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Fostering an Enterprising Learning Ecology for Engineers*

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Over the last decade, many courses have been created in the hopes of getting engineering students more excited about innovation and entrepreneurship. While most of these courses have aimed to teach students business acumen, we believe that, under the right circumstances, traditional engineering courses can get students excited in these topics as well. We present Mechanical Engineering 218 Smart Product Design, a graduate-level mechatronics course sequence at Stanford University, as an example of such a class. In this paper, we explore, in detail, the personal, contextual, and interpersonal factors which comprise ME218's enterprising learning ecology. We also highlight some of the immediate and longer-term outcomes of the course, including gains in students' innovation self-confidence and entrepreneurial intentions.

Keywords: mechatronics; learning ecology; innovation; entrepreneurship

1. Introduction

Concerned about the nation's recent economic downturn and dwindling global competitiveness, several organizations have called on engineering schools to produce innovative and entrepreneurial engineers 'who can invent new products and services, create new industries and jobs, and generate new wealth' [1, p. 22]. Consistent with these calls, new programs have been created at top institutions such as Stanford University, MIT, and UC Berkeley [2]. Many of these programs aim to increase students' understanding of business, emphasizing topics like new venture creation and development. To some critics, this is an improvement over traditional engineering courses which have long emphasized technical competence [2–3]. However, recent thinking by Feland et al. (2004) [4] suggests that teaching technical competence and teaching innovation can be accomplished in parallel.

The main tenet of Feland et al.'s comprehensive design engineering approach is that teams are most likely to achieve innovation when their ideas integrate business, human, and technical factors [4], as illustrated in Fig. 1. This necessitates a need for 'T-shaped people' [5, pg. 75], or people who possess a depth of knowledge in at least one field and a breadth of knowledge in the others. Thus, while many engineering courses in innovation and entrepreneurship focus on business (and in some cases, human) values, students must also be given opportunities to develop deep technical expertise. According to Taatila (2010) [6], these opportunities allow students to become familiar with the latest developments in their field, seeding ideas for future ventures.

Traditional engineering courses actually do play a vital part in preparing students for this type of work. The success or failure of these courses, however, like any course, depends not just on *what* is taught but also on *how* it is taught. In other words, successful courses will be those that inspire high levels of engagement and satisfaction in students.

In this paper, we present Mechanical Engineering 218 *Smart Product Design*, a graduate-level, four-

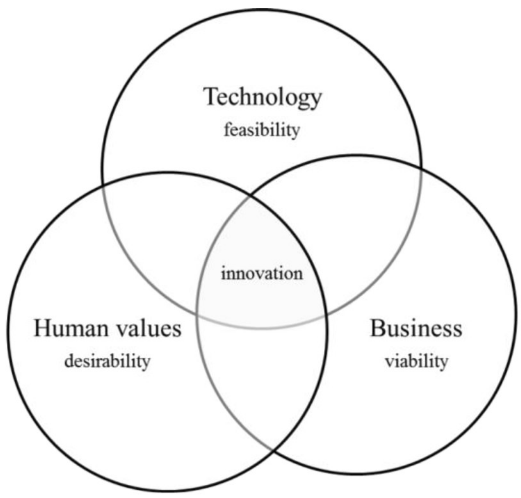

Fig. 1. The comprehensive design engineering approach [4].

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quarter mechatronics course at Stanford University, as an example of a course being taught in this way. ME218 is unique because it combines instruction in a highly technical area with an enterprising learning ecology, which we define as one that encourages its students to be innovative. This paper examines the factors that comprise the ME218 learning ecology and identifies benefits that students gain from participating in it.

2. Theoretical framework

Our investigation of ME218 *Smart Product Design* was guided by learning ecology theory. The term learning ecology was defined by Barron (2006) as 'the set of contexts found in physical or virtual spaces that provide opportunities for learning' [7, p. 195]. Each context consists of a unique configuration of activities, material resources, and relationships that, when taken together, support learning. In her research on adolescents learning technology, Barron demonstrated that those learning ecologies abundant in resources (e.g., books, classes, and mentors) are successful in sparking and sustaining adolescents' interests. Such learning ecologies also motivate students to spend significant amounts of time honing their interests and stimulate more creative thinking [7]. Similar phenomena have also been found in the workplace. Amabile and Gryskiewicz (1989), for example, identified a set of eight factors known to foster innovation at work: autonomy, challenge, appropriate resources, a supportive supervisor, diverse and communicative coworkers, recognition, and an organization that supports creativity [8]. Brunhaver, Korte, Lande, and Sheppard (2010) have also shown that the presence or absence of these factors at work—particularly support from managers, coworkers, and the organization overall—can significantly impact the ability of new hires to achieve peak creativity and performance in their work [9].

Research has demonstrated that a rich learning ecology can encourage innovation and engagement in both adolescents and workers. Hence, extending the learning ecology framework to graduate students in ME218, we feel, is a reasonable extension. In this paper, we present the factors comprising ME218's enterprising learning ecology. We will also show how these factors relate to the two student outcomes of our primary interest: innovation self-confidence and entrepreneurial intentions.

3. Methodology

This study is mixed methods and uses a qualitative-to-quantitative research design [10]. The qualitative data come from a one-hour, semi-structured group interview conducted with five ME218 students in Spring 2010 at the end of their third course in the sequence. Prior to the interview, each researcher generated a list of potential positive factors contributing to the courses' enterprising nature. These lists were based on observations of and conversations with ME218 students and teaching staff, and the researchers' own knowledge of the course. The researchers' lists were then collated into an interview protocol. We asked students to respond, in an open-ended fashion, to prompts about the laboratory space, the course structure, the teaching staff, and the peer environment. The students were also asked to reflect on other additional prompts for their reasons for taking ME218, the amount of time they spent on the course, and their perceptions of ME218 as compared to other courses in their undergraduate and graduate academic careers.

The recruitment and interview process took place over a one week period in the spring of 2010. With permission from the instructor, the researchers visited a ME218 lecture, explained the study to the students, and invited them to participate in the group interview. Out of approximately 40 students, five students, all male, agreed to participate. With the exception of one doctoral student in aeronautics and astronautics, the rest of the students were pursuing a master's degree in mechanical engineering, and three had chosen mechatronics as their master's depth area. Furthermore, while two students had taken ME210, a one-quarter, mezzanine mechatronics course intended for upper-level undergraduate and graduate students, none of the students had had exposure to mechatronics prior to starting their graduate programs. The interview transcripts were analyzed using an open coding approach which allowed themes related to each interview question to emerge inductively from the data [11].

To test the generalizability of the interview findings, the research team then created a quantitative survey that was disseminated to ME218 alumni who had taken the courses in either the 2009–2010 or 2010–2011 academic year. The survey included questions related to the interview findings and other items not covered in the interviews, such as innovation self-confidence and entrepreneurial intentions. Out of a potential pool of approximately 130 participants, 42 alumni responded (32%). Thirty-five of the 42 were male master's students in the Mechanical Engineering program. The remaining seven participants were either female (n = 4) or pursuing a different kind of degree (n = 3); these participants were omitted from the analysis to establish a homogenous cohort of respondents. Of the 35 retained, 27 had chosen mechatronics as their mechanical engineering department master's concentration. In addition, of the 35, five had stopped out of the course sequence after taking ME218A (the first class in the sequence), five had completed ME218A and ME218B (meeting the concentration requirement), 19 had taken all of the courses up through ME218C (the end of the academic year), and one had taken the fourth-quarter project course in addition. The survey data were analyzed in SPSS.

The balance of the paper presents results from our two analyses. First, we share the interview findings using quotes from the five participants and our own observations as evidence. We describe the factors which seem to contribute to a strong enterprising learning ecology, as well as some of the positive outcomes that the course had on the students. Then, we use the survey findings to identify significant relationships between motivation, factors, and student outcomes in our larger survey sample.

4. The ME218 learning ecology

In this paper, we present findings from Mechanical Engineering 218 Smart Product Design at Stanford University. ME218 is a four-quarter, lab and project-based course sequence for master's students in mechanical engineering [12–13]. The learning objective of ME218 is to teach students how to apply mechanics, electronics, and software to the design of programmable electromechanical, or mechatronic, systems [14]. Each course is offered for four or five units, and the first two courses constitute the mechatronics concentration area, one of 14 concentration areas in which mechanical engineering masters students can choose to specialize [14–15].

Established in 1978, ME218 has long been popular among incoming students, with approximately 65 students enrolling in the first quarter and 40 students staying on through the third quarter every year [12]. Among the many reasons for the course's popularity is that it is cross-disciplinary; many of the more traditional mechanical engineering concentration areas, such as fluid mechanics or heat transfer, are not. ME218 is also well-known for the number of its alumni who have joined the ranks of the start-up world; the companies founded or co-founded by ME218 alumni include Tesla Motors, OmniCell, and Mindtribe.

The ME218 sequence is structured so that each course in the sequence builds upon the last. The first quarter, ME218A, introduces students to the fundamentals of mechatronics design. The next quarter, ME218B, focuses on applications of mechatronics systems. ME218C exposes students to more complex topics including the use of multiple, communicating microprocessors. Finally, in ME218D, students work on industry-sponsored projects [14].

In the passages reported in the following sections, students often refer to ME218 as 218 and each of the courses in the sequence by quarter as A, B, C, and D.

A number of personal, contextual, and interpersonal factors were found to comprise the ME218 learning ecology. Personal factors refer to students' motivations for taking the course; contextual factors, to the learning environment and course structure; and interpersonal factors, to the interactions between people within the course. Each type of factor will be described in detail.

4.1 Personal factors

Intrinsic Motivation. Students take ME218 for a host of different reasons. Within the mechanical engineering graduate student population, some come to Stanford explicitly to learn mechatronics and take ME218 and, in many cases, were encouraged to do so by a mentor in industry. Other students become interested in ME218 after undertaking related coursework.

> *It was recommended to me when I had an internship before coming to Stanford, the summer before that, by a guy who was here. I saw him doing all this cool stuff where he was on his computer and making things move. 'How do you do that?' He was like, 'Just take this ME218 class. That's all you need.'*

> *I decided to take [ME]218 because last year I had started my master's program here and I had taken ME210, which is kind of an intro class. And then I was working on a project in ME310 [another engineering design course] and our project happened to involve a lot of embedded electronics and stuff like that. Nobody on our team of four mechanical engineering students really had a good handle on how to do it well. I probably took three or four circuit classes in undergrad but it was very theoretical and I realized I couldn't actually build anything. I felt like I wanted to, so I went and took ME218.*

Despite their different pathways getting to ME218, most students appear to be highly intrinsically motivated to learn mechatronics. They engage in the course because they think mechatronics is fun or interesting, or because they like to build and figure things out. Similar to Walker et al. (2006) [16], there seems to be a connection between high intrinsic motivation and a high level of cognitive engagement in the course. Not only were the students in our group interview willing to devote many hours to ME218, a few said that they like to do mechatronics-related work in their spare time anyway.

> *For me, I'm there a lot because this is what I want to do with my life. And so, being there, working there all night or all day, on some software stuff or on circuits, assembling them and taking ridiculous amounts of time to solder together these really complicated circuits, it's pretty rewarding in the end, and I'd say that as far as [ME]218 goes, I feel like if I had spare time, this is the kind of stuff I'd like to do in that time.*

4.2 Contextual factors

4.2.1 Laboratory space

Physical Layout. ME218 students inhabit a laboratory space dedicated to mechatronics project work throughout the academic year. The ME218 loft, as the students call it, has high ceilings and large skylights but a small floor plan. A door combination is needed for access and it is not immediately close to other labs, making it somewhat isolated from anything else. Group worktables and computer stations take up most of the space, and well-worn furniture serve as bleachers for whatever action is underway. This bootstrapped ethos with its economy of resources and décor was noted and appreciated by the students we talked to:

> *It's very adaptable, I would say. There [are] 16 computer stations, each of which has an oscilloscope and power supply and all of the software tools you would need to write code. You'll find as the projects go on, some stations no longer have power supplies because they've been moved to a different place where they need to be used, and that's okay. An oscilloscope can be moved over somewhere else. And the soldering stations are all mobile, and there's lots of bench space for people to work on. I think that counts for a lot too, because it's [the lab] not huge. I mean, in a perfect world, it could stand to be bigger, but given the size, the footprint that we have, it's adaptable enough that you can make it work.*

> *It would be nice to have chairs with functioning backs but really when that's your complaint for a lab workplace, that's a great facility.*

> *It's hot, the chairs are uncomfortable, and I love it.*

As shown above, comments about the chairs in the lab space were particularly plentiful. The less than flattering nature of these chairs is emblematic, perhaps, of the perspective that the students take on the ME218 loft. It is functional and allows them to accomplish what they need to without extraneous niceties. It is a well-equipped lab space suited perfectly to their needs.

Raw Materials. In addition to computer equipment and fabrication tools, raw materials are readily available to the students. Sheets of acrylic and fiberboard are stacked, waiting to become platforms for future robots, while the 'cabinet of freedom' offers an amalgam of miscellanea.

> *I'm a big fan of the cabinet of freedom. So there's this corner where there's just free junk that's moderately organized but not entirely. There are spray cans and other handy things. When you need something, you can't go to the cabinet of freedom and find what you're looking for, but if you spend some time just cruising through it, you find awesome, cool stuff.*

Past Reports and Projects. Another special feature is the past reports and projects available for students to use as reference material. High up on display around the perimeter of the lab are robots from past year's projects. Dozens of examples model for students novel and clever approaches to solving problems. The students hold these relics in high regard, referring to them as 'trophies.'

> *You can constantly get ideas from the things that are surrounding you, and also from the virtual space. [The instructor] provides reports from past projects. The projects on the website right now are from 2 years ago.*

The 'virtual space' mentioned by the student above is an internal course website with selected reports from previous course offerings. In addition to documenting their final design specifications, each project team must include 'gems of wisdom' to pass down to future students. These gems range from eminently practical, project-related advice to both serious and light-hearted recommendations about how to cope with the intense course load (e.g., 'Keep snacks around, but don't confuse them with solder.') This exchange of information from one class to the next supports what Hargadon (1999) has called knowledge brokering, i.e., having 'valuable and diverse inventories of past ideas that could contribute to creative solutions for new projects' [17, pg. 139].

4.2.2 Course structure

Labs and Projects. The ME218 learning philosophy is that the best way to learn mechatronics is by doing it yourself [12–13]. As such, a hands-on learning orientation permeates the sequence, with lab experiments and design projects reinforcing the lecture material through application. While the design projects increase in time and complexity as the sequence goes on [12], they share three common characteristics. Each project (1) requires the integration of mechanics, electronics, and software to create a unique solution that has never been imagined before, (2) is well-defined, with the design specifications coming from an advisory group of the teaching staff and course alumni, and (3) is open-ended, meaning that there are multiple strategies a team can undertake and no one obviously superior solution [12–13]. The students we interviewed welcomed the autonomy accompanying these assignments:

> *You are given free rein to do whatever you need to do, in some sense, to make it work. And that's a great way of learning since you actually have to make something work, and I think it's a lot more effective for the type of people who go into [ME]218, rather than taking an exam on structured programming or something like that. And that's what's unique about [ME]218.*

Assessment and Celebration. In order to avoid the potential negative effects of competition, teams are graded solely based on whether they meet the minimum requirements specified in the project definition. Often, this means only that that the device has some functionality, i.e., that it can move and accomplish the project task. It is an absolute, objective measure, not dependent on other projects in the class.

> *Graduate school was supposed to be about learning and, particularly with ME218, applying that knowledge in a hands-on way. And so, the way [the instructor] assesses you is primarily on, 'Does it work?'*

Once grading is complete, all students are given the opportunity to publicly celebrate their work [13–14]. Yearly ME218B presentations take the form of a double-elimination, head-to-head tournament in front of a couple hundred person audience. The winner is lauded but so too are robots that demonstrate spectacular failures and ones that elicit cheers due to their 'coolness' factor [12, pg. 794]. Roth (2003) commented that under this celebratory competition format, classes are more apt 'to become a learning community' and 'form lasting professional relationships based on getting the problem solved rather than personal advantage and reward' [18, pg. 10].

Scaffolded Learning. As mentioned earlier, each course in the four-quarter ME218 sequence builds on the topics covered in the last. The students we interviewed repeatedly called out the 'building blocks' they acquired along the way:

> *The first quarter is pretty much a crash course in applied electronics in a system... First you start out with building blocks of electrical circuits, and then we did how you program things in C [the programming language].*

> *It's also nice because when you get to B and C [quarters], you have all those building blocks from A [quarter] to build on, like implementing a PI control. We had to do that for a lab, so I wouldn't have to build it from scratch. We have these modules that we know we can already do and can throw in.*

Thus, scaffolding is built into the assignments [19]. First students practice discrete tasks such as building circuits and writing code, and later they integrate these tasks into open-ended design challenges. As the students achieve greater mastery, they require less support.

Economy of Deliverables. In recognition of the fact that students have responsibilities outside of ME218, deliverables are purposefully kept at a reasonable minimum. For example, students are not asked to provide extensive lab reports, and for their design projects, they are required only to create a website that captures the most salient features of their work (e.g., materials, specifications, etc.) This means of documentation is easily reused both later in the course and as work samples for future job and academic interviews.

> *The main format for documentation, for projects, for us is to build a website. I don't feel like I have to generate this large document that's pages upon pages, and a website is about pictures and videos that can really convey your design and what you did a lot more easily than words can.*

> *We'll frequently go back to our previous websites, see what used there, and grab it.*

> *I think that's [the website] is great because I use it as a portfolio of the work I've done.*

4.3 Interpersonal factors

4.3.1 Teaching staff

Interest and Engagement. The students in our group interview talked expansively about the course instructor and teaching assistants. Since students commit so much time to ME218, they appreciated the interest and engagement put forth by the teaching staff. As noted by the students, these lay in strong contrast with other courses they had taken.

> *Especially A quarter—it just blew my mind. I had never been in a class where the professor and the teaching assistants just cared that much. I mean, there were some nights that [the instructor] would just show up at 10 or 11 [at night]. 'Here are some cookies, guys. It's going to be a late night. Good luck.' That was my favorite thing.*

> *Just the time commitment they [the teaching staff] put in. Last quarter they might have spent more time building the playing field than we spent building our projects and that's saying something. It's really inspiring to have them working the really long, late, ridiculous hours with us. I don't know too many TA's who would both be in the lab working until 3am on a Friday night.*

Trust and Respect. The students we interviewed also reported that the ME218 teaching staff created a safe learning environment based on mutual trust and respect. Even the simplest questions, they said, were fielded by the teaching staff with thoroughness and honesty to the complexity of the material.

> *There isn't any hidden complexity. He [the instructor] will explain everything that needs to be explained, and if he's going to leave something out, he's going to tell you, 'Come talk to me later if you want to know more.' In a lot of undergraduate classes, they'll just gloss over it or try to hide the complexity. This is really cool because you've taken off the gloves and you can really dig in and see the complexity of what's going on.*

Informal Learning Loops. Within the ME218 community, there also exist formal and informal learning loops. Standard in most classrooms, there are formal connections between the instructor and the students. Less formal are the connections inside the ME218 loft where the instructor (and teaching assistants) takes on the role of coach [20]. Also part of these informal learning loops is a group of expert coaches, i.e., ME218 alumni who volunteer several hours in the lab every week to helping the students [21].

> *I think the lines between the teaching staff and students are blurred very much. and I like that. I like that the TA's and [the instructor] will be there alongside you figuring something out. It's a mentorship thing for me, and they're*

very available to you in a technical sense as well as in a personal sense. And I think that's a huge benefit to ME218. You don't have some nebulous professor who's off in an office and [who] comes to lecture to you with no interaction other than that. In [ME]218, it's not that way. It's very much a dialogue rather than a monologue.

4.3.2 Peer environment

Peer Teaching and Collaboration. Every year, there are always quite a number of students (45–60) and teams (12–20) putting their mechatronics knowledge to work in close environs. Charged with the same engineering task, student teams head down different solution paths but share in the experience together. Peer teaching and collaboration are strongly encouraged in this process. As demonstrated by the following example, it appears that only sometimes do the students need to be reminded to collaborate rather than compete.

He [the instructor] tries to maintain that environment of friendliness. Like, we got a little too competitive with our project last quarter. I mean, that's the only time I've seen him actually upset. Like, 'Guys, this is not to try to destroy the other robot, this is to make something cool and have them all working together.'

Camaraderie. Long hours, tedious debugging, and close quarters all contribute to a strong sense of camaraderie among the students. While one student equated ME218 to 'Navy Seal hell week,' others described a similar sustained and intense experience made more palatable by the company of their peers. In many cases, students become so close that they begin to help each other with non-ME218 courses and projects.

It is fun. At some level, there are these other individuals who are sitting here with me, the camaraderie that you build from being there late at night, it's like a 'misery loves company' kind of thing, right? Brothers in arms. You get to know these people very well because you are in high stress situations and you need to help each other through those. You're in the front lines together and so there is something to be said for that. I don't normally dread going into the lab because it's an enjoyable environment being with these people who are working just as hard as me.

I was a TA for a class that one of my teammates was in and hadn't been to the class in a couple of days because he was doing that ME218. So it was last quarter, nearing the project completion, and I was explaining to him the last week of class as the sun rose in the SPDL [ME218 loft].

Team Accountability. Working in projects teams helps to motivate students to put forth their best effort in the course, even when they do not feel like it. This effect stems from the fact that students are now not only accountable to themselves but to their teammates as well.

I think the team element, for me, really makes me go that extra mile, because you have other people who are relying on you to come in, and if it was just me and my individual grade was all I had to worry about, I wouldn't spend nearly as many nights until three or four in the morning. But because it's a collective effort, that makes me go the extra distance.

Such strong commitment to the collective was evident in many of the stories the students told us. Thus, the interactions between students and the teaching staff only help to support the foundation created by the personal and contextual factors in the class. The immediate and longer-term outcomes of ME218 are discussed next.

5. Outcomes

5.1 Immediate outcomes

Mechatronics self-confidence. All of the students we talked to said that they felt more confident in their mechatronics abilities, which they developed through working on the lab assignments and design projects. Some students also felt a deep sense of personal satisfaction after taking the course and viewed their functioning robot as a rite of passage.

I feel like the payoff at the end is always worth it, always, even though other people came to the project presentations last quarter and they were like, 'Oh, it's a little robot that drives around.' They saw basically a RC [radio-controlled] car and said, 'I can buy one of those on the shelf for ten bucks, what's the big deal?' But you know it's a huge deal, and everyone else in the class who's going through the same stuff knows it's a big deal too.

I think that the reward at the end of it makes it worth it, is true. A lot of times, actually for me more often than not, I hate this course going through it. I hate this class. But at the end, when it's all done, I really enjoy it and it was worth it for me.

Problem-solving self-confidence. The students also reported feeling better prepared for hands-on problem solving. That is, after taking the series, they felt more confident in their ability to approach a problem, break it down, and then figure out how to best solve it using the tools that they had learned in the course.

I went to grad school wanting to learn how to actually do things hands-on. That's why I came to Stanford, specifically [ME]218, for that. And I was very frustrated, coming to grad school and taking classes like [an upper-level math class] where I sat in a lecture hall with 200 other students and I did problems sets and I did exams and thought, I thought I was totally done with this. [ME]218, you are done with that. It's all about learning how to do things and coming out of it with the skills to actually do something.

5.2 Longer-term outcomes

Community of Practice. Another outcome listed by the students was entry into the larger ME218 community, comprised of all the former alumni of the course. In a way, ME218 has developed its own community of practice [22], brought together by a

Table 1. Pearson correlations between learning ecology factors and select student outcomes

	Gains in Innovation Self-confidence	Gains in Plans to Start a Company
Personal Factors		
Intrinsic Motivation	0.322	0.032
Contextual Factors		
Satisfaction with Laboratory Space	–0.161	–0.372*
Satisfaction with Lab Assignments	0.549**	0.235
Satisfaction with Design Projects	0.651***	0.372*
Interpersonal Factors		
Satisfaction with Teaching Staff	0.616***	0.488**
Satisfaction with Peer Environment	0.551**	0.317
Student Outcomes		
Satisfaction with Course Overall	0.665***	0.355*
Gains in Innovation Self-confidence	1.000	0.551**
Gains in Plans to Start a Company	0.551**	1.000

Key: *p < 0.05, **p < 0.01, ***p < 0.001.

common interest and shared knowledge (i.e., mechatronics). Just by virtue of having taken the course, the students also have social capital [23] and access to a wide-ranging professional network.

[One of the benefits is] building a network of people that's going to sustain you throughout your career. And there's value in that. In somewhere down the line, I'm looking for a job or they're looking for a job. These are the people I'm going to look to first because I'm intimately aware of what they're capable of, the type of people that they are, and so that network building aspect of it is part of why I came into it, it's part of the goal. And we've always been told, but I don't know how true it is, that the alumni of [ME]218 are a very tight-knit group. And that counts for a lot too. That's part of the reward of going through this boot camp process.

6. Support from the survey results

Our survey results, collected from 35 ME218 alumni from the 2009–2010 and 2010–2011 academic years, yielded good consistency with our interview findings. With an average normalized score 0.88 ± 0.122 (on a scale of 0–1), the group showed high intrinsic motivation to learn mechatronics[1]. Furthermore, most respondents rated themselves as satisfied or very satisfied with the lab assignments, design projects, teaching staff, peer environment, and course overall[2]. All or most of our respondents also agreed or strongly agreed that the course had helped increase their mechatronics self-confidence (n = 35), problem-solving confidence (n = 32), and feelings of kinship with the ME218 community (n = 23). The sole item on which the survey results and interview findings differed was student satisfaction with the laboratory space (i.e., the ME218 loft). The average normalized satisfaction score for this item was moderate, at 0.66 ± 0.258 (again, on a scale of 0–1), and several alumni talked about the small size and lack of newer tools when asked if they experienced any obstacles while taking the course.

Given our interests in innovation and entrepreneurship, the survey also asked respondents about outcome measures specifically related to these topics. We found that 86 percent of our participants agreed (n = 12) or strongly agreed (n = 18) that they felt more confident in their ability to be innovative as a result of taking the course. In addition, almost 60 percent of our respondents said that they were somewhat (n = 16) to much more likely (n = 4) to start their own company, also as a result of ME218. Along these same lines, some of the alumni's open-ended responses about how they intended to use ME218 in the future included comments ranging from 'inventing stuff,' to 'building stuff and developing my own ideas,' to 'hopefully someday starting a company.' To determine which, if any, factors of the ME218 learning ecology may have influenced these gains, we looked at the correlations between these variables, which are shown in Table 1.

The table shows that high intrinsic motivation to learn and do mechatronics was not significantly correlated with gains in innovation self-confidence or plans to start a company. These results suggest that the alumni who were more interested in starting their own companies after taking ME218 were not driven by their deep interest in the topic but rather by another reason.

Table 1 also shows that gains in students' innovation self-confidence were positively correlated with most of the contextual and interpersonal factors at the p < 0.01 or p < 0.001 level, including satisfaction with lab assignments, the design projects, the teaching staff, and the peer environment. Thus, these aspects of the learning ecology may be particularly

[1] The intrinsic motivation construct was comprised of three items (I thought mechatronics would be fun, I thought mechatronics would be interesting, and I like to build stuff); the Cronbach's alpha for these items was 0.733, which is considered to be an acceptable level of internal consistency.

[2] For each of these items, the average normalized satisfaction score was above 0.8.

influential in helping students to become more confident in their innovation skills and perhaps even more willing to take risks.

We notice that gains in plans to start a company was positively correlated with satisfaction with the design projects ($p < 0.05$) and with the teaching staff ($p < 0.01$). These gains were also positively correlated with overall course satisfaction ($p < 0.05$) and innovation self-confidence ($p < 0.01$). Thus, students' entrepreneurial intentions could be influenced just as much by the complete ME218 experience than by any one factor in particular. Alternatively, student's innovation self-confidence could help mediate the relationship between the various learning ecology factors and their entrepreneurial intentions. A second, more expansive survey could help determine whether either explanation is valid.

As an aside, laboratory space was negatively correlated with both innovation self-confidence and plans to start a company. These results indicate that while most of the survey respondents were dissatisfied with the laboratory space, it did not deter them from wanting to pursue either option. Nonetheless, another opportunity for future research could be identifying the course factors that do serve as barriers to students' start-up plans.

7. Conclusions

In this study, we used interview and survey data to identify several factors contributing to the course's enterprising learning ecology. Among them are a dedicated laboratory space filled with abundant resources, a course structure designed to promote autonomy and stretch, and a class community built on feedback and support. Together, these factors seem to create a significant positive experience for those who take ME218. Some of these factors also seem to be related to increases in students' innovation self-confidence and entrepreneurial intentions. Thus, we conclude here that our original hypothesis was correct— while a tradition engineering course can get students more excited about innovation and entrepreneurship, it depends largely on the way the course is taught.

We acknowledge though that this study was not without limitations. First, our findings were based on small, relatively homogenous samples. Our interview and survey samples were comprised of only five and 35 individuals, respectively. These samples were also comprised of male mechanical engineering master's students, most of who had stayed in ME218 through the third quarter. Second, we asked participants to reflect back on their experiences in ME218 one to two years prior, which means their responses could have been influenced by retrospective bias. Future work might include a larger, more diverse study that features pre and post-tests meant to determine how students' attitudes toward innovation and entrepreneurship change after taking ME218.

Another caveat to our study is the fact that it was comprised of a single course, taught at a university located in the Silicon Valley. While the course does not explicitly teach innovation or entrepreneurship, it is situated within a larger culture of entrepreneurship which may have influenced its learning ecology. In fact, several parallels can be drawn between ME218 and the start-up culture, including the long hours that the students and teaching staff spend side-by-side in the laboratory. Thus, further work is also needed to determine whether our findings can be generalized to other courses, programs, and companies outside of the valley. One possible implication of this work might be that engineering schools can help students develop their innovation and entrepreneurial skills not just in a select few classes but throughout their entire program.

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