Introducing Autonomy in an Embedded Systems Course Project

Diane T. Rover
Electrical and Computer Engineering
Iowa State University
Ames, IA USA
drover@iastate.edu

Nicholas D. Fila
Electrical and Computer Engineering
Iowa State University
Ames, IA USA
nfila@iastate.edu

Phillip H. Jones
Electrical and Computer Engineering
Iowa State University
Ames, IA USA
phjones@iastate.edu

Mani Mina
Industrial Design and Electrical and Computer Engineering
Iowa State University
Ames, IA USA
mmina@iastate.edu

***Abstract*— This Research-to-Practice Full Paper presents the redesign of a course project to promote student professional formation in engineering in the Electrical and Computer Engineering Department at Iowa State University. This is part of a larger effort to redesign core courses in the sophomore and junior years through a collaborative instructional model and pedagogical approaches that promote professional formation. A required sophomore course on embedded computer systems has been assessed and revised over multiple semesters. The redesign of the project was initiated with the purpose of promoting student professional formation, interest, autonomy and innovation, and it was undertaken using a collaborative process. This paper describes the course, final project, redesign process, assessment, results and future work. Several conclusions from the research may be useful to other educators. A small change to the course project yielded positive effects in interest and autonomy and may influence longer term effects of the project. There was evidence of difference in engagement with the project. The difference observed was not only due to option selected by students but *why* students selected the option.**

Keywords—student autonomy, innovation, engineering design projects, embedded systems

I. Background

Student professional formation in engineering involves a multifaceted student experience. In the Electrical and Computer Engineering Department at Iowa State University, we are redesigning core courses in the sophomore and junior years through a collaborative instructional model and pedagogical approaches that promote professional formation. Professional formation of engineers refers to the formal and informal processes and value systems through which people become engineers [1]. Professional formation includes development of technical and professional knowledge and skills, of ways of thinking, and of identity as an engineer. Eliot and Turns address professional identity development for engineering undergraduates in part through processes put forth by Ibarra [2] [3]:

- Engagement with professional activities and demonstration of knowledge and skills.
- Involvement with social (professional) networks.
- Sense-making, or discovery of personal and professional interests and goals.

They point out that engineering education programs offer many opportunities for students to engage in the first two processes, such as through coursework, projects, laboratories, student clubs, and internships. However, they pose the question: where in the curriculum do engineering students have the opportunity to make sense of their educational experiences, their skills and their interests as engineers? In their work, they identified sense-making activities relative to external and internal frames of reference of the student. For example, how students define engineering practice and themselves as engineers are internal frame activities. These are of special interest to us in supporting professional formation.

Other studies about student professional formation address instructional practices that use projects and problem-based learning. Projects based on authentic problems and design activities and that give students some autonomy in the design process have been shown to positively impact students' STEM identity, realization of engineering design practices, and engagement [4] – [6].

As a department, we also know what knowledge and skills are expected of students in future jobs based on ABET student outcomes [7] and employer input. As part of our multi-level ABET assessment process [8], we use employer survey results as a high-level indicator of how well our students are meeting outcomes in each of our programs. The survey collects data about student demonstration of workplace competencies necessary for the practice of engineering at the professional level [9]. A core set of competencies has been defined and are measured by the tool, and each competency is defined through key actions. The survey is administered to students and their supervisors during internship and co-op work experiences. Each supervisor (employer) of a student intern (usually a sophomore or junior) provides an assessment of the student's demonstration of each key action in the workplace. A value for each competency is computed as the average of the supervisor's assessment of the associated key actions. A program average for

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each competency is computed by averaging all the supervisor competency values.

Survey results from a recent assessment cycle (2013-2017) are shown in Fig. 1 for the computer engineering program. Results are similar for other programs in the department. The graphs display the average ratings for each core competency by students (self) and supervisors on a scale from 1 to 5, in response the following question: When given the opportunity, how often does the student perform the key actions associated with the competency? (5 – always or almost always; 4 – often; 3 – usually; 2 – sometimes; and 1 – never or almost never). The second graph also compares results for computer engineering students with all engineering students.

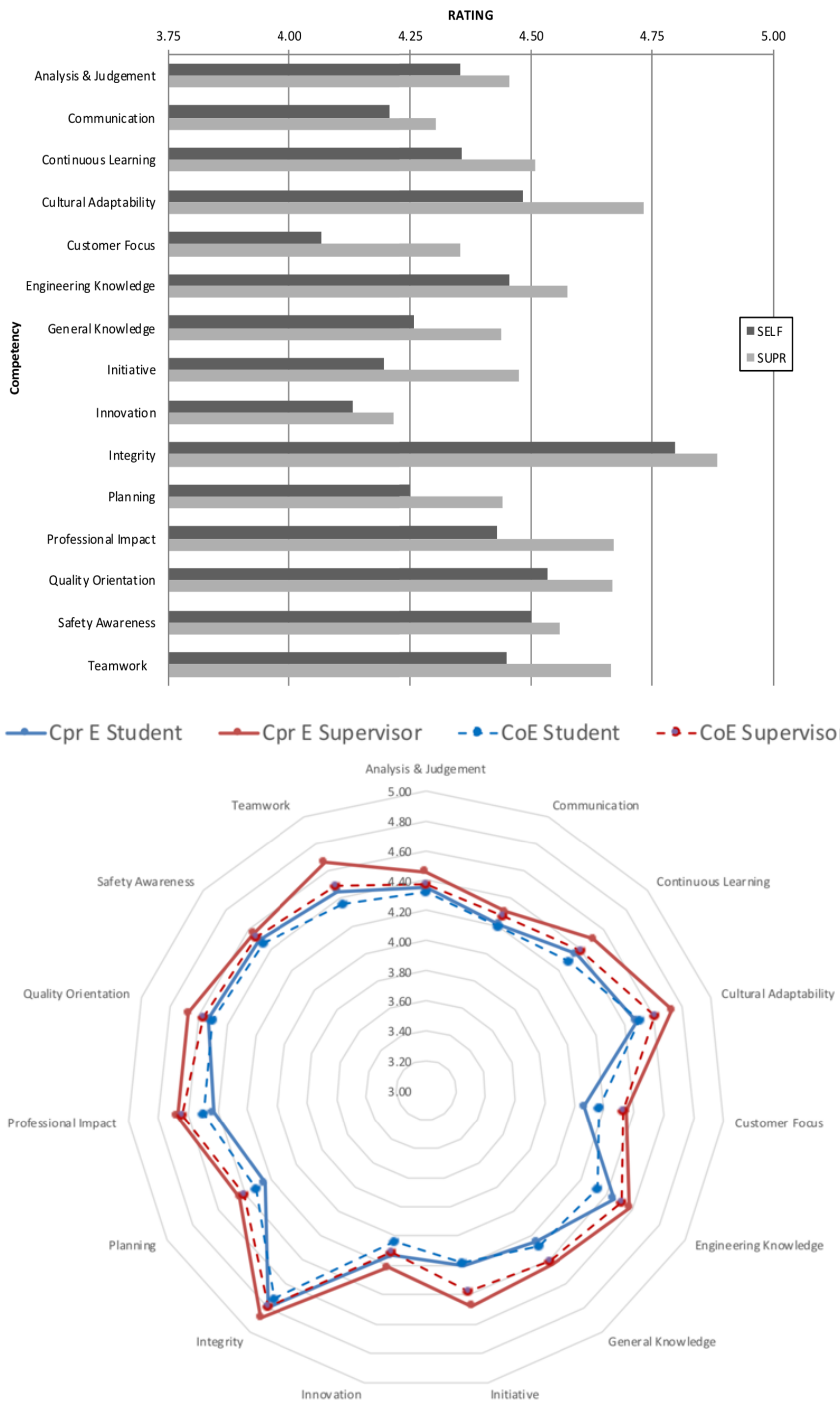

Fig. 1. Core competency survey results for computer engineering (CprE) intern/co-op students (top) and comparison with all engineering students (bottom) (CoE: College of Engineering) (Number of CprE students = 276, Number of CoE students = 5219)

Interestingly, the lowest ratings are for the competencies of customer focus and innovation. As shown by Svihla, Petrosino, and Diller, both of these competencies are central to authentic, realistic design experiences and can be supported with design projects earlier in the curriculum [5]. It's worth noting that many students take internships in their second and third years, and thus the survey data describe the student experience of some students who are relatively early in their programs. This may affect the knowledge and skills that they demonstrate in the workplace and/or their own perception of them. This may also affect the nature of the engineering work assigned to them. For example, there may be limitations on the innovation involved in internship activities compared to what the student sees other engineers working on. Nonetheless, these are potential areas to support professional formation.

Our work draws on recent studies about the ways that engineering students experience innovation [10]-[12]. In particular, recent studies are investigating project and environment characteristics that support student innovation, for example, project contexts that include authenticity, autonomy, support, interest and novelty. Student autonomy has further implications with respect to their educational experiences, motivation, identity and persistence [13] [14]. Studies are also investigating student behaviors commonly linked to innovation: questioning, observing, (idea) networking, and experimenting [15] [16]. These are key skills in engineering design, and challenges students encounter in demonstrating these behaviors can be addressed through course activities.

This remainder of this paper describes the course, a final project in the course, the redesign process, assessment of the revised project, and results.

II. Course Context

A required sophomore course on embedded computer systems has been assessed and revised over multiple semesters. Given the background above, a redesign of the course final project was initiated during a semester with the purpose of promoting student professional formation, interest, autonomy, and innovation.

The Introduction to Embedded Systems course is a 200-level course in computer, cybersecurity, electrical and software engineering majors. It is required in all but software engineering, where it is one of two courses students choose from to fulfill a requirement. Most students take the course in their second year of study, except many electrical engineering students leave it until their fourth year. The course introduces students to hardware and software aspects of embedded systems including microcontrollers, memory-mapped input/output, input/output interfaces, embedded programming in C, initialization and configuration of peripherals in software, general purpose input/output (GPIO) ports, polling and interrupt processing, serial communication (UART), analog-to-digital conversion (ADC), hardware timers (GPTM), input capture, pulse-width modulation, sensors, servo motors, mobile robots, and object detection. The first third of the course covers foundational concepts and skills; the middle third, understanding and using microcontroller peripherals (GPIO, UART, ADC, GPTM modules); and the final third, implementing a project in the lab for an autonomous vehicle application. The course has three lecture hours and two lab hours each week. The weekly labs are guided by undergraduate and graduate teaching assistants. The lecture and lab content and flow are highly integrated. The final project is introduced early in the semester and phased in through class and lab activities prior to exclusively working on it in lab.

The course is situated to support professional formation in various ways. Among the learning objectives for the course are designing and debugging applications on embedded platforms, gaining familiarity with professional responsibilities and opportunities in the field of embedded systems, exploring their career interests in this field, and considering societal and human factors in engineering work and solutions. Students work with partners in the lab and then on teams for the final project. During the first week of the semester, students respond to a short survey asking: 1) What is your view of the role of the course in your program of study and/or career plans? and 2) What do you believe will be the biggest challenge in this class for you? As one might imagine given the different backgrounds and situations of students taking the course, the responses vary widely. Despite wide-ranging goals and needs, we know that most students want to see the relevance of the course to their interests and future jobs.

III. Implementation

The redesign of the final project in the embedded systems course was undertaken using a collaborative process involving a small cross-functional team of faculty, postdocs, and teaching assistants, including instructors of the course and education and design researchers [17]–[20]. The team structure was inspired by prior work [21] and has been under development. The team has leveraged practices and tools from design thinking. Here we describe the ideation, prototyping and testing phases of an instructional design process. We used the Lotus Blossom ideation technique [22], depicted in Fig. 2. The technique starts with a central theme, problem, or core idea to be explored (placed in box 0) and works outward, generating new ideas in surrounding boxes. Each of these new ideas (boxes 1-8) becomes the center for the next round of idea generation.

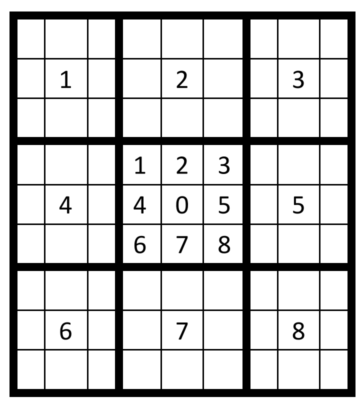

Fig. 2. Lotus Blossom technique for idea generation: box 0 is the core idea to be explored

Our instructional design team set up five Lotus Blossom poster sheets, one sheet for each project context that supports innovation (i.e., five constructs describing how engineering students characterize their innovation project experiences [11]):

- authenticity
- autonomy
- support
- interest
- novelty

Each of these characteristics was placed in box 0 of a sheet. Team members then added sticky notes with ideas for the project, iterating to fill each sheet. Given these ideas, sub-teams then worked on prototypes for the redesign of the final project. The goal of the redesign was to support these characteristics to enhance the student experience, innovation and professional formation, while retaining some aspects of the prior project, e.g., semi-authentic engineering design experience, synthesis of course concepts, and culmination of learning.

A. Prior Project

The mobile robot in the lab is an iRobot Create 2 (Roomba compatible) and can be controlled with Open Interface commands from a microcontroller board. The microcontroller board interfaces to input/output devices added to the robot, including an infrared sensor, ultrasonic sensor, and servo motor (used to get scans of sensor readings). In the final project, teams program the microcontroller to move the robot through a test field and avoid obstacles to reach a destination. Teams were given a design problem for a Mars rover autonomous vehicle application, in which the primary task of the rover is to navigate through hazardous terrain to a retrieval zone where it will send data to mission control. The design criteria for the Mars rover application are predefined as shown in Table I.

TABLE I. DESIGN CRITERIA FOR THE MARS ROVER APPLICATION

Criterion	Description
Reach goal	Find and stop in the zone where it can transmit the data it has collected.
Object detection	Detect surface objects, such as boulders and stalagmites, to avoid collisions and damaging components.
Boundary detection	Identify the boundaries of the “safe zone” to stay within areas with safe levels of solar radiation.
Object/boundary avoidance	Avoid objects it has detected and identified to limit damage.
Information display	Display information in a form that is readable to humans who are controlling and monitoring its activities.
Vehicle communication	Receive commands from mission control.
Reach goal quickly	Navigate the course and reach the goal area within a time limit so that it does not miss the transmission window.
Autonomous movement	Make decisions about movement without human commands (in case commands cannot be received).
Object identification	Determine the type of object it has detected to help determine how it will avoid the object.

B. New Project

Changes to the final project emphasized giving students more options and responsibility in project selection and management. Two project options were offered: a default application context based on a given Mars rover mission, or a student-defined application context (or story) proposed by a team (e.g., another autonomous vehicle application). Teams submitted a sketch of their application, justification for selection, and description of their design criteria similar to Table I. Teams could receive extra credit for a well-developed application story and consideration of user needs. They could document and justify modifications of requirements. These features of the project were intended to promote student interest and autonomy. All teams also completed a contract about teamwork expectations, rules and consequences. This was intended to promote a better team experience, which could in turn promote a more authentic design experience and more innovative design [5]. Example sketches are shown in Fig. 3.

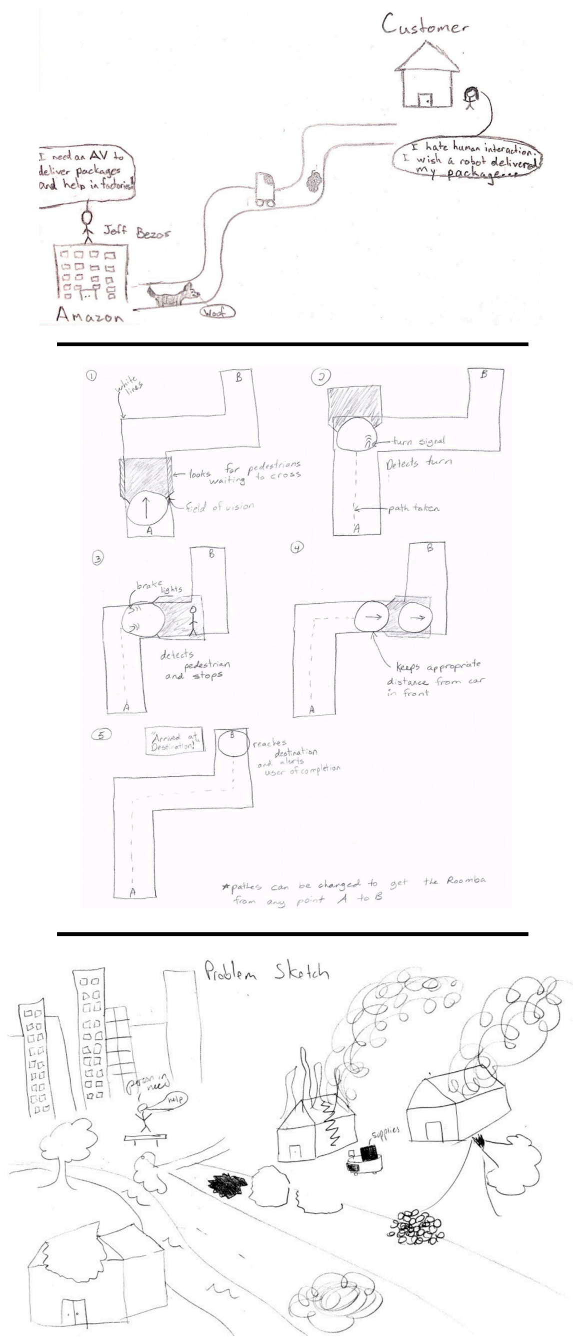

Fig. 3. Sketches of student-defined application stories

IV. Assessment

The effects of project changes were assessed using a final project survey completed by students after finishing the project. The survey consisted of two parts:

1. 25 Likert-type items covering authenticity, autonomy, interest, support, and novelty, rated using strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, and strongly agree
2. four open-response items addressing project selection rationale, favorite part, what they would change, and what they learned

During one semester of the course, 235 surveys were analyzed, out of 245 completed (246 students were in enrolled in the course). Ten surveys were removed due to being incomplete or duplicates. 88 surveys were from projects using the Mars rover application, and 147 were from student-defined application stories.

The Likert-type items were analyzed using the Mann-Whitney U test since data were ordinal. Mean item selections were compared between students who chose the Mars rover application and those who chose to define their own application story. Further, means were compared between two subgroups of application story students based on their rationale for selecting the application story option (as identified through content analysis of the open-ended responses). Students may have stated multiple reasons. One subgroup (n=57) selected the option primarily for extra credit (extrinsic regulation). The other subgroup selected it, at least in part, due to interest in the topic, opportunity to do something new, or perceived personal relevance (intrinsic regulation).

The open-response items were analyzed using conventional content analysis [23] to summarize key themes, resulting in the frequency of responses containing each key theme. Some responses contained multiple themes, and some contained none. On average, a response for an item contained three themes.

V. Results

Fig. 4 and Tables II-VI present results for the Likert-type item analysis across the five characteristics of authenticity, autonomy, interest, support, and novelty. For ease of interpretation, item responses were converted to a numerical scale with 1 denoting “strongly disagree” and 5 denoting “strongly agree”. These numerical conversions were used to create aggregate scores for each of the five innovation conditions, by averaging the five items representing each innovation condition (correcting for reverse-scored items). Fig. 4 presents a comparison of aggregate scores by project option for each innovation characteristic. The survey items for each characteristic and the means for each project option are given in the tables. The first row of each table presents the aggregate values.

It’s interesting to compare the results for the Mars rover option (orange bar in Fig. 4) versus the application story (blue bar in Fig. 4). It’s also interesting to compare the results between the subgroups for the application story, i.e., the application story (intrinsic) (light blue bar in Fig. 4) versus the application story (extra credit) (dark blue bar in Fig. 4). Several results have statistically significant differences as shown in Fig. 4 and the tables, including autonomy and interest characteristics for the application story (intrinsic) project option compared to the Mars rover. For the autonomy characteristic, both the application story and the intrinsic subgroup were statistically significant.

The application story students were generally more positive than the Mars rover students, especially students who selected the application story option for reasons beyond extra credit. Most of the statistically significant items relate directly to a student choosing their own application story.

The data show positive effects for wanting to work on the project and finding help from students or instructors.

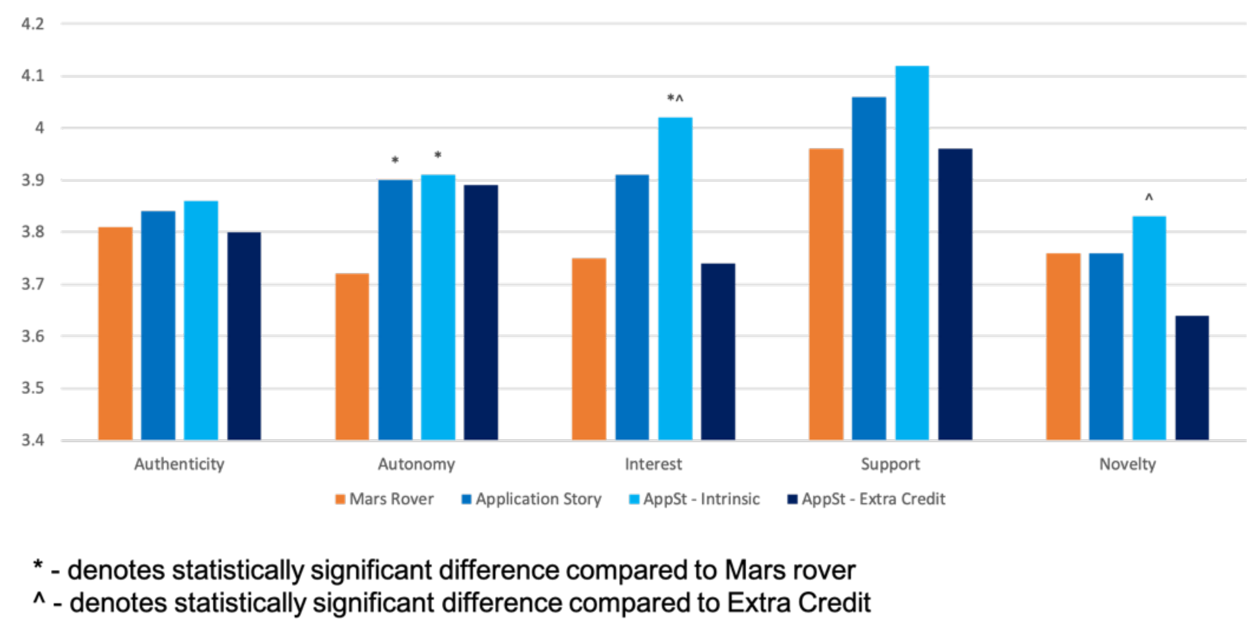

Fig. 4. Comparison of aggregate scores by characteristics

TABLE II. AUTHENTICITY ITEM DIFFERENCES

Item	Mars Rover	App. Story	App-Intrinsic	App-EC	Diff.
Aggregate	3.81	3.84	*3.86*	*3.80*	
The project felt like a realistic engineering experience.	3.94	3.86	*3.94*	*3.72*	
I experienced the whole project from start to finish.	4.19	4.21	*4.26*	*4.14*	
I completed non-technical tasks typical of prof. engr. work.	3.67	3.94	***3.97****	*3.90*	.30
The project was not representation of prof. engr. work.	2.20	2.27	*2.21*	*2.36*	
The project was too artificially constrained.	2.56	2.55	*2.64*	*2.41*	

TABLE III. AUTONOMY ITEM DIFFERENCES

Item	Mars Rover	App. Story	App-Intrinsic	App-EC	Diff.
Aggregate	3.72	**3.90***	***3.91****	*3.89*	*.18,.19*
My team and I were in control of the process we took to complete the project.	4.09	4.21	*4.21*	*4.21*	
The project was open-ended to me.	3.13	3.24	*3.17*	*3.35*	
My team and I had the opportunity to select our own project scenario.	3.74	**4.48***	***4.51****	***4.42****	.74, .77, .68
I felt like I was working on someone else's project.	2.33	2.29	*2.32*	*2.25*	
I didn't have a chance to make important project decisions.	2.04	2.12	*2.02*	*2.28*	

TABLE IV. INTEREST ITEM DIFFERENCES

Item	Mars Rover	App. Story	App-Intrinsic	App-EC	Diff.
Aggregate	3.75	3.91	***4.02*^***	*3.73*	*.27*
The project scenario (e.g., Mars rover or application story) was very interesting.	3.75	3.76	*3.96*	*3.46*	
I enjoyed the tasks I completed during the project.	4.09	4.06	*4.17*	*3.89*	
I wanted to work on the project.	3.75	**4.15***	***4.22*^***	*4.04*	.40, .47
I would have preferred a different project scenario (e.g. Mars rover or application story).	2.72	2.46	*2.41^*	*2.54*	
The project work was not interesting to me.	2.10	1.98	*1.86^*	*2.18*	

TABLE V. SUPPORT ITEM DIFFERENCES

Item	Mars Rover	App. Story	App-Intrinsic	App-EC	Diff.
Aggregate	3.96	4.05	*4.12*	*3.95*	
I was able to find help from teammates, TAs, or the instructors if I needed it during the project.	4.00	4.20	***4.29****	*4.07*	.29
Teammates, TAs, and the instructor created a supportive working environment.	4.17	4.27	*4.39^*	*4.07*	
I was able to thrive in the project environment.	3.70	3.73	*3.8*	*3.61*	
When I struggled with a topic or task during my project work, there was no one to help me.	2.11	2.10	*2.08*	*2.12*	
I did not have a good experience with my team.	1.98	1.84	*1.81*	*1.88*	

TABLE VI. NOVELTY ITEM DIFFERENCES

Item	Mars Rover	App. Story	App-Intrinsic	App-EC	Diff.
Aggregate	3.76	3.75	*3.83^*	*3.64*	
I learned new skills and/or approaches during the project.	4.05	4.00	*4.12*	*3.81*	
I encountered new topics and/or processes as part of my project work.	3.95	3.97	*4.04*	*3.84*	
I tried something new during the project.	3.90	4.03	***4.18****	*3.81*	.28
There really wasn't anything new about the project to me.	2.07	2.23	*2.20*	*2.28*	
The project experience was routine for me.	3.02	2.99	*2.98*	*3.00*	

TABLE VII. REASONS FOR SELECTING PROJECT OPTION (NUMBER OF RESPONSES)

Key Themes	Mars Rover	App. Story
Grade (e.g., extra credit with application story, or confidence in success with Mars rover)	24	88
Interest in application	24	47
Type of project (e.g., novel application story, or default Mars rover)	38	34
Relevance of project	7	9

TABLE VIII. FAVORITE PART OF THE PROJECT (PROPORTION OF RESPONSES)

Key Themes	Mars Rover	App. Story	App-Intrinsic	App-EC
Putting it together	0.23	0.29	0.32	0.23
Accomplishment	0.31	0.23	0.21	0.26
Teamwork	0.14	0.19	0.18	0.21
Specific task	0.15	0.15	0.17	0.12
Application story related	0	0.08	0.10	0.05
Process (e.g., open, iterative)	0.05	0.05	0.03	0.07
Demonstration experience	0.08	0.05	0.03	0.07

TABLE IX. WOULD CHANGE ABOUT PROJECT (PROPORTION OF RESPONSES)

Key Themes	Mars Rover	App. Story	App-Intrinsic	App-EC
Hardware	0.36	0.27	0.29	0.23
Time and space availability	0.26	0.18	0.16	0.21
Grading and demonstration	0.13	0.18	0.19	0.16
Group and project organization	0.07	0.16	0.11	0.23
Nothing	0.07	0.11	0.11	0.11
Own approach	0.08	0.10	0.11	0.07
Project build-up	0.03	0.02	0.03	0

Tables VII - IX present results for the open-response items about project selection rationale, favorite part, and what they would change. Each table summarizes the key themes from content analysis and number or proportion of responses. Table VII compares the frequency of themes found in student responses for the open-response item about reasons for selecting each project option. For example, the extra credit opportunity for their grade was a common reason among students selecting the application story option.

Table VIII presents comparisons about the favorite part of the project as a proportion of the responses. The application story responses are disaggregated by reason for selecting the project. For example, the highest proportion of responses by students motivated more intrinsically on the application story (non-extra credit) was "putting it together" (i.e., synthesis of knowledge/skills and culmination aspects) as the favorite part of the project. This is shown as 0.32 of the intrinsic subgroup (subgroup consists of 90 out of 147 application story projects). Sense of accomplishment was more prominent among students selecting the Mars rover application and the application story (extra credit).

Table IX presents comparisons about what students would change about the project as a proportion of the responses. For example, the highest proportion of responses expressed by all groups dealt with issues pertaining to the robot hardware and availability of the lab and test field. The Mars rover group focused more on challenges with hardware. The application story (extra credit) subgroup also emphasized challenges with team and project organization. This is shown as 0.23 of the extra-credit subgroup (subgroup consists of 57 out of 147 application story projects).

Tables VIII - IX show some positives and negatives related to teamwork. Overall, teamwork was more prominent with the application story groups.

VI. Summary and Discussion

Overall, the final project was a predominantly positive experience for all students. Their experiences and engagement differed depending on which project they selected and *why* they selected it. Students who selected their own application story (especially those who did so for reasons other than receiving extra credit) reported generally better project experiences. Their experience was better with respect to trying new things, working in a supportive environment, and being interested in the project (e.g., application scenario and design tasks). They reported gains in autonomy compared to students completing the Mars rover option. They also reported gains in interest and novelty relative to other project scenarios. These responses demonstrate that students recognized elements built into the project. However, it is difficult to discern whether these responses represent genuine positive experiences or objective accounts of the project conditions.

There were differences in the favorite part of the project between groups. The application story (intrinsic) group favored synthesis of course knowledge and skills, whereas for the Mars rover group and application story (extra credit) group, a sense of accomplishment was more prominent. There were also differences in what they would change about the project between groups, e.g., finding challenges with different aspects of the project. The application story (intrinsic) group focused more on experiential aspects of the project, whereas the Mars rover group commented more on hardware and space issues.

The redesign of the course project yielded positive effects in interest and autonomy, which support innovation, professional formation and other student outcomes. Thus even a relatively small instructional change may influence longer term effects.

VII. Future Work

The survey responses and analysis suggest opportunities to improve the implementation of the project, including addressing hardware and team issues, starting the final project earlier in the course, and adding more fun elements to the project (such as new components). The instructional design team continues to explore support for professional formation, including expanding the connections to sociotechnical issues, user-centered (customer-focused) design strategies, support for autonomy and interest, and support for student behaviors associated with innovation.

Responses to several survey questions were not yet analyzed. These include:

- What knowledge and skills that you learned during the final project would you expect to use in your future engineering work?
- To what extent have you felt like an engineer during the final project?
- What aspects of the final project made you feel like an engineer?
- What aspects of the final project did not make you feel like an engineer?

These questions correspond to sense-making activities in professional identity development [3]. Further analysis of the survey responses would broaden our understanding of potential effects of the project.

The project survey has continued to be administered every semester. With new instructional support added to promote relevant learning experiences, the effect of these supports could be explored to expand on this work.

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