AC 2012-3730: CREATING LOW-COST INTRINSIC MOTIVATION COURSE CONVERSIONS IN A LARGE REQUIRED ENGINEERING COURSE

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Creating Low-Cost Intrinsic Motivation Course Conversions in a Large Required Engineering Course

Abstract

When attempting to create education reform, reformers often point to the unsupportive reward structures and significant time investments for training of faculty as two major impediments to change. In this paper, we present our efforts to minimize these "costs" and develop low-cost, intrinsic motivation course conversions. This intrinsic motivation course conversion aims to lower faculty costs and promote students' intrinsic motivation to learn in order to create sustainable reform and life-long learners. We describe our design process to create such an IM course conversion, and present our evaluation of the conversion. The results indicate that we can create a shift towards intrinsically-motivated students who experience positive learning experiences at low cost to the faculty.

1 Introduction

Much attention has been devoted in recent years to "pedagogies of engagement"[1]. While early efforts in reforming engineering education may have focused more on "teaching the right stuff", more recent efforts have focused on "teaching the right way", with a particular emphasis on moving the student from a passive to an active role. Embedded within this work has been a growing awareness of the importance of students' motivation in the learning process.

But despite major investments to reform engineering education, many instructors are still slow to adopt these innovations. A key barrier is the extent to which such changes require major time investment on the part of the individual faculty member, in the face of competing priorities and because of unsupportive reward structures and significant time investments for training[2].

In light of these impediments and the importance of students' motivation, we have designed a low-cost, experimental intrinsic motivation (IM) course conversion that aims to shift the focus of education reform from training and changing faculty to focus on promoting students' intrinsic motivation to learn and using their motivation as the engine for sustainable reform.

In this paper we describe our initial effort to create this low-cost IM course conversion and our evaluation of these efforts. We begin by providing the theoretical frameworks that situate our work: self-determination theory (motivation framework) and the Goldberg-Laffer curve (faculty cost framework). We then discuss our creation of a quasi-experiment to test the potential of our low-cost IM course conversion according to these frameworks.

Finally, we present results from administrations of the Learning Climate Questionnaire (LCQ) to measure the instructor's supportiveness of students' intrinsic motivation and the Digital Logic Concept Inventory (DLCI) to measure learning gains. We also present brief case studies of the learning activities and motivations of three representative student learning teams.

2 Background

2.1 Interactive Engagement pedagogies and the Goldberg-Laffer curve

A major corpus of engineering education research has focused on documenting Interactive Engagement (IE) pedagogies that promote teacher-student and student-student interactions. These IE pedagogies develop "deep learning" that leads to expertise in a variety of engineering skills and knowledge rather than surface learning such as fact memorization or rote problem solving[1]. For example, IE pedagogies can develop deep conceptual knowledge[3-6], engineering analysis skills[7-9], problem-solving skills[10-11], and team-work skills[12-15]. Each of these pedagogies requires the instructor to be the impetus for change in the learning environment because this type of instruction centers on instructor-chosen learning objectives. Consequently, the instructor must invest significant time to become adept at these pedagogies and create the necessary resources to create change.

Adapted from Arthur Laffer's taxation-revenue model from economics[16], The Goldberg-Laffer curve (Figure 1) hypothesizes that when we attempt to move from "sage-on-the-stage" lectures to "guide-on-the-side" IE pedagogies, we can increase student engagement, but only by increasing the time and energy costs to faculty[17]. It further hypothesizes that there is an "IM space jump" through which we could increase student engagement in the classroom with minimal or no cost to faculty. Instead of faculty-driven change, intrinsically-motivated students drive the change in the classroom and create pedagogical and educational reform. Our IM course conversion experiment is our first attempt to find this IM space jump.

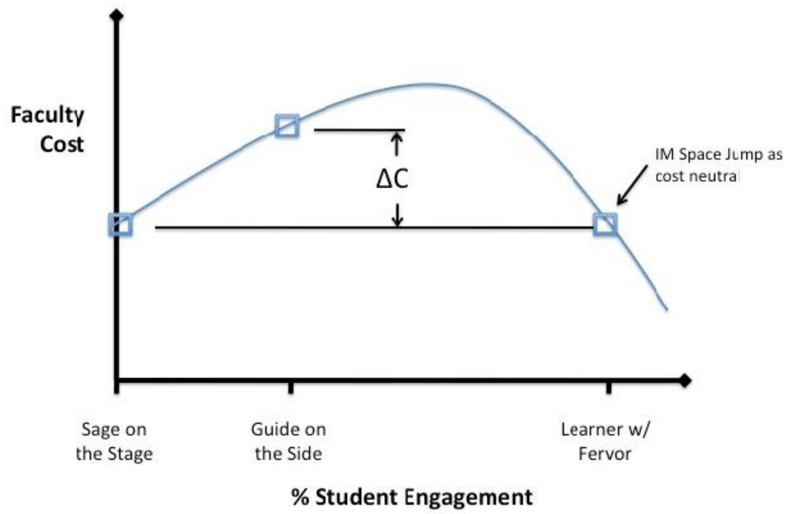

Figure 1: Goldberg-Laffer curve

2.2 Student motivation

An individual's motivation arises from human needs for *competence* (*mastery*), *autonomy*, *relatedness*, and *purpose*[18,19]. In an academic context, students feel *competent* when they master a body of knowledge, enjoy *autonomy* when they control their learning, achieve relatedness when they belong to a community, and gain a sense of *purpose* when the learning objectives of a course align with their personal values or goals. Motivation ranges on a continuum from *extrinsic* (receiving rewards such as grades, complying with rules) to *intrinsic* (satisfying personal interests, or deriving from the inherent value of an activity)[18].

Researchers have found that students learn more under five conditions that tend to promote intrinsic motivation for learning a subject[20]:

1. When students expect to do well
2. When students make decisions about their own learning
3. When the subject matches students' personal interests, or when the learning event itself is interesting – for example, a provocative question or an intriguing demonstration
4. When students find the subject valuable – useful, meaningful, or relevant

5. When learning the subject helps students pursue their own social and academic goals; note that students with mastery goals (related to their own standards) generally enjoy better cognitive, behavioral, and affective outcomes than students with performance goals (in comparison with other students)[21]

Intrinsic motivation improves cognitive development within local factors such as the academic subject, the characteristics of the students, and the institutional context[20,23,24]. The Academic Pathways for People Learning Engineering Survey, APPLES, has also revealed that the strongest motivators to enter engineering were intrinsic, both psychological ("I enjoy engineering") and behavioral ("I like to fix things")[25]. Motivation was positively correlated with persistence and the intention to complete the engineering degree. In engineering courses, IE courses generally improve students' conceptual understandings, academic achievement, intrinsic motivation, and attitudes about the college experience[26,27]. Despite the importance of intrinsic motivation in learning, it seldom has served as the focal point of pedagogical change in engineering.

2.3 Student motivation and pedagogy

Based on their research on intrinsic motivation, Ryan and Deci have developed what they call autonomy-supportive pedagogies[27-28]. Autonomy-supportive pedagogies are based on both instructors' attitudes and the course structures. For example, the literature explains that autonomy-supportive teachers spend more time listening, articulate fewer directives, ask more questions about what the student wants, verbalize fewer solutions to problems, make more empathetic statements, and offer greater support for students' internalization of learning goals (e.g., providing more rationale for why an assignment should be accomplished or for the value of the learning goals)[29].

However, different learning environments are more or less conducive to an instructor's use of autonomy-supportive actions. For example, when K-12 teachers are led to focus on meeting national or state standards, they use fewer autonomy-supportive actions[30]. Similarly, we expect that graduate teaching assistants (TAs) will struggle to be autonomy-supportive when they are told what topics and examples to cover in their discussion sections. To effectively promote students' intrinsic motivation to learn, autonomy-supportive behaviors must be coupled with equally effective, well-defined course structures that guide student learnin[31]. These structures need to be student centered (not standard centered) and focus on meeting students' needs as their needs change throughout the semester.

3 Course Design

This section describes the design of our course and quasi-experiment. We begin with student demographics (Section 3.1) and the general course structures of the experiment IM course (Section 3.2). We then describe how we designed the experimental IM course (Section 3.3).

3.1 Student Demographics

ECE 290 is a large enrollment (about 200 students per semester), sophomore-level, digital logic and computer architecture course required for all electrical and computer engineering majors at a large Midwestern University. The course begins with students learning about logic gates and state machines and culminates with them learning how to analyze a computer architecture, the LC-3. Traditionally, students attend two lectures taught by a professor each week and one discussion section out of eight taught by TAs.

To create the quasi-experiment, in the Fall semester of 2011, six of the discussion sections (159 students) were designated as control sections and were taught with IE pedagogies with an emphasis on in-class exercises and problem solving sessions, group work, and assigned homework and labs. Two of the discussion sections (37 students) were designated as experimental intrinsic-motivation (IM) sections and were taught with autonomy-supportive pedagogies where students could choose their learning activities. Because this was the first offering of the experimental IM sections, we allowed students to leave or enter the sections at their discretion.

In order to account for students' freedom to leave or enter sections, we took careful measurements of student preparation and student motivation in both the IM sections and the IE sections at the beginning of the semester. As described below, these measurements suggest no discernible difference in student populations between the two types of sections.

3.2 Description of the Intrinsic-Motivation (IM) pedagogy and course structure

Based on the literature, we emphasized two design constraints for our IM pedagogy: (1) minimize faculty time and effort and (2) promote each student's sense of autonomy, competence, purpose, and relatedness. The first constraint should improve the adoptability of our pedagogy while the second constraint should promote students' intrinsic motivations to learn.

To minimize faculty time and effort, we decided to make the discussion sections the locus of change for the pedagogy. The presiding faculty members could teach their lectures as they normally would. The changes to the pedagogy were driven instead by the TAs who were in charge of the two experimental IM discussion sections. These TAs changed their teaching activities and grading activities to focus on supporting students' autonomy rather than any one particular learning outcome. Since these TAs also want to become faculty, this increased responsibility for the TAs created a secondary benefit of training these TAs to become agents of change in their future careers.

To create an IM supportive environment for the TAs, the faculty gave the TAs greater autonomy to choose the structure of their discussion sections and to choose grading procedures. This autonomy was supported by a weekly one-hour coaching and peer-support TA meeting. This meeting consisted of training in grading schemes, listening skills, team building skills, and discussions about SDT. This meeting represented the primary cost of the IM course conversion process.

Within these IM discussion sections, students were organized into learning teams (*relatedness*) based upon the students' stated *purpose* for taking ECE 290. Over the course of the semester, these learning teams negotiated a series of *purpose*-based learning agreements with the TA. In these learning agreements, students' were given *autonomy* over three elements of the course: (1) what elective topics they would study (topic selection), (2) how they would learn all mandatory and elective topics (practice selection), and (3) how they would demonstrate their *mastery* of the mandatory and elective topics (mastery selection). We supported the students' sense of *competence* in this new learning environment by giving the students' fewer choices at the start of the semester, and gave them more *autonomy* as the semester progressed (See Figure 2 for a comparison of the control IE and experimental IM sections). We also constantly communicated to the students that we believed that they could use this autonomy to do amazing things.

On the first learning agreements, students were allowed to select only topics, mastery, and practice options from pre-approved menus. Students were given progressively more autonomy, so that on the final learning agreement, students were allowed to choose whatever topics they wanted to study and practice that topic in whatever way seemed best, as long as they could demonstrate mastery of a computer architecture. This final learning agreement gave the students autonomy that was comparable autonomy to a senior design course (see Figure 2).

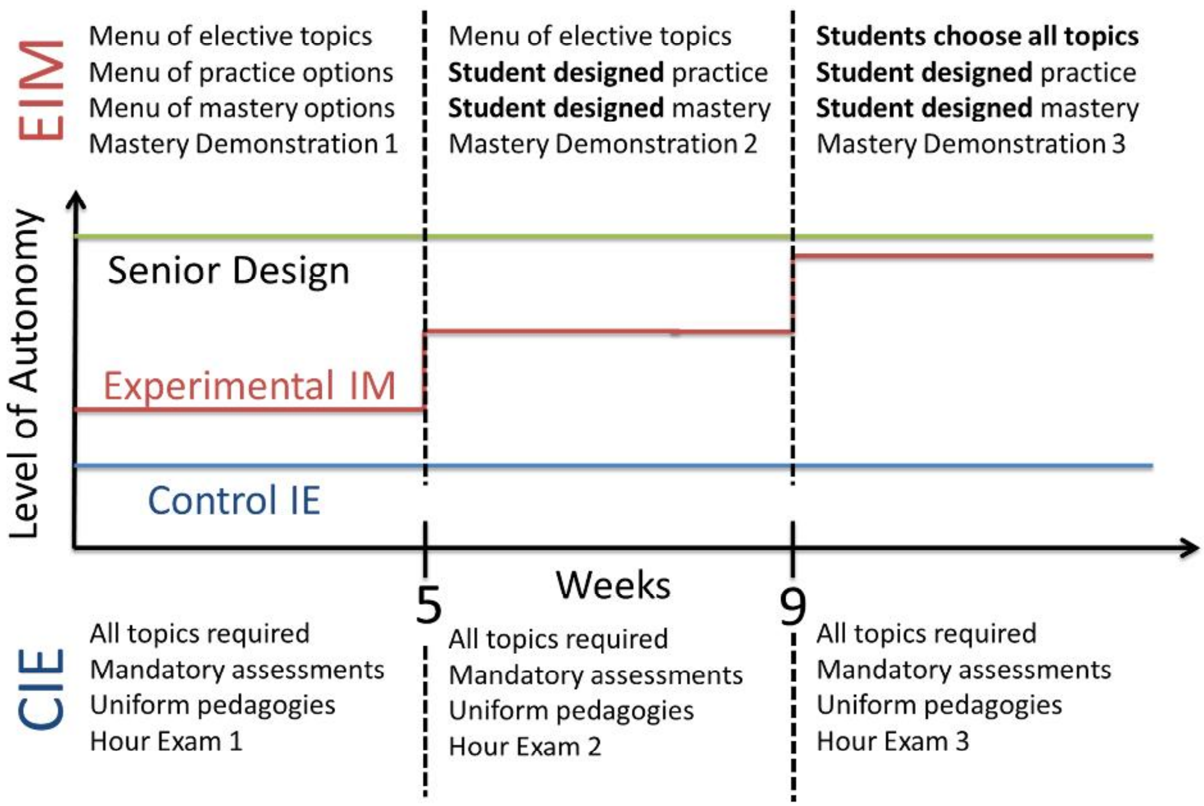

Figure 2: Comparison of learning activities for the Control IE and Experimental IM sections. Increased levels of choice and autonomy in the Experimental IM sections are highlighted in bold. The level of autonomy in a Senior Design course is included for reference.

3.3 IM Course Design Procedure

To create this autonomy-supportive environment, we followed a four step design process: (1) Identify the strategic core, (2) determine negotiable elements, (3) create course structures, and (4) train teaching assistants. These four steps are based on our four goals of promoting autonomy, competence, purpose, and relatedness respectively (See Table 1).

Table 1: Design steps and the IM attributes that they promote

Step	Autonomy	Competence	Purpose	Relatedness
1. Identify strategic core		X	X	
2. Determine negotiable elements	X	X	X	
3. Create course structures	X	X	X	X
4. Train teaching assistants	X	X	X	X

3.3.1 Identify a strategic core

We worked with the course instructors to determine a list of "need-to-know" topics and "nice-to-know" topics. We called this list of need-to-know topics the "strategic core[32]." The strategic core is composed of learning outcomes that are considered indispensable for future learning and would be tested on the final exam. The identification of the strategic core gives students clarity about the purpose of the course.

The negotiation of the strategic core also yielded a set of required activities: the final exam and digital logic concept inventory (DLCI) as summative evaluations.

3.3.2 Determine negotiable elements

After identifying the strategic core, we discussed what topics and activities students could choose. The *negotiable elements* reinforce the strategic core, but give students autonomy to pursue personal purposes and competencies. For example, students could choose to take the hour exams or they could choose to create design projects or education resources.

3.3.3 Create course structures

To present the strategic core and the negotiable elements in a way that supported students' sense of competence, we required students to create three learning agreements that would replace the normal course syllabus. These learning agreements would be completed in purpose-based learning teams to foster students' sense of relatedness. For example, students who wanted to learn about computer architectures were placed in one team and students who wanted to learn about sustainability were placed in a different team. Additionally, the learning agreements scaffolded students into increasing levels of autonomy.

3.3.4 Train teaching assistants

To reinforce the three previous design steps, we trained the TAs on team management skills[33] and autonomy-supportive behavior[29-30,34]. We also had the TAs work through exercises to help them identify the central purposes of the course and each learning team.

4 Assessment Prodecures

In this section, we describe how we assessed the quality of our IM course conversion. We discuss our use of four research instruments. The Digital Logic Concept Inventory (DLCI) was used to measure learning gains and to test for self-selection bias (Section 4.1). Two surveys, open-ended surveys (Section 4.2.1) and the Learning Climate Questionnaire (LCQ; Section 4.2.2), were used to assess motivation outcomes and to test for self-selection bias. Classroom observations were used to develop a better understanding of the classroom dynamics (Section 4.3).

4.1 Digital Logic Concept Inventory

The DLCI is a reliable and validated research instrument that measures students' learning of core concepts in digital logic[35]. The DLCI has been administered for the past two and a half years in ECE 290 and was used to compare students' conceptual learning gains across the different pedagogies. We use both historical data and new data from our quasi-experiment to assess the learning gains of the experimental IM sections

We administered the DLCI as a pre-/post- assessment. We administered the pre-test to check for evidence of self-selection bias during the quasi-experiment and to measure students' normalized learning gains. We compared the pre-test scores of the control and experimental sections with t-tests to determine if the self-selection process created populations of students with different backgrounds. We flagged our results for self-selection bias for $p<0.1$.

The normalized gain g is the standard comparison metric for concept inventory scores from different populations[36]. It measures how much students learned about a topic that they did not know before taking a course. The normalized gain is calculated by using the average pre-test and post-test scores of each course offering with the following equation

$$g = \frac{posttest - pretest}{100 - pretest}.$$

The normalized gain allows scores from different populations to be compared, especially if the populations' pre-test scores are different.

4.2 Survey instruments

To measure students' engagement and motivation in the classroom, we asked students in both the experimental and control groups to complete two surveys: an open-ended motivation survey and the LCQ[28].

4.2.1 Open-ended survey analysis

We administered the open-ended motivation survey to gauge students' reactions to participating in the experimental IM sections and to let students freely describe their motivations for studying the course material of ECE 290. The initial results of this survey were also used to check for selection bias in students' basic motivations for taking the course (e.g., did students in the experimental IM sections have different or more mature motivations for taking the course than students in the control IE sections?). The two open-ended questions asked subjects, *"Why did you choose to participate or to not participate in the experimental intrinsic motivation sections?"* and *"What motivates you to study the topics in ECE 290?"*

Student's responses to these questions were analyzed with a five step method based on ground theory[37].

- Step One: Two authors coded surveys individually.
- Step Two: We compared codes for each survey to create a rigorous set of codes and then discussed our interpretations until we had a unanimous agreement or we coded the survey's response as a disagreement.
- Step Three: To make comparisons between the sections, we reduced the codes to a set of themes which are represented in the results section (Table 4 in Section 5.2).
- Step Four: The authors re-coded the surveys with the reduced code set and then compared each survey with the new code to ensure that the code still best described the survey.
- Step Five: Finally, we compared the control IE with the experimental IM sections.

We calculated an inter-rater reliability, and found 95% agreement on our codes and themes.

4.2.2 Learning Climate Questionnarie analysis

The LCQ asks students to rate the overall autonomy-supportiveness of their discussion sections. The LCQ provides a single numerical rating of the learning climate through 15, seven-point Likert scale items (see Figure 3). These items assess the TA's support of students' decisions (*autonomy)*, affirmation of students' ability (*competence*), approachability (*relatedness*), and communication of purpose (*purpose*). The climate score is calculated with the equation below. Higher scores correspond to a higher level of perceived autonomy support.

$$\text{LCQ rating} = (I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 + I_8 + I_9 + I_{10} + I_{11} + I_{12} + (8 - I_{13}) + I_{14} + I_{15})/15$$

We used t-tests to compare LCQ ratings between the sections, and we set the statistical significance level at $p < 0.05$, because each individual item may not yield a large difference. For the overall instrument, we set the statistical significance level at $p<0.001$, because the aggregate data from all of the items should more easily yield a significant difference.

1. I feel that my instructor provides me choices and options.
2. I feel understood by my instructor.
3. I am able to be open with my instructor during class.
4. My instructor conveyed confidence in my ability to do well in the course.
5. I feel that my instructor accepts me.
6. My instructor made sure I really understood the goals of the course and what I need to do.
7. My instructor encouraged me to ask questions.
8. I feel a lot of trust in my instructor.
9. My instructor answers my questions fully and carefully.
10. My instructor listens to how I would like to do things.
11. My instructor handles people's emotions very well.
12. I feel that my instructor cares about me as a person.
13. I don't feel very good about the way my instructor talks to me.
14. My instructor tries to understand how I see things before suggesting a new way to do things.
15. I feel able to share my feelings with my instructor.

Figure 3: The Learning Climate Questionnaire

4.3 Classroom observations and case studies

One author conducted weekly classroom observations of the experimental IM sections and weekly debriefed the TAs. We report the results of these observations and debriefing sessions to create vignettes of the students' learning experiences and provide examples of how groups responded positively and negatively to the IM learning environment.

5 Results

In this section, we present the results of our assessments. The Digital Logic Concept Inventory (DLCI) revealed positive learning gains and no evidence of self-selection bias (Section 5.1). Our surveys revealed positive motivational outcomes and no evidence of self-selection bias (Sections 5.2 and 5.3). Finally, we present three vignettes of how different learning teams in the experimental IM section responded to the new pedagogy (Section 5.4).

5.1 Results from the Digital Logic Concept Inventory (DLCI)

Table 2 presents the results from the historic and new administrations of the DLCI. The historical data was collected from previous offerings of ECE 290 when the course was taught with three lectures per week with little or no IE pedagogies. The literature shows that 0.1 to 0.3 normalized gains (low gain) on concept inventories are typical for lecture-based courses[35,36,38].

The literature also shows that 0.4 to 0.6 normalized gains (medium gain) are typical for IE-based courses[35,36,38].

The normalized gains of the control IE sections and the experimental IM sections were both statistically significantly higher ($p < 0.01$) than the normalized gains of the lecture courses (see Table 3). There was no statistically significant difference ($p = 0.87$) between the gains of the control and experimental IM sections. These results seem to indicate that the IM pedagogy is just as effective as the IE pedagogy, and that it is significantly more effective than the traditional lecture pedagogy. These gains are an encouraging, and perhaps unexpected, result as the experimental IM section gave students substantially more autonomy in choosing what and how to learn.

There was also no statistically significant difference between the pre-test scores of the different populations. This lack of significant difference provides no evidence of self-selection bias between our two populations.

Table 2: Pre-test and post-test scores for different offerings of ECE 290 along with calculated normal gains. Both the interactive engagement and experimental IM sections improved learning.

	Pre-test	Post-test	Normalized Gain
Historical Lecture Based (HLB)	9.65	13.26	0.25 (low gain)
Control Interactive Engagement (CIE)	9.67	17.11	0.52 (medium gain)
Experimental Intrinsic Motivation (EIM)	9.56	16.94	0.51 (medium gain)

Table 3: *p*-values obtained by performing t-tests on the normalized gains of the different instructional methods

	CIE	EIM
HLB	<0.01	<0.01
CIE		0.87

5.2 Results from open-ended survey analysis

Through our open-ended coding, we found five themes in students' motivations: enjoyment, grades, interest, preparation for the future, and fulfilling a requirement. These themes and their frequencies are presented in Table 4. We also present representative quotations for each theme.

Table 4 - Final motivation codes, percentages, descriptions, and quotations from students

Codes	**CIE**	**EIM**	**What motivates the student?**	**Representative Quotation**
Enjoyment	11%	11%	Student is motivated by an emotional enjoyment, like, or love of the topics in ECE 290 and are choosing to study them.	"I WANT to learn about computer hardware down from the basic things."
Grade	8%	11%	Student is motivated to study for grades.	"GPA"
Interest	34%	29%	Student is motivated by being intellectually interested in the course material, computer architecture, and by problem solving or other challenges.	"I am interested in digital logic and computer architecture."
Prepare for the Future	22%	31%	Student is motivated to prepare for his/her future (career or academically) by achieving mastery over a subject or studying everyday relevant topics.	"It will be useful for my career goals and it's a foundation for my future interest in nanotechnology."
Requirement	23%	15%	Student is motivated to study because the course is required for their chosen major.	"It's required to be a EE."

We found no statistically significant differences in the students' motivations between the two sections, and consequently no evidence of self-selection bias from these themes.

We found a few self-reported motivations that did not fit within our final five themes. These statements included unique statements such as "peer pressure, parent's pressure, self-pressure." Other comments bridged multiple themes such as "so far it is because the class is required but I'm hoping that it will change" and "I want to solidify my choice for a computer engineering degree."

Both sections were driven more by checking requirements off a list (extrinsic motivation) rather than doing what brought them enjoyment (intrinsic motivation). The students were also motivated by being prepared for future courses and goals. Surprisingly, students did not list grades as a major motivator.

Most students did not reveal well developed understandings of their motivation to learn. For example, the majority of statements that we coded as interest, simply said "interest" or "it's interesting." These vague answers indicated that these students may not be as mindful of their motivations as students with other motivations.

5.3 Results from the Learning Climate Questionnaire (LCQ)

Table 5 displays the students' learning-climate ratings from the LCQ. The LCQ was completed by 122 students from the control IE sections and 24 students from the experimental IM sections. The score for I_{13} has been inverted (presented score is calculated by subtracting the actual average from 8) to facilitate comparison and to calculate an overall learning climate score.

Table 5: Average ratings from Learning Climate Questionnaire (statistically significant differences are highlighted)

	Control (IE)	Experimental (IM)	effect size (θ)
I_1	5.1	6.2	0.8
I_2	5.4	6.2	0.7
I_3	5.4	6.3	0.8
I_4	5.2	6.0	0.5
I_5	5.5	6.1	0.4
I_6	5.4	6.0	0.4
I_7	5.6	6.0	0.3
I_8	5.6	6.0	0.3
I_9	5.8	6.3	0.5
I_{10}	5.2	6.2	0.8
I_{11}	5.3	5.7	0.3
I_{12}	5.2	5.3	0.1
I_{13}	5.6	6.5	0.6
I_{14}	5.2	5.7	0.4
I_{15}	4.6	5.1	0.4
Total	5.3	6.0	0.5

The LCQ results revealed significant differences ($p < 0.05$) in students' perceptions of learning climate on 11 of 15 items. Effect sizes ranged from small ($\theta = 0.4$) to large ($\theta = 0.8$). The difference in overall rating was also significantly different ($p < 0.001$) with a moderate effect size (θ = 0.5). These results indicate that students perceived greater support of our four IM attributes of autonomy, competence, purpose, and relatedness.

5.4 Three brief vignettes of representative teams

In this section, we present three brief vignettes that are representative of the three different types of learning teams we observed. Quotations are reconstructed from field notes and are intended to create an impression rather a recreation of events.

5.4.1 Learning Team 1

Student 1: "So why are you taking this course?"
Student 2: "Well, I'm just taking this course because it's one of my last required courses in computer engineering. I'm not interested in computer engineering, so I'm just hoping I can do something more interesting than the LC-3."

Composed of students who were pursuing degrees in electrical engineering rather than computer engineering, Learning Team 1 was organized around the team purpose of "intellectual growth." After their TA gave an overview of the course and guidelines, they immediately began to discuss their goals and aspirations for the semester and wrestled with what activities they should pursue. For the first learning agreement, they decided to focus first on improving their design skills and using professional engineering design tools. They completed laboratory and simulation assignments well in advance of their peers, chose to study elective topics that gave them multiple perspectives on the optimal design of circuits, and choose to complete an ambitious design project (The course instructor said, "If they can complete that project, they certainly don't need me."). The team connected well, met regularly, and remained on task during their scheduled meeting times.

"Student 1: We don't think that the written homework is really helping us learn that well, so we would rather write tutorials that explain the basic concepts to other students. Would that be okay?"

When crafting their second learning agreement, this team pursued meeting the needs of their fellow students. To help themselves learn the course content, they decided to create online tutorials (an option that was not available in the original menu of practice options) that would help other students learn the basic concepts of their learning agreement. These tutorials were well received and were posted on an open-source courseware site *Connexions.* Instead of focusing on improving their design skills, the team decided to work towards solving a real-world problem: an annoying traffic light in the center of campus. They created mock-ups of the intersection, planned placements for sensors and buttons that would make the intersection "smarter," and designed the logic to control the traffic light in the engineering design software that they had already mastered.

On their final learning contract, the team focused on developing their research skills and analysis skills. They decided to write a research paper that compared two computer architectures that were developed from competing schools of thought. They found and documented their sources, wrote a collaborative paper, and demonstrated deep understanding of computer architectures.

5.4.2 Learning Team 2

> *Student 1: "I mean, it seems that we will get lower grades simply because we're in the experimental section."*
> *Student 2: "Yeah, I really don't want to mess up my basics. This is a prerequisite for so many other classes, and I don't want to screw up my GPA."*
> *TA: "I can guarantee that we won't "mess up your basics," because the topics that are listed as essential are the basics. So as long as you make sure you learn the essentials, you should be fine and you won't need to worry about your grades."*
> *Student 3: "Can you at least tell us which are the easiest activities that will help us get an A?"*

Learning Team 2 was composed of students who were primarily concerned about getting good grades and good jobs. When informed about the course policies and procedures, this team responded with fear. They were worried about not gaining a strong foundation in the course material. They were worried about grades. They worried about an increased workload. Surprisingly, the team chose to pursue a mastery demonstration that was unlike anything they had experienced: creating new homework problems and solutions for the course. The team struggled. They continuously attempted to renegotiate their grading schemes: even two weeks after they had turned in their demonstration. The demonstration was turned in on crumpled papers with hastily drawn diagrams and some students could not solve their own problems. The team did not work together during class time and team members did not help each other learn.

Student: "We thought this option would be easy, but it turns out we all just got bad grades."

The learning team learned that their grades depended less on their activities and more on their effort. During the second learning agreement, the team responded to their failures by completing a design project. With the TA's help, the students also focused their attention on creating a better defined grading scheme for their design project. On the third learning agreement, the team pursued an even more ambitious project of designing an original computer architecture. Unfortunately, the initial failures of communication and team building created a rift in the team and the team members developed poor communication and teamwork. The TA attempted to improve this teamwork by making the team members give anonymous feedback to each other, but only one member completed the feedback. In the end, some team members created promising design projects, while other members failed to contribute.

5.4.3 Learning Team 3

Student 1: "What if we did 'circuitception' where our designed circuit could design other circuits?"

Student 2: "That'd be awesome!"

Student 3: "Or how about we design a calculator with buttons and display?"

Student 4: "What if we just designed our own architecture?"

Learning Team 3 was composed of computer engineering majors who wanted to design computer architectures for their careers. When told about the autonomy that they would possess, the team immediately began to buzz with excitement and with little guidance from the TA, they quickly brainstormed a list of project ideas that they might pursue that semester. They created traditional ideas such as creating some basic games like tic-tac-toe or utilities such as a calculator, but they also generated truly creative ideas such as "circuitception" – circuits that could create new circuits.

By the end of the first class session, this team had determined that they wanted to learn as much and do as much as this class would allow them. By the end of the second class session, the team had decided that they want to build their own architecture, so the TA suggested that they build a four function calculator (add, subtract, multiply, and divide) that included some other basic digital logic functions (AND and OR) as well as digital buttons and outputs. Within minutes, the boards of the classroom were covered with their proposed circuit designs, specifications, and divisions of labor with all team members huddled around. The TA offered some advice to guide the team and the team became unleashed.

By week four of the semester, the team was meeting in the simulation lab for hours, including during the normal class time, and had completed their calculator. By week eight, the team upgraded their calculator into their first rudimentary computer architecture.

For their third learning agreement, the team decided to learn advanced topics of computer architectures and teach them to each other. The team studied ideas as diverse and advanced as sustainability in computing, layout and creation of transistors on a micro-chip, and multi-core processors. These students learned topics that are covered by courses at least a full year in advance, and they even taught the TA some new ideas. The final presentations was a mix of presentations and celebration. The team designed their own logo, advertised their presentation, bought pizza for themselves and the TA (though the TA abstained for ethical reasons), and presented their new knowledge for over two hours.

6 Discussion

The students in our control IE sections and our control IM sections began the semester as similar populations of students. The students had similar prerequisites and displayed comparable levels of domain knowledge prior to entering the course as demonstrated by the DLCI. The students' motivations were similar as well. Some students were motivated by grades or by their enjoyment of learning, but most were motivated by their desire to pursue a career in electrical and computer engineering or general interest in computers. For some students, this motivation meant that this course was a hurdle to overcome, but for others this motivation made this course a critical gateway on their paths to becoming engineers.

We presented three case studies to capture how students' motivations affected their interaction with the course and their learning outcomes. Learning Team 1 served as an example of students who normally would consider ECE 290 to be a hurdle to overcome: a tangential requirement for electrical engineering majors. However, with the increased autonomy and purpose of the experimental IM section, we observed this team reshape the course to help them pursue their personal goals. Rather than learning only about how a computer works, this team used the opportunity to develop many of the "soft skills" or nuances of engineering. They developed teamwork skills, explored the tradeoffs of different design methods, found ways to use their engineering skills to help their fellow students, and learned how to conduct background research on a topic that they had never seen before.

Learning Team 2 experienced mixed success. The team struggled to find an identity that captured the imagination and motivations of the members, but many of the members discovered that success in education is achieved more by effort rather than by ability. The team pursued harder challenges as the semester progressed, despite an initially low motivation level. As the team members remarked, regardless of the difficulty of a learning task, success, grade-wise or learning-wise, is moderated by effort. When students are responsible for their choices, they can shift less blame onto the system or their abilities, but must wrestle with how their motivation is affecting their performance. Unfortunately, the group chafed and many members failed to become intrinsically motivated students as the group struggled to create community and a strong sense of purpose.

Learning Team 3 is an example of a team that became "unleashed" and far exceeded our expectations. The team developed a close community around a central purpose of learning about computer architectures. With the autonomy to follow their team purpose, this team demonstrated extraordinary mastery of the material and powerful intrinsic motivation.

Our surveys and testing corroborate our qualitative observations. From the results of the DLCI, we observed that students in the experimental IM section learned their fundamentals better than students from previous lecture-based offerings of the course. These students also learned as much as students who were taught with IE techniques which have been shown to improve learning.

From the LCQ results, we believe that the students in the experimental IM sections also experienced a more autonomy-supportive classroom than students in the control IE sections. The

LCQ did not reveal significant differences on four items. These four items reveal affective responses to instruction that are beneficial to an autonomy-supportive learning environment, but are not necessarily indicative of an autonomy-supportive learning environment. Encouragement to ask questions (I_7), trust in the instructor (I_8), sympathy to emotions (I_{10}), and instructor care for students (I_{11}) are beneficial to all good instruction. Items that specifically targeted our four IM course conversion goals – such as instructor provided choices (I_1 - autonomy), ability to be open during class (I_3 – relatedness), sense of confidence in ability (I_4 – competence), and understanding of goals (I_6 – purpose) – revealed significant differences with medium to large effect sizes.

Combined with the students' learning gains that were demonstrated by the DLCI, we believe that students in both sections received beneficial instruction from competent instructors who cared about their students. However, the IM sections created a different learning environment that we believe has and will promote students' intrinsic motivation to learn.

Finally, we also developed a pedagogical reform that required little effort from the presiding faculty. Aside from the initial creation of the strategic core and the negotiable elements, the faculty instructors invested no additional time or resources into the experimental IM section.

Although the actual investments required by faculty to make this change are relatively low, we want to highlight that issues of faculty identity can present a significant barrier to adoption. The approach outlined here requires that the faculty member cede some control both to the student and to TA's; this loss of control can often be at odds with faculty conceptions of the roles and responsibilities of a faculty member. Thus, although this approach may help to address concerns about reward structure and faculty training, it still requires careful planning and negotiation.

Some of the typical costs of pedagogical reform were transferred to the TAs instead. The TAs needed to spend some more time making course administration decisions, and they needed additional training to develop the autonomy supportive behaviors that benefited the classroom. However, the costs were being absorbed by individuals who were more intrinsically motivated to invest the time and energy to make the change. The TAs received training that supported their personal purpose of becoming future faculty.

7 Conclusions

When discussing pedagogical and education reform, we need to critically consider how increasing student engagement often costs many engineering faculty time and energy that they give only begrudgingly. In this paper, we presented our initial efforts to design and assess a low-cost, IM course conversion. By transferring the high cost of reform to the TAs and students, we were able to increase student learning and motivation with little to no cost to the faculty. We believe that this IM course conversion model can eventually lead to sustainable change as students become empowered to direct and guide their own learning even when the faculty are unwilling to change their standard teaching practices. Perhaps, these intrinsically motivated students can eventually provide the pressure and rewards needed to motivate other professors. Not only did we empower students, but we were able to provide meaningful training and practice for TAs who hope to become faculty.

We created this low-cost, IM course conversion by focusing on promoting students' intrinsic motivations to learn rather on promoting specific course content or any one interactive engagement pedagogy. We have shown that the experimental IM pedagogy can promote students' intrinsic motivation to learn and create more positive learning environments. Additionally, this IM-based pedagogy promoted comparable deep conceptual learning as a discussion-based IE pedagogy.

A growing body of literature has been showing that students' motivation and engagement is as important to the learning process as well-designed pedagogies and interventions[20]. This quasi-experiment provides more evidence for this observation. In this particular IM classroom, students were not required to complete any particular learning activity. Students' conceptual-learning gains and acquisition of design skills stemmed from students' motivation and pursuits rather than well-crafted learning activities. Perhaps, many interactive engagement techniques could become even more effective if paired with deeper understanding and focus on improving students' motivation.

Future studies will need to evaluate the scalability of this model to more sections and more TAs within the same course as well as the scalability of this model to several courses across the curriculum. We will also need to further explore methods for effective TA training, and distilling what elements of the IM course conversion are most critical to the process. We believe, though, that this IM course conversion promises to provide a sustainable and effective method of pedagogical change and eventually curricular change.

References

1. Litzinger, T., Lattuca, L. R., Hadgraft, R., & Newstetter, W. (2011) Engineering education and the development of expertise, *Journal of Engineering Education, 100* (1), 123–150.
2. Felder, R. M., Brent, R., Prince, M. J. (2011). Effective instructional development strategies. *Journal of Engineering Education, 100* (1), 89–122.
3. Crouch, C. H. & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics, 69* (9), 970–977.
4. Chen, J. C., Kadlowec, J. A., & Wittinghill, D. C. (2005). Using technology for concepts learning and rapid feedback in statics. In *Proceedings of the American Society of Engineering Education Annual Conference and Exposition.*
5. Marrs, K. A. & Novak, G. (2004). Just-in-time teaching in biology: Creating an active learning classroom using the internet. *Cell Biology Education, 3*, 49–61.
6. Herman, G. L. (2011). Teaching signal processing according to what your students know. In *Proceedings of the Sixth Signal Processing Education Workshop*, Sedona, AZ, January 4-7, pp. 231–236.
7. Ogilvie, C. A. (2009). Changes in students' problem-solving strategies in a course that includes context-rich, multifaceted problems. *Physical Review Special Topics – Physics Education Research, 5* (2), 1–14.
8. Diefes-Dux, H., Verleger, M., Zawojewski, J.,& Hjalmarson, M. (2009). Multi-dimensional tool for assessing student-team solutions to model-eliciting activities, In *Proceedings of the American Society for Engineering Education Annual Conference and Exposition,* Louisville, KY.
9. Verleger, M. V. & Diefes-Dux, H. A. (2008). Impact of feedback and revision on student team solutions to model-eliciting activities. In *Proceedings of the American Society for Engineering Education Annual Conference and Exposition,* Pittsburgh, PA. 7807.
10. Walker, A., & Leary, H. (2009). A problem based learning meta analysis: Differences across problem types, implementation types, disciplines, and assessment levels, *Interdisciplinary Journal of Problem-based Learning, 3* (1), 12–43.
11. De Graff, E. & Kolmos, A. (2003). Characteristics of problem-based learning. *International Journal of Engineering Education, 19* (5), 657–662.
12. Lochhead, J., & Whimbey, A. (1987). Teaching analytical reasoning through thinking aloud pair problem solving. In *Developing Critical Thinking and Problem-Solving Abilities*, ed. Stice, J. E., *New Directions for Teaching and Learning*, *30*, San Francisco: Jossey-Bass, San Francisco.
13. McDowell, C., Werner, L., Bullock, H. E., & Fernald, J. (2006). Pair programming improves student retention, confidence, and program quality. *Communications of ACM*, *49* (8), 90--95.
14. Fila, N. D., & Loui, M. C. (2010). Work-in-progress: Who's driving? Structured pairs in an introductory electronics laboratory. *Proceedings of the Fortieth ASEE/IEEE Frontiers in Education Conference*, Washington, D.C., October 27-30, 2010 (pp. F3C-1 to F3C-2).
15. Linsenmeier, R. A., Kanter, D.E., Smith, D. E., Linsenmeier, K. A., & McKenna, A. F. (2008). Evaluation of a challenge-based human metabolism laboratory for undergraduates, *Journal of Engineering Education, 97* (2), 213–222.
16. Wanniski, J. (1978). Taxes, revenues, and the `Laffer Curve*,' The Public Interest.*
17. Goldberg, D. E., Herman, G. L., Stolk, J. D., & Somerville, M. (2011). Toward routine, low-cost intrinsic motivation course conversion*, 2011 Symposium on Engineering and Liberal Education*, Union College.
18. Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, 55, 68–78.

19. Pink, D. H. (2011). *Drive: The Surprising Truth about What Motivates Us*. Riverhead Trade, New York.
20. Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of Educational Psychology*, 95 (4), 667--686.
21. Dweck, C.S. (2006). *Mindset: The New Psychology of Success*. Random House, New York.
22. Pintrich, P. R., Marx, R. W., & Boyle, R.A. (1993). Beyond cold conceptual change - The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63* (2), 167-199.
23. Sinatra, G. M. (2005). The 'warming trend' in conceptual change: The legacy of Paul R. Pintrich. *Educational Psychologist, 40* (2), 107–115
24. Atman, C. J., Sheppard, S. D., Turns, J., Adams, R. S., Fleming, L. N., Stevens, R., Streveler, R. A., Smith, K. A., Miller, R. L., Leifer, L. J., Yasuhara, K., & Lund. D. (2010). *Enabling engineering student success: The final report for the Center for the Advancement of Engineering Education*. Seattle, Wash.: Center for the Advancement of Engineering Education, University of Washington. http://www.engr.washington.edu/caee/final_report.html
25. Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, *93* (3), 223--231. http://soa.asee.org/paper/jee/paper-view.cfm?pdf=800.pdf
26. Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005). Pedagogies of engagement: Classroom-based practices. *Journal of Engineering Education*, *94* (1), 87--101. http://soa.asee.org/paper/jee/paper-view.cfm?pdf=244.pdf.
27. Ryan, R. M. and Deci, E. L. (2002). *Overview of self-determination theory: An organismic dialectical perspective*, In Handbook of self-determination research (2002), pp. 3-33. University of Rochester Press, Rochester, NY.
28. Black, A. E., & Deci, E. L. (2000). The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective. *Science Education*, *84*, 740-756.
29. Reeve, J. M. & Halusic, M. (2009). How K-12 teachers can put self-determination theory principles into practice. *Theory and Instruction in Education, 7*, 145–154.
30. Reeve, J. (2009). Why teachers adopt a controlling motivating style toward students and how they can become more autonomy supportive. *Educational Psychologist, 44* (3), 159–175.
31. Jang, H., Reeve, J. M., & Deci, E. L. (2010). Engaging students in learning activities: It is not autonomy support or structure but autonomy support and structure. *Journal of Educational Psychology, 102*(3), 588–600.
32. Herman, G. L. & Loui, M.C. (2012). Identifying the core conceptual framework of digital logic. In *Proceedings of the 2012 American Society for Engineering Education Annual Conference and Exposition*. In Press.
33. Oakley, B., Felder, R. M., Brent, R., & Elhajj, I. (2004). Turning student groups into effective teams. *Journal of Student Centered Learning, 2*(1), 9–34.
34. Torres, A & Herman, G. L. (2012). Motivating learners: A primer for engineering education teaching assistants. *Proceedings of the 2012 American Society for Engineering Educaiton Annual Conference and Exposition.* In Press.
35. Herman, G. L., & Loui, M. C. (2011). Administering the Digital Logic Concept Inventory at multiple institutions. *Proceedings of the* 2011 *American Society for Engineering Education Annual Conference and Exposition*, (pp. AC2011-1800). Vancouver, BC. June 26-29.
36. Hake, R. (1998). Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*, 64–74.
37. Strauss, A. & Corbin, J. (1998). *Basics of Qualitative Research*. Sage, Thousand Oaks, CA.
38. Buck J. R. & Wage, K. E. (2005). Active and cooperative learning in signal processing courses. *IEEE Signal Processing Magazine*, *48*(2), 76–81.