- choice Likert-scale questions rating EM skills as well as twenty first century skills (Table 2).

Table 1: Cost breakdown of the material used during the module

Material	Estimated Cost	Use
Play Doh	\$5	Scaffold modeling
Beads, wires, toothpicks, wire screens, adhesives	\$10	Porosity and fine features in the play doh model
3D printing material	\$30	Final scaffold
Service	\$50	Estimated service charge
Syringe pump	\$0	Porosity measurement
Syringe, hypodermic needle	\$5	Porosity measurement
Food color, cleaning alcohol	\$5	Porosity measurement

Table 2: Learning objectives evaluated during pre and post surveys

#	Mindset objectives
1	Identify an opportunity
2	Investigate the market
3	Evaluate technical feasibility, societal benefits, or economic feasibility
	Twenty first century learning objectives
4	Test concepts quickly
5	Design and communicate an engineering solution
6	Develop partnerships and team collaboration (juniors and seniors)

IV. Results

The survey was taken by 13 out of 20 students (N= 13). The overall score on the technical questions was 23±33 % before the module while the score increased to 73±26% after the module (p-value=0.0004). Likewise, statistically significant improvement was measured in both EM and twenty-first century skills. The results from Likert-scale questions from pre and post survey is shown in figure 3. The p-value for skillset 1 through 6 was 0.005, 0.003, 0.05, 0.0007, 0.003 and 0.006, respectively.

V. Discussion

Makerspace is an active learning technique that encourages students to tinker and give shape to their ideas in a collaborative environment. The goal of this study was to create a high impact pop-up makerspace environment for a regular engineering course for a limited resource facility. The module took four 75 min classes which included all the components needed to assess the EM and 21st century

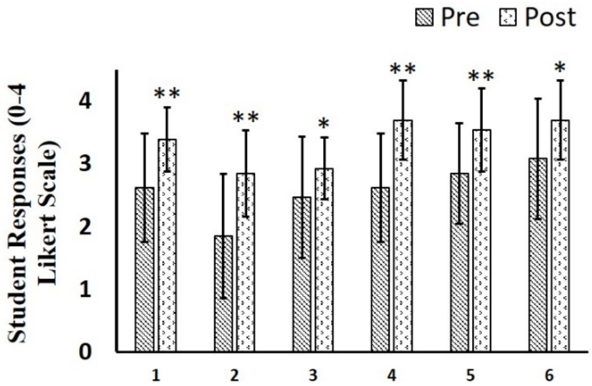

Fig. 3: The results from pre and post survey analyzing EML and 21st century skills. The description for each skill is given in Table 2. The statistical analysis shows significant improvement across all the skills (p-value < 0.005, * p-value <0.05) after the completion of the makerspace module.**

learning objectives. As seen from the technical assessment, the average score improved 3 times between pre and post survey. This indicates a significant improvement in the understanding of target technical concepts related to scaffold design and fabrication. It also improved the understanding of the course material and in-class verification of the design consolidated the importance of specifications associated with designing a scaffold. This is also confirmed by key words from qualitative-responses such as *"learned how important porosity and interconnectivity is"*, and *"develop an idea that targets specific target specifically porosity"*.

A. Learning Objectives (LO)

The EM learning objectives targeted two out of three C's (**curiosity, creating value** and connection). Since students were given a scenario where they were part of a research team in a company, their objective was to create value for their target stakeholders. Results show a significant improvement in evaluating societal and economic benefits of the new product thereby assessing creation of value. Curiosity was assessed by asking the students to research the existing market and finding an application appropriate for the product which helped in understanding customer needs. All three EM learning objectives (Table 2: LO 1 through 3) showed a significant improvement in student skills (Fig. 3). Literature shows a close link between makerspace and entrepreneurship. The module confirmed that social and shared space in makerspace cultivates community based learning which helps in development of entrepreneurial skills [11].

The module embedded the following 21st century skills: critical thinking, creativity, collaboration, communication and problem solving. During the module, students solved an engineering problem by designing and verifying it's working. The fourth learning objective in Table 2 focused on problem solving and creativity which showed 1.3 times improvement in designing and testing skills. Collaboration and communication are integral to makerspace which were assessed in learning objective (5) and (6). The module included these two aspects by organizing brainstorming and design selection group meetings. Additionally, the class consisted of undergraduate juniors and seniors who were grouped such that each group had atleast one student from each category. This grouping mechanism elevated the level of the project since both the categories brought their skillset to the table. Participating students also felt their collaborative skills improved post-module. Research has shown that lower level students appreciate upper level student's mentorship which supports critical thinking and constructive discussion [5].

B. Qualitative Survey

The qualitative open-ended responses were categorized into skill development, likes and suggested improvements in the module. Overall the participants felt an improvement in their technical skills such as consideration of design criteria, using CAD software for designing, design optimization and verification. This showed enhanced student engagement and better understanding of the material through experiential learning [12].

The improved student learning can be linked to 'what students liked in the module?'. For example, "*creating own scaffold*" was the most interesting part of the module for the students. Makerspace provides a sense of ownership to the students which connects them to the subject matter more effectively than a traditional classroom lecture [13]. Final testing stage was also universally liked by the students which helped in better understanding of equations in an active learning environment. It was interesting to see student's suggestions regarding module improvement. Though most of them were regarding more time for designing, two standout comments were *"Addition of a quick tensile test of compression" and "More ideas about different ways to make scaffolds".* These two comments represent student involvement as they wanted to try different design iterations as well as conduct a durability test on the scaffold. Thus, the module not only helped in imparting technical knowledge but also encouraged students to think beyond the module and apply concepts from previous lectures to this subject.

C. Sustainability

Collectively, a total cost of \$100±10 incurred on the module including supplies, cost of fabrication and service. The CAD software used in this module is provided by the university to all the engineering disciplines and we used 3D printer housed in biomedical engineering laboratory. No special paid services were obtained for this module and the cost of service in Table 1 represents an estimated cost for future module implementation purpose. Most of the supplies for brainstorming and testing were purchased from local hardware and craft store which kept the cost low. Thorough initial planning and designing the module around available resources helped to stay within reasonable budget. This module is in-line with current trend about sustainability in makerspace. Literature supports thoughtful planning to make makerspace an inclusive and affordable activity in classrooms [14].

VI. CONCLUSION

To conclude, this work showed that pop-up makerspace module can be easily integrated into an engineering course without the need for designated expensive makerspace facilities and huge budget. This limited budget module successfully showed an overall improvement in technical, entrepreneurial and 21st century skills. Students were engaged during the module which amplified their learning through active exchange of creative ideas. For future, this pilot study can be extended to other core engineering courses. It can also be used as an outreach tool to engage middle and high school students in STEM education.

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