Design, Implementation, and Assessment of a Summer Pre-collegiate Program at Harvard School of Engineering and Applied Sciences (SEAS)

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Fawwaz Habbal has served as the Executive Dean for the Harvard School of Engineering and Applied Sciences (SEAS) from 2007 to present. He is also a Senior Lecturer in Applied Physics at SEAS. Prior to Harvard, he held the position as Corporate Vice President, responsible for research and product design at Polaroid Corporation where he served as a Senior Research and Engineering Fellow as well. After leaving this position he initiated two start-ups related to imaging. Dr. Habbal's research interests focus on superconductivity, magnetic materials, silicon nanowires for photon detection and nano-photonics more broadly.

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Michael Raspuzzi is a second year Master in Design Engineering student at Harvard John A. Paulson School of Engineering and Applied Sciences and Graduate School of Design. His most recent teaching roles involve instructing in innovation and entrepreneurship summer classes at SEAS as well as in the Collaborative Design Engineering core studio. His former roles include managing director of Life Changing Labs at Cornell University, founder of LCL's summer startup incubator, founder of LCS's global high school entrepreneurship and computer science program, and director of the Caldwell House.

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Pre-Collegiate Program Background and Direct Objective

As new experiments and design-based projects are envisioned, they must be evaluated and assessed before they become part of the curriculum. Initially, we introduced such new items to a small group of the Harvard College students, but as the demands for new experiments increased, it became difficult to have a thorough evaluation through the small sample of students. We decided to engage a different student body of diverse backgrounds by establishing a pre-collegiate program. This program attempts to prototype and develop multiple new active learning initiatives before integrating them into the full curriculum. Indeed, the program became a valuable platform to develop, to experiment, and to evaluate new exercises, which has been shown to help increase interest in engineering professions [1]. The outcome of the yearly program helped modify and enhance our formal offering for the college students.

Program Structure

This program is structured as a pilot for curriculum development and is designed with flexibility in mind to create a cohesive cohort through team-based learning. It aims to offer our teaching staff the ability to select the topics they aim to pilot and test during the summer before they are implemented in our school curriculum. While topics may change in different years, the general outcome continues to be a rich selection of multiple engineering and applied sciences topics that become available for the summer pre-collegiate students. Written text and background information are provided to the students prior to the start of the program on the selected topic in preparation to have them immersed in a new pedagogy with different learning outcomes than their previous learning environments. The topics differ between years, and the programs emphasizes different developing fields of technology as well as emerging humanity challenges. Students from all different backgrounds are invited to participate (Figure 1) in these exercises.

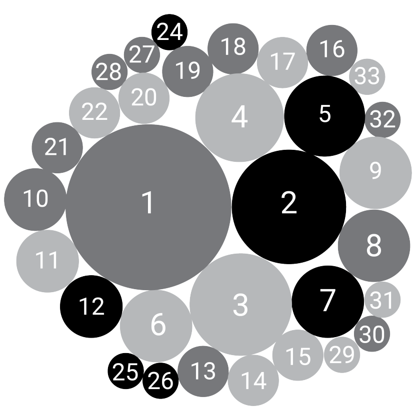

Figure 1: The students' diverse interests collected in pre-program assessment and in round table discussion on the first day of class with corresponding number of responses for each subject area. Black represents the sciences and physics, dark gray represents computer science and engineering, and the light gray represents arts and humanities:
1. Computer Science (23); 2. Physics (10); 3. History (8); 4. Art (6); 5. Chemistry (5); 6. Music (4); 7. Math (4); 8. Genetic Engineering (4); 9. Economics (4); 10. Software Engineering (3); 11. Psychology (3); 12. Biology (3); 13. Game Design (2); 14. Literature (2); 15. Linguistics (2); 16. Information Technology (2); 17. Graphic Design (2); 18. Environment (2); 19. Engineering (2); 20. Education (2); 21. Aerospace (2); 22. Architecture (2); 23. Philosophy (1); 24. Nuclear Physics (1); 25. Molecular Biology (1); 26. Medicine (1); 27. Mechanical Engineering (1); 28. Material Science (1); 29. Law (1); 30. Electrical Engineering (1); 31. Geography (1); 32. Design Engineering (1); 33. Dance (1)

Program Elements and Students' Experiential Learning
Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) undergraduate engineering curriculum is embedded within the traditional liberal arts education of Harvard Faculty of Arts and Sciences. Typically, students tend to take several courses outside of engineering, including general education, humanities and social sciences. The liberal arts education provides an interesting background that allowed us to offer complementary courses that enable developing and implementing proposals for mitigations to real challenges facing society. In addition, for the students to be effective in making their proposals, it is necessary to train them on how to translate their theoretical learning to practical experiences. Thus, many of SEAS courses have experiential components, some imbedded at the classroom, and others are practiced at the teaching labs.

Since our goal is to use the experiences of the pre-collegiate program as a guide to enhance the practical experiences of Harvard College students, the pre-collegiate curriculum had to be modified yearly to match the evolution of the new engineering courses at SEAS. Thus, through the pre-collegiate curriculum, we were able to test some of our hypotheses and the effectiveness of our pedagogy. First, we tested the interdisciplinarity of some of our courses, which is important for us as many of our courses are geared for a wide range of student concentrations, including, ME, EE, Bioengineering and Environmental Engineering, and students take these courses together and work collaboratively regardless of their concentration.
Our program focuses on teaching systems analysis that emphasizes the importance of interdisciplinary collaborations in solving complex humanity challenges. Secondly, some students want to bring forward their innovative ideas to the commercialization stage, and we want to support their aspirations. Thus, we included in the pre-collegiate curriculum some aspects of innovation and entrepreneurship. Thirdly, we consider design thinking as an important enabler of innovation. Design thinking is an iterative and interdisciplinary collaborative process through which students are able to exercise and practice different types of thinking, including divergent, convergent, critical, analytical, and integrative thinking.

Teaching Dynamics
The teaching methodology for the program assumes that students have no prior knowledge in any particular subject area, but through the workshops, mentorship, and the hands on activities outlined in figure 2, they learn quickly. Two of the most important aspects of the curriculum, prior to their enrollment in the lab, include learning design methodologies (in Figure 2, 3.1-3.3) and understanding systems and systems analysis (in Figure 4.1-4.3). Through the design process, students can translate the technical and theoretical aspects of the curriculum and convert them into built objects and working prototypes, and iterate on their work. After introducing the definition of design, students begin thinking through doing; starting with simple exercises such as using marshmallow and spaghetti to build towers. Such challenges take only ten minutes, during which, groups build the largest freestanding structures. This gives students the chance to

experience the nonlinear design process firsthand, which provides a foundation for introducing the next steps of empathy, definition, ideation, prototyping, and testing. Once the process is discussed, the exercise of the spaghetti tower is introduced again with a new constraint of having to hold the weight of a lime.

WEEK ONE	Monday	Tuesday	Wednesday	Thursday	Friday
Session One 10:00am - 11:30am	1.1 Introduction to the Program	2.1 Engineering and Science	3.1 Introduction to Design Thinking	4.1 Introduction to Systems Design	5.1 Introduction to Drone Technology
Session Two 1:00pm - 2:00pm	1.2 Introduction to YYY Active Learning	2.2 Introduction to Entrepreneurship	3.2 Rapid Prototyping Exercise	4.2 Learning About Systems Control	5.2 Learn and Assemble Drone Kit Exercise
Session Three 2:30pm - 4:00pm	1.3 Team Forming Exercise	2.3 Lab Safety Training	3.3 Design Exercise	4.3 Learning About Systems Control	5.3 Learn and Assemble Drone Kit Exercise
WEEK TWO	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Session One 10:00am - 11:30am	Lab 1: Design Day	Lab 2: Fabrication Day	Lab 3: Test and Analysis Day	Lab 4: Competition Day	Lab 5: Final Presentation
Session Two 1:00pm - 2:00pm	Lab 1: Design Day	Lab 2: Fabrication Day	Lab 3: Test and Analysis Day	Lab 4: Competition Day	Lab 5: Final Presentation
Session Three 2:30pm - 4:00pm	Lab 1: Design Day	Lab 2: Fabrication Day	Lab 3: Test and Analysis Day	Lab 4: Competition Day	

Figure 2: Week 1 and Week 2 daily schedule for the program.

By going through the process again with the same team members, the students can apply what they have learned in the first experience and repeat the process. Following the second challenge, a longer discussion of different ways of prototyping with different materials takes place with a demonstration. And finally, the third module brings this learning together with a user interview and brainstorming for students to use the systemized approach to ideate and prototype.

A number of instructional modules were developed for the program. Chronologically, these modules include introductions to the several concepts, such as differences between science and engineering, innovation and relationships to entrepreneurship, rapid prototyping, and theoretical and practical systems design. Following the content, we introduce exercises for team formation, understanding systems dynamics, and learning about the technology that is provided in the drone kits.

Week two of the program was structured to allow students to use their leaned skills, with tools and techniques to complete a design project. Project topics vary each year. This year's project resembled a rescue mission to provide critical aid to victims of a recent earthquake. Students were tasked with designing solutions for rapid assistance by air for a disaster area in a remote location. To evaluate their design, the final design competition consisted of students utilizing basic materials and rudimentary prototyping techniques to modify the framework of an existing quadcopter kit. Their design was intended to safely carry an egg payload to a designated landing zone while minimizing weight and maintaining maneuverability of their designed device. Along with the challenge of balancing those constraints in the complex quadcopter system, students had to work alongside a multicultural team and work within a tight time constraint.

Program Assessment and Evaluation

Assessment was integrated into the pre-collegiate program to evaluate the three areas outlined in ASEE guidelines [2]: a) student inputs, b) student outcomes, and c) the educational environment. As they entered, students were given a baseline assessment upon arrival to measure inputs, and as the program began, topic based assessments were given to students at the conclusion of each workshop to measure educational environments (Figure 3).

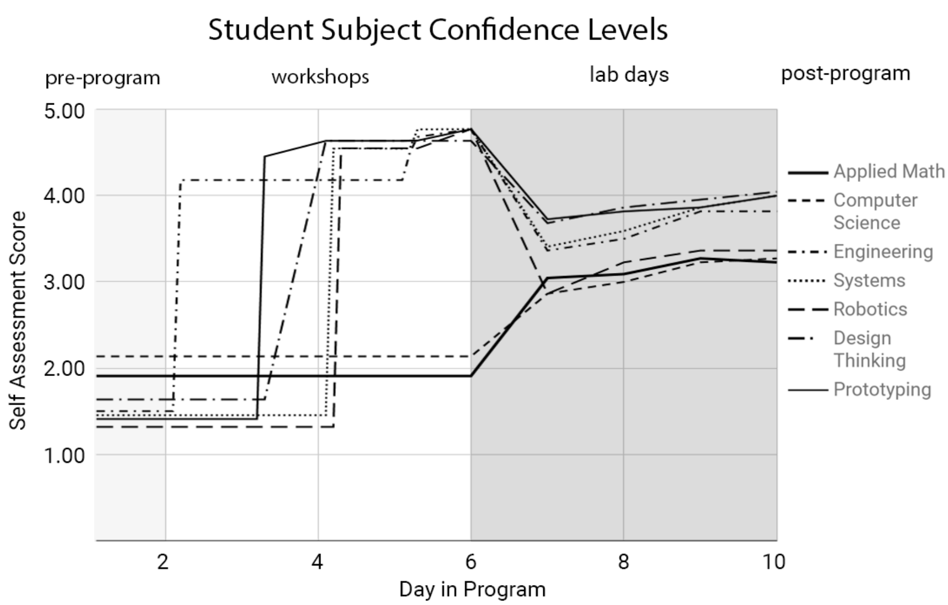

Figure 3: The students' average confidence levels collected from a daily survey in the selected areas of Applied Math, Computer Science, Engineering, Systems, Robotics, Design Thinking, and Prototyping throughout the program. Assessments included: gathering information on students' exposure to and familiarity with topics prior to the start of the program, self-evaluations of the effectiveness of each segment and evaluations of teaching methods- the group dynamic, project based learning and comprehension of foundational concepts being introduced.

Confidence levels were used as a formative metric to measure a student's self-perceived ability to measure the outcomes of each workshop analyzing the component level of the program [3,5]. Instructors held discussion-based assessments at the conclusion of each day, and incorporated some of the most actionable feedback in real time into the teaching activities for that week. We do not conduct proficiency testing during this program. However, once the tested hands-on exercises are implemented into the curriculum, student's proficiency is measured through a variety of course-based testing and evaluation method [4].

Reflection on Students' Level of Confidence

We focused on short term and long-term effects of the program on the students' learning: short term defined as what happens during the program from day to day and week to week. Assessments on the longer term are defined as the inferred change from the pre-term and post-term assessment evaluation. We note that within the program, the first major increase in self-determined level of confidence for students was between their introduction to the program and the completion on the first workshop on that specific subject. The average increase (Figure 4) from pre-term assessment to daily assessment after the respective workshop was 2.68 for Engineering, 3.09 Systems, 3.23 for Robotics, 3.00 Design Thinking, and 3.23 Prototyping.

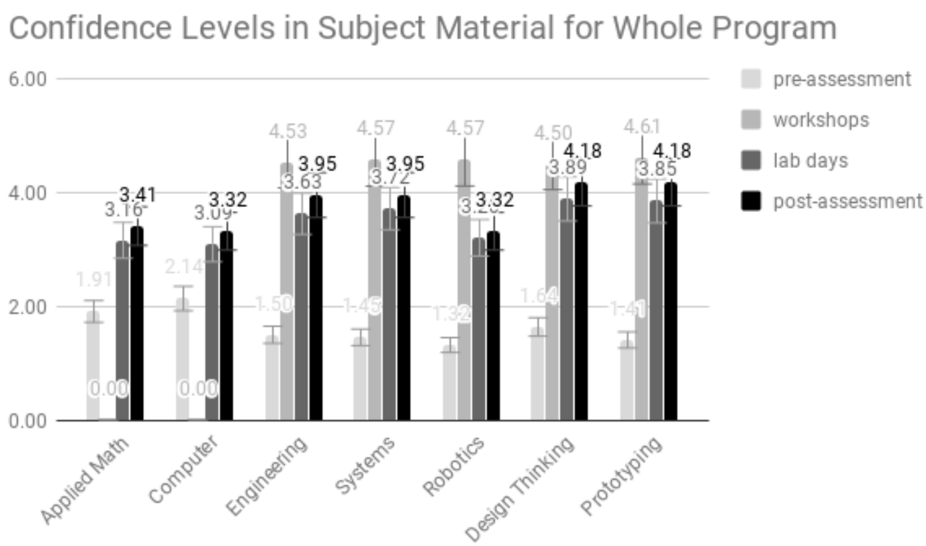

Figure 4: The average confidence level at each stage of evaluation for different Engineering and Applied Sciences topics.

Applied Math and Computer Science were excluded because there were no dedicated workshops for those subject areas. This increase shows a raise in self-perceived confidence directly after being taught the specific subject. As revealed in Figure 2, this single highest point of confidence during the workshop period decreases as students enter the lab days between day 6 and 7, where they were engaged in multiple subjects at once and surveyed thereafter. We are looking to validate this over multiple iterations of the program as currently this data is from one program with n=22 students sampled. Our data and in-class observation show that students start with a high degree of confidence and then realize that their knowledge is lacking. In fact, we identify a general trend of decreased self-reported confidence levels as students progressed from week one of skill-learning and the hands-on workshops, into week two of design-based open-ended competition days. Students begin asking in-depth questions as they obtain sufficient skillsets, tool and techniques. This normally takes place in week one workshops and toward the completion of design projects. We believe students who transition from knowledge gathering into skillset practice gain a realistic appreciation of their ability to analyze, evaluate, and apply their expertise toward solving open-ended challenges, thus their reported level of confidence increases (Figure 3).

Program Conclusion and Future Planning

To incorporate active learning in our curriculum, we established state-of-the-arts teaching facilities and infrastructure. We also created a human organization to enable the students and respond to their specific needs. The active learning part of the curriculum is a result of a close and tight collaboration between the faculty and the teaching staff, which led to a rapid increase in the active learning activities over the past seven years. Piloting such new activities over the course of pre-collegiate programs has allowed us to effectively examine, revise, and implement different active learning components that are well-aligned with the curriculum. This piloting mechanism ensures a thorough testing of the new activities and provides us with detailed and useful student feedback to refine our teaching skills and further develop learning exercises before they are fully implemented in our curriculum.

The success of this pilot program depends on the effective transition from conceptual and theoretical frameworks into applied hands-on experiences. As students were tasked to apply the knowledge they gained from classroom lectures in the lab section, the students were severely challenged. This indicates that their own appreciation of the depth of their knowledge was not as solid as it can be. Furthermore, we observed a consistent increase in students' level of confidence throughout the second half of the program as prototypes were finished, tested, and measured. We intend to continue using the SEAS Pre-Collegiate Program as a valuable educational test bed. Our future focus is to further improve the confidence level of enrolled students as they engage in the designed workshop and the subsequent active learning exercises.

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