Creating an intrinsic-motivation-driven course design method

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Abstract— **The low-cost intrinsic motivation (IM) course conversion project is an effort to create a new system of course design that focuses on creating scalable and sustainable courses that emphasize promoting students' IM to learn. Unlike many course design methods such as idea-based learning, project- or problem-driven learning, or "flipped" classrooms, which first ask, "How do we help students learn X better," we ask "how do we foster intrinsically-motivated learners who want to learn X?" While this course design method still uses theories of cognition to design course structures, it uses motivational constructs such as purpose, autonomy, relatedness, and competence as the primary design considerations of a course. Secondarily, the course design method considers and documents the financial, time, political, and psychological costs of course design. In this paper, we present a preliminary attempt to formalize this IM-driven course design method as well as a system for evaluating the short- and long-term costs of implementing a specific course design.**

Keywords—intrinsic motivation; course design; learning theory; engagement

I. Introduction

While course design has historically favored the cognitive outcomes of learning, there is a growing understanding in educational theory that the affective or motivational outcomes of learning moderate the cognitive outcomes as motivational constructs such as self-efficacy beliefs can accelerate how students learn challenging course material and help them persist in learning activities when they fail [1-5]. Concurrently, research on why instructors do not adopt effective teaching practices often cite that instructors are unwilling to overcome the time and financial costs needed to learn and implement new teaching techniques [4, 5]. Further, many instructors who attempt to adopt new teaching methods are often discouraged by students' initial apathy or even hostility toward new teaching methods [4]. In this paper, we present a course design method called the low-cost intrinsic motivation course conversions that maximizes learning by focusing on both student and instructor motivation [6]. While content and techniques are still important, they play complementary or secondary roles to the goal of fostering motivated learners and designing courses that instructors are motivated to teach.

The paper begins with brief backgrounds on motivational theory and course design methods followed by a description of the course design method. The method has three stages: evaluate the current course, create structured spaciousness, and manage the cost of the design. The paper concludes by applying the method to a sophomore level computer engineering course. By creating purpose-rich assessments that provided students with autonomy over their learning objectives, the revised course provided better support for students' intrinsic motivations to learn and increased performance on standard cognitive learning outcomes as compared to an active learning focused design [6].

II. A Primer on Motivational Constructs

While any motivation theory can help an instructor better motivate students, we chose Self-Determination Theory (SDT) and its emphasis on psychological needs. SDT describes how the satisfaction of certain psychological needs can shape the orientation and amount of an individual's motivation in a situation or context [7]. This sole focus on needs provides a condense set of constructs that can serve as the quality criteria for a course design method. The orientation of motivation affects the amount and quality of learning and ranges on a continuum from amotivation through extrinsic motivation (receiving rewards such as grades, complying with rules) to intrinsic motivation (deriving from the inherent value of an activity) [2,7]. Table 1 presents four motivational orientations to simplify SDT to a digestible and memorable continuum: amotivation, external regulation, identified regulation, and intrinsic motivation.

TABLE I. Four Motivational Orientations from Self-Determination Theory

Motivational Orientation	**Simplified Description**
Amotivation	Disengagement from an activity or context (e.g., "I'm not good at math.")
External Regulation	Engagement is regulated by the threat of punishment or promise of reward (e.g., "I need an A.")
Identified Regulation	Engagement is regulated by a desire to achieve internalized values or goals. (e.g., "I hate proofs, but they help me understand the concepts.")
Intrinsic Motivation	Engagement satisfies intrinsic psychological needs. (e.g., "I love solving proofs because I enjoy figuring out why things work.")

Students tend to learn more when they are intrinsically motivated to learn [1,2]. We can support students' motivation

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generally and shift them towards an intrinsic orientation by supporting their senses of Purpose (what I do matters), Autonomy (I am in control), Relatedness (others care about me), and Competence (I can be effective) [7] (PARC needs).

The type of motivation also has a hierarchical structure that varies by time scale or domain [8]. Motivation can be situational (e.g., a homework assignment or a group meeting), contextual (e.g., a semester-long project, a course, or learning engineering), or global (e.g., a person's default motivational orientation). A person's motivational orientation may vary across these three levels in every situation and over time [8]. For example, a student may globally use identified regulation with the goal of self-betterment, but contextually be intrinsically motivated to write a simulation program, but situationally be externally regulated by a deadline simultaneously. As students experience more situations in engineering courses that intrinsically motivate them to learn, these situational motivations can lead to a contextual intrinsic motivation to learn engineering [9]. Conversely, students who are initially intrinsically motivated to learn may become amotivated as they experience amotivating situations [9].

III. Brief Background on Course Design

Research has documented five main categories of course design methods [10]. These course design methods often focus on desired cognitive learning outcomes, careful sequencing of learning activities for optimal learning, or departmental pressures and mandates [10]. Backwards course design, and its successor idea-based learning, was the first course design method and was cognitively focused [11-13]. In idea-based learning, a designer's first objective is to identify a small number of "big ideas" or central concepts that connect the course content (e.g., force and energy in mechanics or equilibrium in fluid mechanics) [11]. These central concepts are broken down into enduring understandings: canonical examples that critically inform how students will think about the concepts [11-12]. Students' enduring understandings are then supported by situational learning activities. The course designer's goal is to create a series of learning activities that spiral around these central concepts by stepping through the enduring understandings with the goal of helping students develop an integrated conceptual framework of the material that leads to deeper learning [11].

Course design methods such as the "flipped classroom" or just-in-time teaching are structured around the cognitive principles of providing rapid feedback; repeated, spaced exposures to content; and opportunities to actively manipulate concepts [14]. A designer may not change the order of topics or the course content, but the method of content delivery is modified so that students are exposed to content outside the classroom and actively engage with content in the classroom.

Course design methods such as problem-based learning and inquiry-based learning focus on a mixture of cognitive and affective outcomes in their design principles [15-17]. A primary critique of traditional course design strategies is that the cognitive skills needed to succeed in the traditional classroom are not the skills needed in authentic tasks in industry or the "real world" [15]. Problem-based and inquiry-based methods in contrast promote the cognitive skills of critical, analytical, or metacognitive thinking by requiring students to engage with more "authentic" learning environments [16]. A secondary goal is that students will be more motivated to learn as they engage in problems that they encounter in the real world with their peers (i.e., increased senses of purpose and relatedness) [15].

Although each of these research-based course design methods can improve students' motivation to learn, most instructors who implement these methods have at best only their intuitions about how to better motivate their students. In other words, the course is designed first to promote certain cognitive outcomes, and promoting students' motivations to learn is considered as a matter for troubleshooting student resistance or amotivation [18]. For example in Hansen's recent book on idea-based learning, students' motivations are only briefly mentioned as part of the development of learners as they become more mature in their learning. [11].

IV. The IM-Course Design Method

The philosophy of the IM-course design method is captured by a central image of structured spaciousness. This image is composed of two complementary palettes that may need to be held in tension. First, the structure of instruction provides objectives that communicate the purpose of instruction and instill the confidence in learners to succeed. Spaciousness conveys a sense of freedom or self-determination, but also the time and place for the cultivation of community and relatedness. With this central image, we present a general framework for creating structured spaciousness.

Following the principle of creating structured spaciousness, this course design method intends to provide structures that guide and embolden the course designer, yet provide spaciousness so that the course design method is not prescriptive. We provide examples as illustrations of the principles rather than as masters to be copied. A course design will be most effective only when the instructors also possess the senses of purpose, autonomy, relatedness, and competence about their courses that undergird their motivation to teach.

The design method is iterative and has three primary steps: A) Evaluate the current course design's support of students' intrinsic motivation, B) create structured spaciousness by generating potential modifications to improve the course design's support of intrinsic motivation, and C) manage the cost of the proposed modifications to inform decisions about which modifications to adopt. After managing the costs, the designer should evaluate the course conversion to determine if the design objectives were met. If not, then additional iterations may be needed.

A. Evaluate the current course design

An evaluation of a course's existing design can provide a point of reference for reimagining the course and assessing the costs of any revisions. To perform this evaluation, the course designer must consider how students in the course would experience the course and how it meets their psychological

PARC needs. For example, the designer could rate the course as providing low, moderate, or high levels of support for each need (see Table 2). After evaluating the course, the designer can use the evaluation to identify opportunities to improve the course's effect on students' motivations to learn. For example, a designer might rate the purpose of the course as low because the homework assignments lack meaningful contexts that connect with students' interests, so the designer might create assignments based on students' expressed interests in taking the course or replace homework with projects.

TABLE II. COURSE EVALUATION GRID: BASED ON SUPPORT OF PSYCHOLOGICAL (PARC) NEEDS FOR MOTIVATION

	Rate the course's support of each need		
Purpose	*Low*	*Moderate*	*High*
I believe that this course is a valuable part of my education			
I find the course's learning objectives to be compelling, useful, and comprehensible			
The course material captures my interest and is relevant to my life			
Autonomy	*Low*	*Moderate*	*High*
I have control over learning goals and content			
I get to develop and use my own learning strategies			
I get to choose deliverables, resources, due dates, teammates, or specify course policies			
Relatedness	*Low*	*Moderate*	*High*
I get to work collaboratively with my peers			
I feel connected to my instructors			
My work has positive impacts on people outside the classroom			
Competence	*Low*	*Moderate*	*High*
I believe I can be successful and achieve the learning goals			
I can engage in challenging and meaningful goals			
I get positive formative feedback on my learning process, not just my performance			

The designer must also evaluate the costs that are incurred by teaching the course in its original form. A more detailed description of cost analysis is provided in the section on cost management. The goal of an IM course conversion, though, is to either maintain or lower the costs required to teach the course. This goal cannot be achieved without careful accounting of the costs of teaching the current course. Identifying high cost components of a course can similarly reveal opportunities for improvement in the course design.

B. *Create structured spaciousness*

Based on the analysis of the original course design, the designer should generate a list of potential modifications for the base course design. These modifications could be major or minor, but at this point in the design process the goal should be focused on imagining idealistic designs regardless of their feasibility. While the designer's ideals may not be realizable, identifying these ideals is critical for creating a sense of aspiration or stronger sense of purpose in the design process. This stronger sense of purpose is critical during the cost negotiation phase which requires critical evaluation of the ideas and a priority structure for decision making. For example, in one course, the designer wanted to focus on developing students' collaborative problem solving skills, but was required to administer a final examination. While the ideal summative feedback was identified to be a final project completed in teams, this option became untenable. However, the identification of this ideal informed the structure of the final examination, which became more design focused and required students to create smaller components of a bigger system as if they were working in teams.

Further, the designer is also encouraged to borrow or use principles of course design from other course design methods. However, the evaluation of these methods will be based on motivational rather than cognitive outcomes. For example, the designer can use problem-based learning techniques to better support students' sense of purpose.

To facilitate ideation around modifications, we use our image of structured spaciousness to guide the ideation process.

1) *Identify a strategic core (Creating structure)*

From both the motivational and cognitive perspectives [11], the designer needs to determine a narrow strategic core of goals, outcomes, and/or objectives of the course. From the perspective of IM course design, the focus for identifying a strategic core is primarily to enhance the students' sense of purpose in taking the course. In other words, the focus is on *why* certain concepts and skills are important and not simply on what should be on the list of possibly important concepts or skills. Identifying a strategic core secondarily provides a decision-making framework for determining which activities or content are negotiable or non-negotiable for the students. Without a strategic core, the course can easily become bloated, overwhelming students with excess content. Alternatively, the purpose of the course can become diluted, and students fail to understand why the course is valuable or important.

A narrowly defined strategic core can also improve students' sense of competence by creating a manageable list of course goals. If the designer can reduce the course goals to two or three strategic objectives, students can develop a better sense of what they need to master to be successful, which in turn can increase their sense of competence. Further, a strategic core can reveal what assessment activities to include in the course and provide stronger rationales for them, thereby helping students feel that they are receiving the feedback that they need to succeed.

The identification of a strategic core can lead in many directions that depend on how the course fits within its broader curriculum; a first-year course which serves as the gateway to the discipline will have a different type of core from an upper-level technical course. For gateway courses, the purpose of the course may lean more towards helping students understand the value and nature of the discipline or helping the students to better understand the expectations of the discipline. For technical courses, promoting purpose and competence can often be achieved by narrowing the focus of the course to a few core concepts or skills that will be critical to the students' later success. Purpose can also be promoted by providing opportunities that intersect with students' broader interests or that demonstrate the usefulness of the course material.

As mentioned earlier, we encourage designers to identify the ideal forms of feedback and assessment that they believe would best support students' sense of competence and reinforce the purpose of the course. A discussion of feedback methods is beyond the scope of this paper, but there is an abundance of literature on effective feedback techniques (e.g., [19]). For example, the use of rubrics can support purpose and competence by specifying what students are expected to do and learn [20].

As an example of redefining the strategic core, a sophomore-level technical course was originally defined by a week-by-week list of topics that was incomprehensible to the incoming student and lacked a week-to-week cohesion between the topics. This lack of cohesion diluted the purpose of the course and many students delayed taking the course for as long as possible because they did not understand why the course was useful. To refine this course, we identified the conceptual core "big ideas" as prescribed by idea-based learning [21]. Identifying the core big ideas empowered the instructors to cut the number of topics covered by the course in half and to provide a greater sense of purpose to the course. The course objectives now consist of three core big ideas and choices for students to explore how those big ideas are used in practice. In accordance, course assignments and feedback changed to help students better achieve mastery of these three big ideas. For example, the instructors and teaching assistants (TAs) now create a menu of short projects that demonstrate how the core concepts apply to different sub-disciplines [6, 22]. Students complete these projects during the first five weeks of the semester. The instructors and TAs each become a supervisor for the project that they find to be most interesting (e.g., a TA researching sensors would likely choose to supervise projects related to sensors). Similarly, the students choose one project that they find most interesting. By pairing students with instructors based on interests, we found that the instructors and TAs were more eager to provide feedback to the student project teams, improving course performance and the course climate's support of the students' intrinsic motivation to learn [6, 22].

Identifying a strategic core may provide a tertiary benefit by lowering the psychological tolls assessed when engaging instructors who are normally resistant to pedagogical change or reform. For many instructors, their sense of competence may be based on their sense of expertise and knowledge of the course material. If a reformer begins the conversation about change with an instructor by addressing pedagogy first rather than content, the reformer is situated as the expert rather than the instructor. This power structure can be demotivating for the instructor who may seek to maintain their sense of competence in content rather than engage in their lack of competence in pedagogy. With careful engagement about the content, these instructors gain increased autonomy to make changes and reconsider the structure of a course, thereby increasing their motivation for change. The reformer's goal is then to nudge and guide the application of the instructor's motivation.

2) Designing supportive spaciousness

From the perspective of SDT, an instructor's level of autonomy supportiveness is the most critical aspect of promoting students' intrinsic motivation to learn [23-26]. Autonomy supportiveness can be derived situationally from the instructor's attitudes and actions during instruction or contextually from the course design and the cumulative effect of the instructor's attitudes and actions [24]. Different course designs can facilitate or discourage an instructor's use of autonomy-supportive behaviors [24-26], so the designer must carefully construct spaciousness in the course to facilitate the instructors' use of autonomy-supportive behaviors. Designers can create this spaciousness in the course design by intentionally giving students control over course policies, choices in content coverage or deliverables, or using inquiry-based course designs that are driven by students' questions.

In conjunction with creating spacious course structures, instructors must also consider how they interact with students and reformers must help instructors identify and value autonomy-supportive behaviors. For example, autonomy-supportive instructors 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) [25-26].

Similarly, the designer can use their initial evaluation of the course to reveal opportunities to promote students' sense relatedness. For example, students' sense of relatedness with their peers can be promoted through the use of team-based learning techniques. While a review of effective team-based learning techniques is beyond the scope of this paper, instructors can use the principles of SDT to provide some guidance on how to promote positive team environments. For example, instructors need to help students develop their sense of purpose in their teams. Instructors can help students internalize the importance of learning in teams, help structure teams around a common interest or purpose, or help students identify complementary roles in their teams in order to create good teams which in turn promote students' sense of relatedness. Since relatedness can take time to form, the designer must craft the space for this relatedness to grow.

C. Manage the costs of potential course designs

In order to evaluate the cost of an innovation or to determine how to best minimize the costs of an innovation, there needs to be an accounting of the resources available to, and costs incurred by, the course.

1) Costs of reform and course design

In our efforts to reform courses, we have identified four major costs that act as barriers to change for instructors: time sinks, financial costs, psychological tolls, and political taxes. While the barriers of time, money, and politics (tenure and promotion) are often well documented [5], the psychological tolls are rarely formally discussed in the literature.

Time sinks (e.g., grading, lecture preparation, course management, etc.) reduce the likelihood that a future instructor will adopt a similar teaching method. Financial costs can constrain the design and analysis tools available to students or restrict hiring additional teaching assistants. Political taxes can restrict what types of innovations will be acceptable to a department. Finally, psychological tolls can reduce an instructor's willingness to try new techniques. The psychological tolls of an innovation are particularly critical to address since they are also best addressed by understanding motivation and other affective orientations of the instructors. By addressing an instructors' understanding of their own motivation, it may help them better understand how to address their students' motivations. The remainder of this subsection is anecdotal from our experiences in executing education reform, but also develops from critical reflection of theory in practice.

To better understand the nature of psychological tolls, let's discuss common barriers to adoption from the perspective of the needs outlined by SDT.

Purpose-barriers: Many instructors refuse to adopt new pedagogies, because the effort required to make the change does not fit within their value system. Perhaps the instructor does not believe that teaching is valued. Perhaps the instructor does not value the proposed outcomes of the teaching method. Perhaps the instructor does not believe that a teaching method is so much better that it justifies the increased financial or time costs. Instructors with this barrier may benefit from journal articles and cognitive arguments, but they may also need to believe that a specific teaching method is beneficial to themselves and not just the students. Discussions of cost-benefit analysis or appeals to intellectual stimulation may prove more successful than evidence of effectiveness.

Autonomy-barriers: Many instructors are threatened by giving students autonomy because they then feel a loss of control and a loss of their own autonomy. In the presence of this loss of control, many instructors may perceive a course as a failure despite its successes. For example, letting students wrestle with core concepts in groups without direct supervision (high autonomy for students) can feel like a failure if the students do not get the right answer during that group work. For many instructors, they feel that instruction has only been successful if the students report the right answer with affirmation from an expert (low autonomy for students). This desire for control can persuade many instructors that many active learning or inquiry-based learning techniques are ineffective, despite any evidence to the contrary. The concept of structure spaciousness may be valuable in helping instructors redefine their sense of control and autonomy. Instructors can feel a greater sense of autonomy when they better understand where and when they are choosing to delegate control to their students and what types of control benefit learning.

Competence-barriers: When attempting to use a new teaching method, an instructor's sense of competence can easily be lowered by the unfamiliar. Early failures in attempts with new teaching methods can further lower the sense of competency. An instructor who has tried and failed may not need to be convinced of the efficacy of a method, but rather may need better support structures, mentoring, or simply a positive experience with a pedagogy.

Relatedness-barriers: Students often resist pedagogies that differ too much from their expectations and create an adversarial environment. Instructors can easily be deterred by negative student feedback as it can erode their sense of relatedness with their students. Instructors can also feel a depleted sense of relatedness if they are isolated in their attempts to adopt new pedagogies. Without a community of supportive colleagues, the aforementioned losses of competence or autonomy cannot be offset by a strong sense of communal values and support. This barrier can be addressed by fostering supportive instructor communities or bolstering an instructor's sense of competence so that criticisms are not as damaging.

Knowing how to address an instructor's concerns and objections requires careful noticing of, listening to, and questioning of assumptions, experiences, and beliefs. Alternatively, instructors must critically reflect on their objections to better understand how their motivations may be directing their cognitive decisions and processes.

Finally, costs can be short-term or long-term. For example, generation of video lectures might be a high short-term cost of video production and have low long-term costs of hosting the videos. In contrast, assigning written homework assignments from a textbook might have a low short-term cost of selecting problems and incur a high long-term cost of grading. High short-term costs can block initial adoption of a pedagogy, and high long-term costs can block the sustainability of a pedagogy after initial champions stop paying for those costs.

2) Resource identification and generation

The course designer needs to identify what resources are available to the course and how those resources are being used in order to develop a strategy for how to offset the long-term and short-term costs of an innovation. A low-cost IM course conversion creates change to the course through a mechanism of deliberate cost-swapping.

It is best to invest in short-term costs when those short-term costs can lower the long-term costs of teaching a course. For example, investing in the creation of video lectures, online grading systems, and problem solving activities for a flipped classroom has a high short term cost, but it can potentially lower long-term costs as the entire course becomes scripted, the instructors no longer need to prepare lectures, and fewer assignments need to be manually graded.

Cost swapping can also take the form of exchanging costs of the same type. For example, changing course content or using drastically different pedagogies from a departmental norm can incur high political taxes and resistance. To offset this tax, our reform efforts tend to focus on the large enrollment required courses that few, if any, instructors want to teach. While some political systems might dislike our pedagogies, other political systems gratefully accept our help with these understaffed and poorly rated courses.

Finally, course designers should also consider how any high costs can be distributed among the students. Students can contribute to an IM course conversion by deciding content (e.g., finding interesting real-world examples), creating course materials (e.g., homework assignments, video lectures, etc.), content delivery (e.g., collaborative creation of wikis), and formative and summative assessment (e.g., peer review) [27]. By carefully distributing some of the cost of reform among the students, the course design can further support students' purpose, autonomy, relatedness, and competence, fostering their intrinsic motivation to learn [27]. In perhaps a best possible scenario, intrinsically motivated students can become the engine that drives education reform rather than the instructors. We have seen hints of this new engine forming in our efforts as students who experienced an IM course conversion have returned to help teach the course for free as peer mentors, others have filmed video lectures, and still others are developing online auto-grading tools.

As the designer manages the costs of different course modifications, the modifications will change and present new costs or new resources. Consequently, the evaluation and decision process must necessarily be iterative. After the design, costs, and resources of the modifications stabilizes, the designers should evaluate and compare the costs and IM support of the different proposed modifications. The final course design should reflect a balance between strong support of students' IM to learn, yet with low costs to the instructors and institution.

V. An Example IM Course Conversion Process

In this section, we conclude by providing an example of how this course design method was used to perform a low-cost IM course conversion on a large enrollment course that focused on technical computer engineering skills during the sophomore year.

Every semester, the course enrolled 200-250 students. The students would attend two lectures and one discussion section (~30 students per section) per week. Prior to the course conversion, students would complete a weekly battery of online homework problems and then a written homework problem set. Students would also complete seven prescriptive laboratory exercises over the semester and two or three midterm examinations depending on instructor preference. The course culminated with a comprehensive final examination.

A. Evaluating the current course design

The initial evaluation of the course revealed that the weekly homework problem sets created one of the greatest hindrances to students' motivation to learn and highest costs to the course.

1) Evaluating support of PARC needs

Written homework problem sets typically contained four to eight problems assigned after a week of instruction on the topics. Students were given a week to complete the assignment, and then students would receive their graded problem sets at least a week after turning it in. The problem sets often used rote, context-less problems (low purpose). All students completed the same assignments (low autonomy). Students were required to submit their assignments independently (low relatedness). Because it would take on average of three weeks for students to receive feedback, student rarely read the TA's comments and the feedback did not provide students with feedback on how to adjust their learning strategies (low competence). Finally, the large enrollment and impersonal nature of the problem sets led to rampant cheating (low relatedness and competence).

2) Evaluating course costs

The course employed a cohort of TAs to help with the course for a total of 80 hours per week of which an estimated 64 of those hours were spent grading. The remaining TA hours were divided between instructing discussion sections, office hours, and staff meetings. Due to this high grading load, the course also needed to hire undergraduate graders to lighten the grading load on the TAs so that they could engage in their other course duties. New problem sets were written each semester in an attempt to combat cheating.

B. Creating structured spaciousness

Because grading consumed so many resources and students were not receiving effective feedback, we focused on changing the mechanism for feedback on the homework assignments. We created a construct called the weekly consultation meeting. The weekly consultation meeting took place the week after students were introduced to the course material, shortening the feedback cycle (high competence). During the weekly consultation meeting, the TAs met with teams of five students for an hour to discuss the homework assignment (high relatedness) and address students' personal difficulties (high competence). Students received 50% of the homework grade for bringing a completed homework assignment and could earn the remaining 50% by contributing meaningfully to the group discussion about the assignment (high relatedness). Further, we added a menu of challenge problems to the homework assignments which were based on various real-world design problems that highlighted how the course material was relevant (moderate purpose). Students picked one challenge problem from the menu to solve based on their interests (moderate autonomy).

As a byproduct, the emphasis on oral discussion of the problem sets virtually eliminated the cheating problem in the course as writing down the correct answer was no longer sufficient for full credit. Rather than coming to the consultation meetings with copied answers, students would come with targeted questions.

C. Managing the costs of potential course designs

We made this modification low cost by swapping the time intensive process of grading for a similarly time intensive process of weekly consultation meetings. With 250 students in the course and five student teams, the TAs needed to spend 50 hours per week providing feedback to students on their homework assignments. With this reduction from 64 hours of grading, we also no longer needed to hire an undergraduate grader to support the course, and thus reduced the financial cost of the course as well. Changing the TAs' duties also incurred low political taxes and psychological tolls. Since most TAs had never taught with different pedagogies, they did not resist the new grading paradigm.

We also maintained a lower time cost to the modification by not requiring the primary course instructors to change their preferred lecture delivery methods. Further, allowing the instructors to continue teaching with familiar methods also reduced the political tax and psychological toll of the innovation.

Iterations on the design method revealed additional opportunities to increase students' sense of purpose and autonomy in the course. The weekly consultation meetings created the time and place to infuse student-led project-based learning in the course. Since students had weekly team meetings with course staff, they could work with these same teams on extended, purpose-driven projects in lieu of midterm examinations. At the beginning of the semester, students were given a choice of projects to complete and were organized into teams based on their expressed interest in different projects (high purpose, high autonomy, and high relatedness). This switch to projects created a new short-term cost of creating rubrics and project ideas, and this cost was swapped with the long-term cost of writing and grading examinations.

As we demonstrate in other publications [6, 22], this deliberate cost swapping method created a low-cost innovation which better supported students' intrinsic motivation to learn as indicated by the Learning Climate Questionnaire. Climate scores rose from five points out of seven on a Likert scale to six points [22]. The course conversion additionally improved students' cognitive outcomes and conceptual learning as students' learning gains as indicated by a concept inventory revealed that students' conceptual understanding improved to 50% learning gains as compared to 25% learning gains in previous offerings of the course [22].

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