Tinkering and Making to Inspire Engagement in First-Year Mechanical Engineering Students

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***Abstract*— This is innovative practice paper describes a tinkering- and maker-based approach to engaging first-year students. Engineering students should get right into building and making. Much of what they will learn across the undergraduate engineering curriculum is about building (learning CAD tools, manufacturing processes) as well as analyzing built things or the characteristics/behaviors of physical phenomena (many of their engineering sciences courses). In teaching an introductory engineering course to first-year students, there is both the need to address the array of (broad) topics across engineering and get students excited about their major. By introducing a collaborative making project very early in the course, the hope is to get students excited, introduce them to working collaboratively and creatively to solve problems, and make some implicit link making connections and spurring curiosity. The general approach to using tinkering and making as pedagogy is to 1) introduce a topic with a simple hands-on activity that can be done in the classroom in 30 minutes, 2) send the remainder of the class period discussing and debriefing, 3) follow up with specific technical content related to activity, 4) bridge to a more in-depth design challenge. This is also to encourage tinkering and making/thinking through materials with a number of considerations: what is success in this challenge, how to work through a creative design process, and how to balance a number of systems considerations (materials, time, role/jobs of people during the short demonstration window).**

With a making- and design-based approach the ambition is to make it more fun and worthwhile for students as well as help the instructor enjoy teaching the course/coach students through the design process, making skills, and applying those learning to solve problems that they care about. By tinkering, it is meant to start by showing students the basics (of some area of engineering fundamentals, of making) and expect them to then take that knowledge and skills further through exploration by imagining and building a physical solution, in an interactive and reflective way. Project based and design challenges are pedagogical approaches that can really engage and excite students. For a 1st year introduction to engineering course, we aim to bring making through hands-on design projects/challenges throughout the semester in small chunks (2-3 weeks). (*Abstract*)

***Keywords*— First year curriculum, prototyping, design thinking, pedagogical content knowledge** *(key words)*

I. Introduction

This is innovative practice paper describes a tinkering- and maker-based approach to engaging first-year students. Product development, design, and making are core to the educational mission of the Department of Mechanical Engineering at the South Dakota School of Mines & Technology. By their very nature, these topics are ambiguous for student learners and faculty alike. Most engineering programs in the US include an introduction to engineering course in the first semester of the freshman year. An introduction to engineering course plays a crucial role in motivating freshman students to persist in engineering since the other courses in their schedules are typically math, science, and general education classes. The undergraduate curriculum is a traditional array of mechanical engineering topics. At present, there are design-oriented courses alongside theory courses. The experience for both faculty and students alike is quite siloed, either by teaching assignments (vertically) or students' mashup of courses each semester (horizontally). The ambition of this project is to inject making and contextually relevant design activities at the foundation of the curriculum with cornerstone freshmen introduction to design. We transformed an existing introductory course with small, medium, and large design activities and design project content, based on product design pedagogy, making connections for students to the local and global context of mechanical engineering.

II. Rationale for Making Better Learners by Making and Design

Making and design provide collaborative student-centered, progressive educational opportunities. Placed within their mechanical engineering education, such practice and work can help students persist from 1st to 2nd year, from sophomore to junior, on to graduation. Teaching project-based learning, though, can be an unfamiliar pedagogy for engineering instructors [1] and for student learners, too. Different than traditional engineering courses, teaching engineering design involves using active teaching pedagogy. However, many engineering educators are not familiar with active teaching pedagogy and tend to have reservations when asked to implement it in the classroom. The current increasing popularity of engineering design as an undergraduate engineering course is the result of engineering institutions' response to calls from employers in industry, ABET, and the National Research Council for reform in the way engineering graduates are trained [2]-[4]. Now, engineering schools have senior capstone projects, which allow students to use the knowledge of the engineering design process to create discipline-related artifacts [2]. Some institutions also teach freshman design courses with the additional hope that the course will help promote students' interest and retention in engineering, motivate learning of upper division courses, and promote students' performance [5, 6].

Research has also shown that "engineering design" can be used as a tool for enlightening students about professional practice as well as a strategy for curbing attrition in engineering [5], [7]-[9]. Teaching engineering design requires a different strategy from those normally observed in most engineering classrooms. The type of strategies that are better suited for teaching design are those associated with active learning. Reference [10] defined active learning as "getting students to do anything course related other than watching, listening to instruction and taking notes." Design courses are fashioned to allow students to work in teams while solving ill-structured problems that may have multiple "correct" solutions and undefined constraints that influence the choice of solution. Teaching design education requires implementing strategies that are unfamiliar to many engineering educators.

III. Literature: Connection to Research on Engineering Education

We situate our literature review in making, closing the research to practice loop, faculty change, and a diffusions of innovations perspective. Different intellectual communities have focused on different aspects related to making. The human-computer interaction field has studied hacking and tinkering in the context of do it yourself (DIY) tools and practices [11], [12]; design research, ad-hoc prototyping and tinkering using local objects [13]. Flexible space for activity is growing in popularity and use in the way of hacker spaces [14], maker spaces [15] and fab labs [16] in academia. While the literature on Making is relatively recent, it can be easily situated within design research. Engineering design is defined as "a systematic, intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy specified constraints" [6]. This statement alludes to the purpose of engineering design, which is the development of products that meet pre-defined objectives and criterion. Conversely, the goal of design education is to help students focus on, understand, and experience the engineering design process and not the creation of artifacts [5], [17].

Design thinking has become increasingly popular parlance in the engineering design community as well as in design education [17] and business circles [18]-[24]. This design thinking approach has become useful as a differentiator for schools [25] and companies [26] alike. Design thinking describes a user-centered design process rooted in engineering design practice. Research has also shown that "engineering design" can be used as a tool for enlightening students about professional practice as well as a strategy for curbing attrition in engineering [5], [7]-[9]. Engineering education has a strong history of faculty professional development workshops to elicit change within engineering education. For example, Felder, Brent and Prince have offered a National Effective Teaching Institute (NETI) workshop annually to engineering educators [27]. An evaluation study concluded that the NETI workshops have met their goals which include increasing teaching effectiveness [28]. This seems like a promising model for implementing change in engineering educators, but there is some concern that these are faculty that are already likely to adopt new teaching strategies and that this self-report data is not conclusive. In Reference [29], the authors acknowledge that although evaluation data of workshops and professional development programs indicate, in some cases, these workshops are effective at causing change in instructional teaching, that this self-reported data is often not accurate [29]. The report mentions a study that combined self-reported surveys with observations finding that 75 surveyed participants reported using student-centered teaching practices, yet the observations indicated that most of the instruction was lecture or lecture with demonstrations – still a teacher-centered teaching practice [30]. They indicate that these workshops change educators' awareness of student-centered strategies even though they may not change their teaching practice. We are taking a systems perspective by including students and faculty experiences to understanding how to support sustainable impact from our planned intervention.

IV. Project Approach & Activities

The goals of this work are to provide concrete learning experiences (as contrasted with the mostly abstract nature of introductory engineering science topics) for first-year mechanical engineering students to interest them and increase excitement and persistence (through curiosity and making the context of the abstract concepts more concrete) and scale and sustain such impact. In the longer term, we seek to better understand how student learners may engage with hands-on activities through making and contextually presented design activities and challenges.

In teaching an introductory mechanical engineering course to our first-year students, there is both the need to provide a brief introduction to the array of (broad) topics across the field of mechanical engineering and get students excited about their major. By introducing varying levels of active learning activities and collaborative projects very early in the course, the hope is to get students excited, introduce them to working collaboratively and creatively to solve problems, and make some implicit link to spurring curiosity. The general approach to using making as pedagogy is to 1) introduce a topic with a simple hands-on activity that can be done in the classroom in 30 minutes and spend the remainder of the class period discussing and debriefing, 2) follow up with specific technical content related to a more in-depth activity, and 3) bridge to a more in-depth design challenge.

We have developed a small number of activities during the Fall semester with ~60 first-year students. As an example of activities for exploring mechanics of structures include piloting an introduction activity in which students build playing card towers, a design challenge for a crane constructed out of popsicle sticks, and a design challenge to create miniature golf holes (in a class session, with cardboard and lengths of wood). Project based and design challenges are pedagogical approaches that can really engage and excite students. For a first-year introduction to mechanical engineering course, we aimed to bring making through hands-on design projects/challenges throughout the semester in small chunks (2-3 weeks). Each of the activities listed below in Table 1 were implemented in Fall 2021. The introduction to mechanical engineering course is taken in the first year for 2 credits and meets for 4 hours per week.

Regarding the activities listed in Table 1, the introductory activities were done in roughly 30 minutes of a first class of a 3-

week course module, meant to be an empirical exploration of the topic, using simple materials, and meant to both engage students in a fun task and give a basis for understanding the topic. We used a debriefing of these activities to bridge to more technical content or concepts. Reflection was guided by general discussion questions focused on some Socratic dialog – like what was happening, what was surprising, etc. The design challenges were used as a means to build on this introductory experience, supported by selected readings from the course textbook [31] and problem sets. There was significant time in class devoted to students working together to tackle these purposefully ambiguous design challenges.

TABLE I. TOPICS AND ACTIVITIES OVERVIEW

Topic	***Small Activity***	***Large Activity***
Design Process & Collaboration	Marshmallow challenge	Build an Olympic Torch
Mechanics of Structures	Playing card tower	Cranes, Miniature Golf Hole
Materials and Manufacturing	Casting a part	Campus foundry
Fluids	Coke & Mentos, Tin Foil Boats	Buoyancy (boats)

A. Area: Design Process and Collaboration

Small activity: *Introduction: Marshmallow Challenge***.** Using spaghetti sticks and tape, collaboratively build a structure that can hold a marshmallow.

Large activity: *Design Challenge: Build an Olympic Torch.* Student teams were asked to design and construct a tower out of cardboard to hold plastic cups. They were constrained on materials (mostly cardboard and hot glue), not allowed to touch the cups with their hands (had to imagine and build a tool to do so), and not allowed to enter in a 10'x10' space for the tower to be assembled and placed in 3 minutes, see Figure 1.

Fig. 1. Build an Olympic Torch activity

B. Area: Mechanics of Structures

Small activity: Introduction: Playing Card Tower (mechanics) Groups were asked to build a structure with playing cards, tape, and scissors to hold a couple of Gummi Bears on top. The structures were tested in a windy environment (a hair dryer), Figure 2.

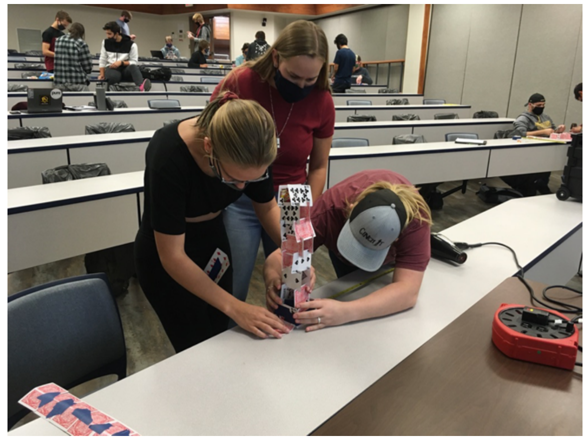

Fig. 2. Playing card tower activity

Large activity: Design Challenge: Mechanics: Cranes (Moment forces and Equilibrium) Groups were asked to construct a crane out of popsicle sticks and hot glue. There were then asked to add weights (mass) at some distance to have it in balance, Figure 3.

Large activity: Design Challenge: Miniature Golf Hole Build. (Vector addition) Student teams were given lengths of wood and small sheet of cardboard. Student teams created holes; across the class section 9 holes were created. We played through the miniature golf course in 1 subsequent class period.

Fig. 3. Cranes activity

C. Area: Materials and Manufacturing

Small activity: Casting a part. Making a mold and molding a plastic part. We quickly had students made a mold of something they had on hand using a small container of Play-Doh. And then using 2-part plastic/polymer students mixed and poured into molds. Examples: key, Gummi Bear, pencil point.

D. Area: Fluid Engineering

Small activity*:* *Introduction: Diet Coke and Mentos.* Prior to talking about fluids engineering (and Poiseuille's Law) we launched soda streams from Mentos and Diet Coke. Nozzles were 3D printed, Figure 4.

Fig. 4. Coke and Mentos activity

Small activity*:* *Introduction: Tin Foil Boats.* Given small sheets of tin foil (10”x14”) groups were asked to build 3 variations on what boats they thought would hold the most mass. Then, in a container of water, groups tested out their assumptions with weights (nuts and bolts).

Large activity*:* *Design Challenge: Buoyancy (Boats).* Student teams designed (in CAD) small “boats” that were 3D printed. The aim was to support the most weight (mass) (ball bearings) in a small-scale wave tank.

V. Limitations and Considerations

Teaching using active learning strategies requires implementing strategies that are unfamiliar to many engineering educators. Therefore, it is expected that faculty members encouraged to teach in a more active learning way will exhibit some concerns about such things. Reference [32] discussed that faculty members received teaching innovations with mixed feelings. He noted that some expressed a preference for teaching what they believe students need to know as opposed to teaching skills that would be learned anyway within the first few months on the job. In their review of how engineering design is taught via capstone projects, [2] also reported that engineering faculty members were concerned about teaching design because (1) they believed it will take more time and manpower than a traditional course, (2) many of them do not know how design is done in practice, and (3) they perceived that they may not be supported in their endeavor to teach the course. Reference [33] added that engineering educators are also concerned that the time spent teaching design may hinder other work.

VI. Discussion

We explore specifically how design and making-based pedagogy [34] can be instilled through pedagogical innovations through new activities with supporting faculty. Through a framework of “additive innovation” [35] of supporting sharing ideas, remixing them, and sharing them back again, student leaners and faculty can be encouraged to take pedagogical risks towards more active learning. This can help make connections for student engineering learners through real-world application and context, often absent from introductory coursework, engineering fundamentals, foundational engineering courses in the first year, and not readily evident from a map of the program curriculum.

With a making- and design-based approach the ambition is to make it more fun and worthwhile for students as well as help the instructor enjoy teaching the course/coach students through the design process, making skills, and applying those learning to solve problems that they care about. By tinkering, it is meant to start by showing students the basics (of some area of engineering fundamentals, of making) and expect them to then take that knowledge and skills further through exploration by imagining and building a physical solution, in an interactive and reflective way. Project based and design challenges are pedagogical approaches that can really engage and excite students. For a first-year introduction to engineering course, we aim to bring making through hands-on design projects/challenges throughout the semester in small chunks (2-3 weeks. Introductory activities and design challenges can be associated with a number of technical topics for mechanical engineering: mechanics of structures, material and manufacturing, and fluids engineering. There is a cluster of learning goals that are overarching these sets of activities: applying a creative problem-solving design process, design under constraints (materials, time, tools), collaborate in teams, empirically explore a specific engineering phenomenon, and have fun.

With product development and hands-on building experiences underrealized and engineering science a prevalent approach to teaching college students, the opportunities that do exist to explore one’s interest in conceptual product design and its associated making and tinkering are lacking. Today, means to foster creativity in an academic setting are limited. Coupled with calls for competitiveness and worries of unending economic straits, a search to find new means to create innovators and learning models in the classroom is needed. With a ubiquity of information and promises of technology, such potential can be manifested in the Maker Community, often thought of as through 3-D printers, lasers to cut material precisely, and open-source collaborative efforts. We seek to illuminate the engineering classroom experiences of product design and making in ways beyond just tools and places – for those who engage in authentic engineering practice through imagination and making; design and analysis; and also tinkering, hacking, and tweaking to create some new innovation. In the formal engineering curriculum, making may or may not fit. We seek to study making in the engineering classroom and making learning better to understand what students know and how they have come to know it.

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