

The Intrinsic-Motivation Course Design Method*

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Because engineering faculty seldom use research-based instructional strategies, the engineering education community has become increasingly concerned with how to help faculty sustainably integrate education research into their teaching practices. We developed the Intrinsic-Motivation (IM) Course Design Method to make motivation theory accessible to faculty and to help faculty think more concretely about the costs that demotivate them and make their course designs untenable. Our course design method complements existing course design methods by providing an approach to designing for motivational outcomes. In this paper, we describe the IM Course Design Method and then illustrate how this method was used to refine the design of a sophomore-level engineering course that enrolled over 200 students. We then present evaluation evidence from this course to suggest that application of the method can increase students' intrinsic motivation in engineering courses.

Keywords: intrinsic motivation; course design; diffusion of innovation

1. Introduction and Background

Translating research to practice has been described as the “valley of death,” as research rarely makes the leap to affecting practice [1–3]. This gap is particularly prevalent in the strategies and methods that faculty use to motivate their students. In science, technology, engineering, and mathematics (STEM) education, the research-to-practice gap for improving how faculty motivate their students is exacerbated by at least three challenges [4–6]. First, faculty distrust the research that supports research-based instructional strategies (RBIS) as it often conflicts with their identities as technical content experts [6]. Second, faculty are not willing to pay the perceived time and financial costs necessary to implement RBIS [7–10]. Third, motivation research is particularly difficult for outsiders (e.g., engineering faculty) to interpret and apply without assistance, often running counter to their intuitions [11]. Born out of these challenges, we created the Intrinsic-Motivation (IM) Course Design Method to provide one avenue for bridging this valley of death. The goal of this method is to enhance the intrinsic motivation (i.e., their inherent interest in learning or teaching a subject) of both faculty and students simultaneously.

Course design methods provide faculty with a disciplined approach to shift their focus from simply sequencing content to designing their course to achieve desired outcomes [12]. These methods have historically focused on improving students' cognitive outcomes, while either ignoring motivation completely or treating it as a secondary or tertiary outcome [12–17]. However, educational research has been increasingly revealing that students' affect or motivation moderates their cognitive outcomes [18–20]. Affective constructs such as self-efficacy beliefs can accelerate how students learn challenging course material and help them persist in learning activities when they fail [4, 5, 18, 19, 21]. Motivational orientations toward learning have similarly been shown to improve learning and persistence, as intrinsically motivated students are more likely to invest in higher-order cognitive behaviors such as self-regulation [22–25]. As concerns about attrition and student disengagement abound in engineering education, we need to more deeply consider the motivational outcomes of our courses.

The challenges of getting faculty to use RBIS can also be thought of as a motivational problem. For example, the commonly cited challenges of time and financial costs can be understood as motivational

barriers [10]. Moreover, many instructors who attempt to adopt RBIS are often discouraged by student resistance or perceived failures and stop using RBIS shortly after beginning to using them [5, 26]. The ability to persist through failure and invest in the reflective and higher-order cognitive practices needed to improve can be gained by building faculty's intrinsic motivation to learn how to improve their courses [8, 26–33]. Our course design method aims to lower the costs that can prevent faculty from changing their courses. We also apply motivation theory, where possible, simultaneously to both faculty and students in the hopes of sustaining faculty engagement in research to practice.

The paper begins with a brief background on motivational theory and course design methods, followed by a description of our proposed course design method. Our method can be used as a stand-alone course design method or it can be used as an add-on to the presented course design methods. The paper concludes by describing the application of the method to a sophomore-level computer engineering course (COMPE I) and evaluating the effectiveness of the course design method in that course. We present evidence from both cognitive (the Digital Logic Concept Inventory [34]) and motivational instruments (the Learning Climate Questionnaire [35, 36]) as part of an ongoing evaluation of the course design method. This paper synthesizes and expands on prior conference papers [37, 38]. For the remainder of this paper, we refer to the user of this course design method as “designers” with the understanding that all designers may not be faculty.

2. Background

To provide background for the course design method, we discuss the rationale for the method

and then provide brief literature reviews on student motivation and course design methods.

2.1 Interactive engagement pedagogies and the Goldberg-Laffer curve

Most RBIS in engineering education can be described as interactive engagement (IE) pedagogies (i.e., active learning) that promote “deep learning” rather than shallow memorization or rote learning [39–44]. Faculty are often reluctant to adopt these RBIS because the time, financial, and training costs are perceived as prohibitive [6–10]. We posit that these perceptions stem from the rhetoric surrounding RBIS: Faculty are promised better learning outcomes if they change their teaching styles from “sage-on-the-stage” lectures to “guide-on-the-side” IE pedagogies. When students resist these changes or faculty experience initial failures, they stop using these IE pedagogies, considering them to be not worth the cost [8, 26].

Conceptually adapted from Arthur Laffer's taxation-revenue model from economics [45], The Goldberg-Laffer curve (Fig. 1) is a rhetorical device that aims to invite faculty to join intrinsically motivated students in improving learning [46]. While the move from “sage-on-the-stage” to “guide-on-the-side” has historically been viewed as a cost by faculty, the Goldberg-Laffer curve proposes that if students experience intrinsically motivating courses, then they would in turn demand to have more courses that intrinsically motivate them and would provide the energy, ideas, and manpower to create them. Instead of solely faculty-driven change, these “learners with fervor” drive the change in the classroom, reducing the costs to pedagogical and educational improvement. The curve ultimately hypothesizes that there is an “IM space jump” through which students become so intrinsically motivated and engaged in their learning that faculty will perceive

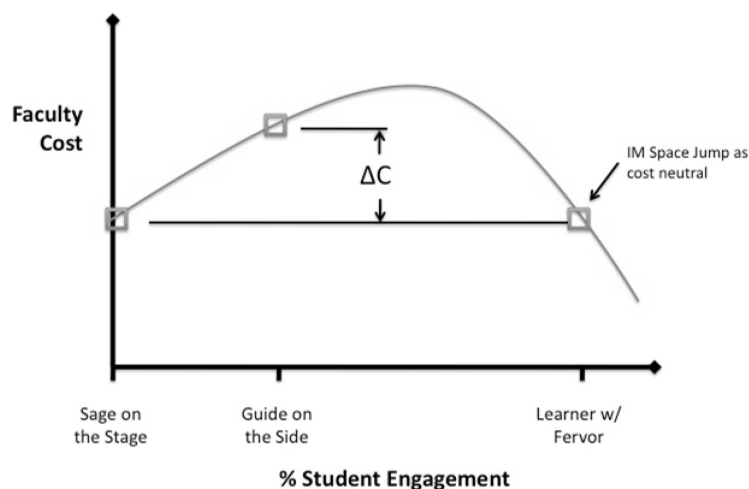


Fig. 1. Goldberg-Laffer curve.

no costs to their teaching above and beyond that of their traditional lectures. The creation of this course design method was conceived in part to explore this idea.

2.2 Student motivation

Helping faculty integrate motivation theories into their curriculum and instruction is challenging as there are a variety of motivational theories that ascribe different names to similar constructs (e.g., expectancy versus self-efficacy) or rely on different primary mechanisms for explaining motivation (e.g., the cognitive-motivational approach of Expectancy-Value Theory [47] versus the psychological needs-based approach of Self-Determination Theory [48]) [11]. This complexity, in addition to common counter-productive beliefs about motivation (e.g., overreliance on controlling or reward-based forms of motivation), provide significant challenges for faculty to effectively translate motivation research into their practice [29]. The goal of this paper is to package one motivation theory—Self-Determination Theory (SDT)—into a framework that makes it straightforward for faculty to apply.

We chose SDT because it emphasizes psychological needs. The needs-based structure of SDT aligns well with the goals of design—devising a solution for an identified need [49]. 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 [35, 48, 50]. This sole focus on needs provides a condensed 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 motivation from the inherent value of an activity) [48]. Table 1 presents four motivational orientations from the broader range of orientations in SDT to give readers a sense of how motivation can vary [51]: amotivation, external regulation, identified regulation, and intrinsic motivation.

Students tend to learn more when they are intrinsically motivated to learn [18]. SDT posits that when instructors rely on using rewards or other extrinsic motivators (e.g., grades), students' motivation shifts toward external regulation and amotivation [52]. Instructors can support students' motivation generally and shift them towards an intrinsic orientation by meeting certain psychological needs, supporting their senses of *autonomy* (I feel in control of my learning, I feel that I can make meaningful choices), *relatedness* (I feel that what I do matters, I feel like I belong), and *competence* (I am confident that I can succeed, I'm getting positive feedback) [48, 50, 53]. Faculty can readily relate to these needs through the way that they pursue their research interests. Faculty generally engage in research because of intrinsic motivations, having the academic freedom (autonomy) to choose what they research, having communities of like-minded researchers that they meet at conferences or over coffee (relatedness), and having the relevant expertise to achieve their research aims (competence).

In the context of the IM Course Design Method, we have found that faculty resonate with the addition of the psychological need of *purpose* (a sense of utility or interest) to the design of their courses [11, 47, 53, 54]. Purpose provides the primary avenue for addressing the course content in our design method and creates an avenue for connecting our course design method to cognitively-focused course design methods. We refer to these four needs as *PARC* (purpose, autonomy, relatedness, and competence) *needs* for the remainder of this paper. A defense of the addition of purpose to the method is available for interested readers in section 2.4.

SDT further reveals that the design of IM-supportive pedagogies depends on both instructors' attitudes and class structures [35, 48]. Instructors with IM-supportive attitudes 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) [30].

Table 1. 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., "Proofs are boring, 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.")

However, different learning environments are more or less conducive to an instructor's development of IM-supportive attitudes and actions. For example, when K-12 teachers are led to focus on meeting national standards, they use fewer IM-supportive actions [29]. Critically, although a different course design can improve students' motivation, instructors can reinforce the course design by changing their teaching practices.

2.3 Brief history of course design

Faculty frequently adopt ad hoc course design methods that emphasize sequencing a series of isolated topics that conform to departmental norms and mandates [55]. These types of course designs frequently lead to an emphasis on lower order learning skills such as understanding and remembering [17, 55]. Formal methods of course design focus on elevating higher order (i.e., more significant) learning outcomes over individual topics [12–17]. These outcomes-based course design methods lead designers to first identify these significant learning outcomes and then work to identify the teaching methods, assessment procedures, learning activities, and so on that will yield those outcomes.

Because of its compatibility with outcomes-based instruction, Backwards Course Design and its direct successors Learning by Design and Idea-based Learning serve as popular methods of course design that are cognitively focused [12, 14, 56]. 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) [12, 14]. These central concepts are broken down into enduring understandings: canonical examples that critically inform how students will think about the concepts [12, 14]. 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 and helping students develop an integrated conceptual framework of the material that leads to deeper learning [12, 14].

Course design methods such as Felder and Brent's Effective Course Model [15], Fink's Integrated Course Design [17], and the Content Assessment Pedagogy Model by Streveler, Smith, and Pilotte [16] emphasize a cyclic design process in contrast to the linear model described by Backwards Course Design [14]. In these methods, the designer follows many of the procedures prescribed by backwards course design, but the methods provide rubrics and worksheets to iteratively evaluate and refine the alignment between the desired outcomes

and the implemented content, assessments, and pedagogy. Each of these models explicitly elevates affective goals such as life-long learning or developing new interests and values as potential outcomes, but content and cognitive outcomes are still central, while motivation outcomes are absent or implied [14, 57].

2.4 Justification for adding purpose to the course design method

The psychological need for purpose was added to the course design method as a way to reduce faculty resistance to the method and to increase the synergy of our method with existing course design methods. As described in the previous section, many course design methods begin by requiring the designer to identify the "big ideas" that govern the course. The goal of identifying the purpose of a course for students is analogous to the big ideas.

Identifying the purpose of a course first can lower 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 [6]. If a coach or mentor begins the conversation about change with an instructor by addressing pedagogy first rather than content, the mentor is situated as the expert rather than the instructor. This power structure can be demotivating for the instructor [6]. By beginning the course design process with purpose, we have found that faculty more readily accept the rest of the implications of SDT. Starting with purpose situates the instructor as the indispensable expert on their technical content, engaging their psychological needs of autonomy, relatedness, and competence.

From a theoretical perspective, purpose is encapsulated within the other needs of SDT: autonomy needs are met when the person feels that they are making *meaningful* choices and relatedness needs are met when the person feels that what they do *matters* [50]. Similarly, in his MUSIC model of academic motivation, Jones posits that motivation can be described using five constructs, three of which align with the needs described in SDT: eMpowerment (autonomy), Usefulness, Success (competence), Interest, and Caring (relatedness) [11]. The two constructs usefulness and interest can both be considered as components of purpose. Indeed, in our administrations of the MUSIC Model for Academic Motivation Inventory, our factor analyses revealed that items meant to measure usefulness and interest loaded onto a single factor separate from empowerment, success, and caring. We suspect that this factor loading reflects that engineers are interested in a topic precisely

because it is useful. Other motivation researchers such as Pintrich similarly join usefulness and interest into a single construct (task value) in their frameworks [58]. Because adding purpose to our design method does not undermine SDT and is useful for engaging faculty, we added the construct to the course design method.

3. The IM course design method

We provide a central image for courses designers, we describe the IM Course Design Method as creating *structured spaciousness*. This image is composed of two complementary palettes, 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. This imagery combats two common mistakes: overemphasizing structure to create controlling environments [29] or overemphasizing autonomy and paralyzing students with too many choices [59]. In contrast to a cattle chute or an open field, a structured yet spacious course design is like a track and field event in which all members of a team are expected to be running and jumping, but they have some freedom to choose whether and how to specialize in long distance or sprinting or high jump. With this central image, we present a framework for creating structured spaciousness.

In accordance with this philosophy, the course design method provides structures that guide and embolden the course designer, yet provides spa-

ciousness so that the course design method is not prescriptive. We provide examples as illustrations of the principles rather than as masters to be copied. This method will be most effective when the instructors possess the senses of autonomy, relatedness, and competence about their courses that undergird their motivation to teach.

The design method is iterative and has three primary steps (Fig. 2): (1) evaluate the current course design's support of students' intrinsic motivation, (2) create structured spaciousness by generating potential modifications to improve the course design's support of intrinsic motivation, and (3) 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 to determine if the design objectives were met. If not, then additional iterations may be needed.

3.1 Evaluate the current course design

An evaluation of a course's existing design provides a baseline for reimagining the course and assessing the costs of any revisions. The course designer must consider how students in the course would experience the course and how it meets their psychological PARC needs. Because a designer's perception of what might be motivating will likely be slightly different from the students, the use of surveys can inform the designer's decision making, but is not required. We provide an evaluation rubric (see Table 2) to offer a tool for faculty as they reflect on how their course designs affect students' motivation. The presented evaluation grid is based on SDT, reflecting language from surveys such as the

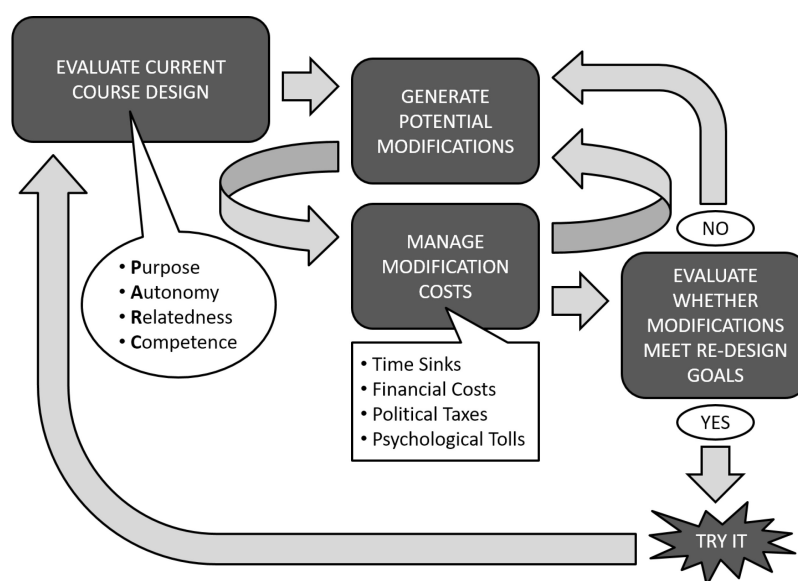


Fig. 2. Process diagram for the Intrinsic-Motivation Course Design Method.

Table 2. Course Evaluation Grid: Based on Support of Psychological (PARC) Needs for Motivation

Students' psychological PARC needs for motivation	Rate the course's support of each need		
	<i>Low</i>	<i>Moderate</i>	<i>High</i>
Purpose			
I feel a sense of accomplishment because of this course.			
I am able to learn interesting things in this course.			
The course material captures my interest.			
Autonomy	<i>Low</i>	<i>Moderate</i>	<i>High</i>
I have control over my learning goals.			
I feel like I have input into how I learn.			
I have meaningful choices over course structures.			
Relatedness	<i>Low</i>	<i>Moderate</i>	<i>High</i>
I get to work with peers who care about me.			
My instructors take my feelings into consideration.			
My work has positive impacts on people outside the classroom.			
Competence	<i>Low</i>	<i>Moderate</i>	<i>High</i>
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.			

Learning Climate Questionnaire [35, 36] and the Basic Need Satisfaction at Work Scale [60]. Designers are welcome to modify the grid.

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 section 3.3. The goal of an IM course design, 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.

3.2 Create structured spaciousness

Based on the initial evaluation, 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 can help the designer think more creatively and identify possibilities that would not be readily apparent by considering constraints too soon. For example, in the COMPE I course redesign, 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. To

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

3.2.1 Identify a strategic core (creating structure)

The designer needs to determine a strategic core of goals, outcomes, and/or objectives of the course, primarily to enhance students' sense of purpose in taking the course. In other words, the focus is on *why* certain concepts and skills are important. 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, diluting the purpose of the course and limiting possible avenues for autonomy.

A strategic core can improve students' sense of competence by creating a manageable list of course objectives. If the designer can identify two or three strategic course objectives, students will perceive that the course objectives are attainable. 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. Finally, the strategic core can bolster students' senses of autonomy, helping students perceive that the choices they do get to make are meaningful, and it can bolster students' senses of relatedness, helping students perceive how what they are learning can help them impact the world.

As mentioned earlier, we encourage designers to identify their ideal forms of feedback and assessment, before considering cost. 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., [61]). For example, the use of rubrics can support purpose and competence by helping students know what is expected of them and what they will learn [62].

As an example, COMPE I was originally defined by a page-long list of topics that was incomprehensible to the incoming student and lacked a week-to-week cohesion between the topics. 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 [63]. Identifying the core big ideas empowered the instructors to cut the number of topics covered by the course in half. The course objectives were pared down to three core big ideas and a list of choices for students to explore how those big ideas are used in practice.

3.2.2 *Designing autonomy support (creating 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 [30, 35, 48, 64]. 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 [64]. Different course designs can facilitate or discourage an instructor’s use of autonomy-supportive behaviors [29, 30, 64], so the designer must carefully construct spaciousness in the course to facilitate the instructor’s use of autonomy-supportive behaviors. Designers can create structured spaciousness by enabling students to shape course policies, or supporting students’ inquiry-driven learning path.

Similarly, the designer can use their initial evaluation of the course to reveal opportunities to promote students’ sense of relatedness. For example, designers can create collaborative activities in which students build a sense of relatedness with their peers [65]. 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 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. Since relatedness can take time to form, the designer must provide the space for this relatedness to grow.

3.3 *Manage the costs of potential course designs*

To make a course design sustainable, the designer

must account for the costs incurred by, and the resources available to, the course and the instructor.

3.3.1 *Costs of change and course design*

We define cost as any expenditure (e.g., time, money, political capital, emotional energy) that might cause an instructor to discontinue using a chosen course design or teaching method. These costs are considered important for instructor motivation [6, 10], but cost is one of the least understood and researched motivational constructs, both in general and in educational contexts [66]. Given, the lack of formal definitions of cost from a motivational perspective, we draw from research on organizational change in university settings that identify barriers to successful change. In this literature, barriers to change arise from social, economic, and political factors [67]. Additionally, faculty frequently cite time as the primary barrier to changing their teaching practices [6, 10]. Synthesizing this literature, we identify four major costs that act as barriers to change for instructors: time sinks, financial costs, political taxes, and psychological tolls. While the barriers of time, money, and politics (tenure and promotion) are often discussed [4–6], the psychological tolls are rarely formally described in the literature [6].

Time sinks (e.g., grading, lecture preparation, course management, etc.) reduce the likelihood that a future instructor will continue using a 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. These taxes can come from departmental norms, policy, or culture. For example, the departmental requirement of a final examination restricted the choices of the COMPE I redesign. Alternatively, prerequisite structures can make it impossible to cut some content that does not fit the strategic core. Finally, psychological tolls can reduce an instructor’s willingness to try new techniques.

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, while high long-term costs can block the sustainability of a pedagogy after initial champions stop paying for those costs.

Psychological tolls are critical to address because they relate directly to instructor motivation and are likely to inhibit engagement with changes in a

course design. We briefly describe some psychological tolls that faculty may experience through the lens of the SDT.

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 [29]. The imagery 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.

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 their sense of competency [8, 26–28]. 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 [26, 32, 33]. As faculty develop their intrinsic motivation for creating change, they will increase their ability to persist through failures and develop the critical reflection skills needed to learn and improve, much like their students [4, 5, 18, 19, 21–25].

Relatedness-barriers: Students often resist pedagogies that differ too much from their expectations and create an adversarial environment [10]. 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. This barrier can be addressed by fostering supportive instructor communities [32, 33].

3.3.2 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. The IM Course Design Method 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 exchan-

ging costs of the same type. Changing course content or using drastically different pedagogies from a departmental norm can incur high political taxes and resistance. In our efforts, we have offset this political tax by teaching the large-enrollment, required courses that few, if any, instructors want to teach. While some political systems might dislike the motivation-supportive pedagogy other political systems gratefully accept assistance 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 design 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) [68]. By carefully distributing some of the cost of change among the students, the course design can further support students' purpose, autonomy, relatedness, and competence, fostering their intrinsic motivation to learn [68].

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 stabilize, 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.

4. An example IM course redesign process

In this section, we provide an example of how this course design method was used to redesign a large enrollment course that focused on technical computer engineering skills during the sophomore year. The course redesign was piloted in two discussion sections during Fall 2011 and was delivered at full scale to the whole course during Fall 2012 and Fall 2013 with different instructors each semester.

4.1 Evaluating the current course design

COMPE I had developed a bad reputation among both students and faculty as a purposeless required course. Worse, faculty viewed teaching the course as burdensome because of the high enrollment and dated course material.

In Table 3, we present our initial evaluation of COMPE I's support for students' psychological PARC needs before we implemented the IM course conversion. The COMPE I course design

Table 3. Course Evaluation Grid for COMPE I Before Revision

Students' psychological PARC needs for motivation	Rate the course's support of each need		
	<i>Low</i>	<i>Moderate</i>	<i>High</i>
Purpose			
I feel a sense of accomplishment because of this course.	x		
I am able to learn interesting things in this course.	x		
The course material captures my interest.		x	
Autonomy	<i>Low</i>	<i>Moderate</i>	<i>High</i>
I have control over my learning goals.	x		
I feel like I have input into how I learn.	x		
I have meaningful choices over course structures.	x		
Relatedness	<i>Low</i>	<i>Moderate</i>	<i>High</i>
I get to work with peers who care about me.	x		
My instructors take my feelings into consideration		x	
My work has positive impacts on people outside the classroom.	x		
Competence	<i>Low</i>	<i>Moderate</i>	<i>High</i>
I believe I can be successful and achieve the learning goals.		x	
I can engage in challenging and meaningful goals.		x	
I get positive formative feedback on my learning process, not just my performance.	x		

was standard for the department. 200–250 students attended two lectures per week, completed a weekly battery of homework assignments, took two to three midterm examinations during the semester, and took a comprehensive final examination. The course also employed eight discussion sections (~30 students per section) to better engage students, and it had laboratory assignments in an attempt to motivate students with more hands-on design activities.

4.1.1 Evaluating support of PARC needs

Frank discussions with course instructors revealed that the faculty perceived that many course topics, while once useful, were now dated. The instructors labeled these topics as simply “nice-to-know” (low-purpose). Similarly, the course syllabus objectives were organized as a list of topics that students needed to learn (low purpose). The instructors would occasionally use real-life examples, but the conceptual simplicity of context-less problems was the norm (moderate purpose). Due to low attendance at lectures, most instructors decided to make attendance mandatory (low autonomy).

All students completed the same course assignments on the same schedule (low autonomy). The course had adopted a policy of giving students full credit on homework assignments if the students achieved a 90% or higher, to give students a little bit of freedom to make mistakes without the external pressure of getting a perfect grade (low autonomy, moderate competence). The course provided students with an online homework system that facilitated rapid feedback with opportunities to seek additional practice for certain problems (moderately-low autonomy, moderate competence). Exams were completed individually and frequently

had low means (e.g., 60%) (low autonomy, low relatedness, low competence).

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). Students were required to submit their assignments independently (low relatedness). Because it would take an average of three weeks to receive feedback, student rarely read the TA's comments and the feedback did not provide suggestions 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).

4.1.2 Evaluating course costs

The course employed a cohort of four teaching assistants (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.

4.2 Creating structured spaciousness

The initial evaluation of the course revealed several avenues for improvement such as giving students some degree of autonomy over their learning, creat-

ing more engaging and interesting homework assignments, and improving the perceived value of the course to both students and faculty.

We began by creating a new strategic core of content for the course to increase students' sense of purpose. Working with prior course instructors, we identified core conceptual ideas for the course that the instructors found compelling and essential for all students (this process is described in detail in other publications [63, 31]). We identified three primary concepts (state, information encoding, and abstraction) that organized all of the course content and would be clearly applicable to both electrical and computer engineering students (high purpose). Using these core concepts, we ranked the relative importance of all topics on the existing syllabus to determine a minimal set of topics that students needed to learn. All topics not in this set were removed from the syllabus or became optional applications of the course content that students could explore (moderate autonomy). For example, to learn more about information encoding, computer engineering students could choose to learn about IEEE floating point notation while communications and signal processing students could choose to learn about error detection and correction in transmitted binary codes.

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 that were context-rich, based on a diversity of real-world design problems, and highlighted how the course material was relevant to different disciplines (moderate purpose). Students picked one or two challenge problems 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.

4.3 *Managing the costs of potential course designs*

We managed the cost of the course redesign by piloting the IM course with a subset of students during the Fall 2011 semester before scaling to all students during the Fall 2012 semester. The pilot enabled swift changes to course structure when problems were identified.

We made this course design 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 teams of five students each, the cohort of TAs collectively 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 incurred low, if any, political taxes and psychological tolls. Since most TAs had never taught with different pedagogies, they did not resist the new grading paradigm, but accepted it as the norm.

We also maintained a lower time cost to the modification by not requiring the primary course instructors to change their preferred lecture delivery methods. Allowing the instructors to continue teaching with familiar methods reduced the political tax and psychological toll of the innovation as new instructors willingly accepted the new course design in Fall 2013.

4.4 *Iterations on the design method*

To further increase students' senses of purpose, autonomy, and relatedness, we replaced the mid-term examinations with student-defined, student-led projects. The adoption of these projects was made possible by the prior commitment to the weekly consultation meetings. During these meetings, students could now choose whether to discuss the homework or their projects in greater depth with their team leader (high autonomy and competence). 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).

Students completed three projects over the course of the semester. For each project, students wrote a learning agreement that specified their learning goals and project objectives. These learning agreements were used to help students understand what was expected from these projects since most students had never engaged in project-based learning

before (moderate competence). To scaffold students' autonomy during these projects, we increased students' level of autonomy for each project, as shown in Fig. 3. The first learning agreements supplied a menu of projects with associated required objectives (e.g., use specific combinational logic design practices) for students to choose from. The second learning agreement had required objectives (e.g., use of multiple, interacting state machines) but students were allowed to propose any project that met the objectives. The third learning agreement had only an open-ended learning objective—demonstrate a deep understanding of a computer architecture. This learning objective gave students the freedom to more deeply explore how knowledge about computer architectures might be useful in their future studies. For example, electrical engineering students who wanted to study power were encouraged to explore low-power processors and understand their trade-offs. This final learning agreement gave the students autonomy that was comparable autonomy to a senior design course (see Fig. 3).

Increased levels of choice and autonomy are highlighted in bold. The hypothetical level of autonomy in a Senior Design course is included for reference.

To further support students' autonomy, we also developed a formal petition process through which students could petition to change any component of the course. Several learning teams took advantage of this process. For example, one learning team petitioned to have only two learning agreements so that they could undertake larger projects for each

learning agreement. Some students similarly petitioned to not take the final examination so that they could try to complete ambitious projects that would not have been possible if they had to complete them during the standard time frame.

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.

The use of projects unintentionally created new avenues for students to support their senses of relatedness and purpose and lower the cost of change. Two student teams elected to pursue larger projects that they planned to use in their student organizations. In particular, one team's project (a programmable LED cube) was designed to be used in the student chapter of IEEE to help other students get excited about what they could do as electrical or computer engineering majors. Similarly, five teams elected to execute educational projects (creation of video lectures and new context-rich homework problems) that they hoped would help their peers learn the material better. One team with members experienced in programming decided to create web-based simulation tools to help their peers interact with and explore the course content. These students invested back into the education of their peers and provided primary evidence that intrinsically-motivated students could lower the cost of education change (see the Goldberg-Laffer curve in Fig. 1).

To further reduce the cost of the course design, we tested our hypothesis that intrinsically-motivated students could lower the cost of education reform.

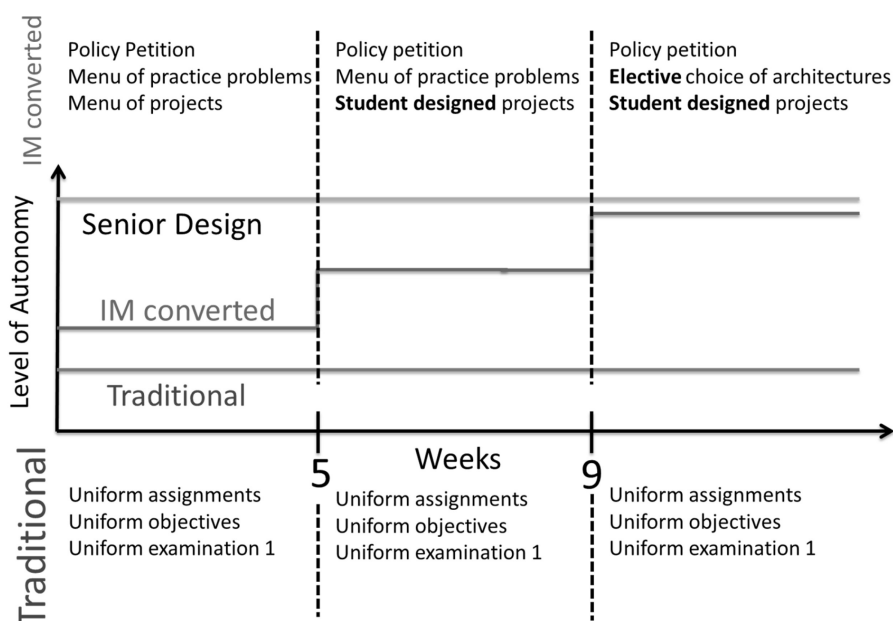


Fig. 3. Comparison of learning activities for the Traditional and IM converted offerings of COMPE I.

To try out the idea, we recruited four students from the first version of the IM course to serve as peer mentors. Receiving one hour of independent study credit for their time, these peer mentors acted as team leaders for three learning teams during their weekly consultation meetings to reduce the teaching load of the TAs. The students had had a positive experience in the course and recognized an opportunity to learn project management skills. The increased use of peer mentors could lower the financial cost of the IM course by reducing the number of TAs required.

Table 4 provides our evaluation of the final version of the course’s expected support for students’ intrinsic motivation needs.

5. Evaluation procedures

We evaluated the quality of our IM course design with two validated and reliable instruments: the Digital Logic Concept Inventory [34] (DLCI; Section 6.2) to measure students’ learning gains and the Learning Climate Questionnaire [35, 36] (LCQ; Section 6.3) to assess how much the learning environment supported students’ intrinsic motivation to learn. The results of these evaluations are reported below. As discussed in prior publications, pre-course administrations of the DLCI and motivation surveys indicated no significant differences between students in traditional lecture-based or Interactive Engagement (IE) offerings of COMPE I and the IM converted offerings [31]. In depth qualitative evaluations of students’ motivational change are described in other publications [69].

The IE offering of the course was offered at the same time as the IM converted offering as a control and to not withhold a potentially positive pedag-

ogical change from students. These students attended the same lectures as the IM-offering students and had access to all of the same homework assignments. However, students were required to complete specific assignments and did not participate in the creation of learning agreements. IE pedagogies were integrated into the non-IM discussion sections: students worked in small groups of 4 students to engage in context-rich collaborative problem solving.

5.1 Sampling

All students from COMPE I were recruited during every semester of the study. However, only data from students who gave their consent through the IRB-approved processes are reported. Given the similarity in populations, but the widely varying sample sizes, we decided to consider only p-values less than 0.01 to be statistically significant for all statistical tests.

5.2 Digital logic concept inventory

The DLCI has been used in COMPE I as a pre/post-assessment since 2008 (except in Fall 2013 because the instructor forgot to allocate sufficient time for the instrument) to measure the effectiveness of different pedagogies in promoting students’ conceptual learning of digital logic concepts. The normalized gain g compares concept inventory scores from different student populations to evaluate the effectiveness of different pedagogies [27]. The normalized gain is calculated by using the average pre-test and post-test scores of each course offering with the following equation:

$$g = \frac{\text{posttest} - \text{pretest}}{100\% - \text{pretest}}$$

Table 4. Course Evaluation Grid for COMPE I After Revision

Students’ psychological PARC needs for motivation	Rate the course’s support of each need		
	Low	Moderate	High
Purpose			
I believe that this course is a valuable part of my education.			x
I find the course’s learning objectives to be relevant to my life.			x
The course material captures my interest.		x	
Autonomy	Low	Moderate	High
I have control over my learning goals.			x
I get to develop and use my own learning strategies.		x	
I have meaningful choices over course structures.		x	
Relatedness	Low	Moderate	High
I get to work collaboratively with my peers.			x
I feel connected to my instructors.			x
My work has positive impacts on people outside the classroom.	x		
Competence	Low	Moderate	High
I believe I can be successful and achieve the learning goals.		x	
I can engage in challenging and meaningful goals.			x

5.3 Learning climate questionnaire

The LCQ is based on SDT and measures the IM-supportiveness of a learning environment and its instructors. The LCQ uses 15, seven-point Likert scale items to provide a single numerical rating of the learning climate [35, 36]. A numerically higher climate score reflects a more IM-supportive classroom climate. During every administration of the LCQ, students were instructed to rate the IM-supportiveness of their teaching assistant or weekly consultation team leader. The TAs were chosen as the focal point of the LCQ because in every course offering, students have regular interactions with the TAs in more personable settings than the large lecture hall setting.

While most items are asked with a positive phrasing (i.e., the instructor supports my sense of autonomy), Item 13 uses a negative phrasing to ensure that the survey respondents are carefully reading the items. If the student rating on Item 13 did not differ from that students' survey mean by more than 2 points on the Likert scale, we concluded that the student did not read all of the survey carefully and their data was removed from the dataset. Only nine surveys were removed from the dataset by this criterion (all from the Fall 2012 term), and for all but one of those surveys the students had rated the course as having a perfect seven point score for the climate. We suspect that the higher rate of improperly completed surveys was a result of survey fatigue caused by the final examination.

5.4 Limitations of the evaluation method

This evaluation method is specific to a single course at a specific institution. The evaluation results are not intended to demonstrate the superiority of an IM course design over IE course designs generally. The evaluation is presented only to provide evidence that the course design can achieve the intended goal of increased motivation and learning. The evalua-

tion also does not provide sufficient resolution to determine which elements of the course design were most effectual at promoting learning gains or students' intrinsic motivation to learn.

6. Evaluation

6.1 Results from the Digital Logic Concept Inventory (DLCI)

Table 5 presents data from the DLCI. The aggregate lecture-based data was collected from previous offerings of COMPE I when the course was taught with three lectures per week with little or no IE pedagogies. The table also shows the gains of the IE-based offerings of COMPE I, the pilot IM course, and the scaled IM courses. The literature shows that 0.1 to 0.3 normalized gains (low gain) on concept inventories are typical for lecture-based courses and 0.4 to 0.6 normalized gains (medium gain) are typical for IE-based courses [70]. Administrations of the DLCI were reliable with a Cronbach α of 0.75 and an average response rate of 88%.

As expected from the literature, the normalized gains of the IE pedagogy, pilot IM pedagogy, and scaled IM pedagogy are all statistically significantly higher than the normalized gains of the lecture-based pedagogy of the course when using Welch's t-test ($p < 0.01$). Surprisingly, the scaled intrinsic motivation pedagogy achieved statistically significantly higher gain than the pilot intrinsic motivation pedagogy and the interactive engagement pedagogy.

6.2 Results from the learning climate questionnaire (LCQ)

Table 6 displays the students' learning-climate ratings from the LCQ.

The LCQ was highly reliable with a Cronbach's α of 0.93 and a 65% response rate. Cronbach's α was comparable across all administrations. The LCQ

Table 5. Pre-test and post-test scores (out of a range of 0-24) for different offerings of COMPE I along with calculated normal gains. Both the interactive engagement and intrinsic motivation pedagogies improved learning.

	Term(s)	N	Pre-test	Post-test	Normalized Gain
Aggregate Lecture Based	2008–2010	688	9.65	13.26	0.25
Interactive Engagement	Fall 2011	128	9.67	17.11	0.52
Pilot Intrinsic Motivation	Fall 2011	37	9.56	16.94	0.51
Scaled Intrinsic Motivation	Fall 2012	220	8.74	18.64	0.65

Table 6. Climate scores for COMPE I when taught with interactive engagement pedagogies, pilot intrinsic motivation pedagogies, and scaled intrinsic motivation pedagogies

	N	Climate Score
Interactive Engagement (Fall 2011)	122 (of 158)	5.3
Pilot Intrinsic Motivation (Fall 2011)	24 (of 37)	6.0
Scaled Intrinsic Motivation (Fall 2012)	148 (of 220)	5.9
Scaled Intrinsic Motivation (Fall 2013)	82 (of 163)	5.9

results revealed that the IM converted offerings provided significantly more support for students' intrinsic motivation to learn with a moderate effect size (Cohen's $d = 0.5$). These results were consistent across six different primary faculty instructors (two per semester) and fourteen different graduate teaching assistants.

7. Discussion of the evaluation

As demonstrated by the DLICI, students had higher conceptual learning gains in the IM course design than in the traditional lecture course and comparable learning gains with an IE course design. However, the IM course design provided better support for students' intrinsic motivation to learn when compared to the IE course design. This evaluation is not intended to show that an IM course design is better than IE course designs, but it does provide a proof of concept that courses designed primarily to promote students' motivation have the potential to improve students' motivation and learning outcomes.

These results accord with hypotheses drawn from the literature. The goal of IE pedagogies is to help students to engage in "deep" conceptual processing of the course material [7]. Complementarily, students who possess an IM orientation toward learning are more likely to naturally engage in "deep" conceptual processing [71]. Consequently, course design, whether cognitively—or motivationally—focused, must carefully consider how to engage students in this deeper processing. Since both design methods promote the use of deep information processing, it is reasonable to expect that either approach can yield better learning outcomes than traditional didactic lecture instruction.

However, there is emerging evidence that IE pedagogies are not universally better than lecturing, particularly when those pedagogies are delivered by faculty who were required to adopt them [6]. Complementarily, research has also demonstrated that faculty who use more autonomy-supportive behaviors tend to be more effective than their peers who use the same pedagogies [29, 64]. It is possible, then, that the effectiveness of IE pedagogies is just as dependent on students' motivational orientation as they are on the specific learning activities. We believe that our results provide ample reason to continue exploring the effectiveness of the IM Course Design Method or other motivation-centric course design methods.

The evaluation also revealed that these gains in student learning and motivation can be achieved at low cost to the faculty and institution. The primary costs of the course came from the development and refinement of project grading rubrics for the open-

ended projects and the training of teaching assistants on team leadership and grading methods. These costs were offset by the reduced time spent writing and grading midterm examinations, and once suitable rubrics are designed their time costs becomes negligible. As we demonstrate in other papers, these course changes were sustainable, even after transferring the course to new instructors [72].

In contrast, changing the roles of the TAs in the course from discussion leaders and graders to project leaders and consultants lowered the amount of time needed from TAs to support the course. The reduction in hours removed the historic need for an undergraduate grader to keep up with the grading demands of the course. Similarly, and perhaps most importantly, the role of consultant and project leader is a role that can be filled by undergraduate students. Our initial efforts have revealed that intrinsically-motivated students can become part of the engine that drives education reform and the adoption of RBIS.

8. Conclusions

The intrinsic motivation course design method provides a proof of concept that courses designed to promote students' intrinsic motivation to learn engineering can indeed improve students' motivation and their learning outcomes. Aligning with Self-Determination Theory, our method provides designers with a simple process that can boost their sense of competence to make changes to their courses, yet is flexible enough to provide designers with autonomy and control over the exact design of their courses, providing avenues to support the intrinsic motivation of faculty to apply motivation research to their practice. The application of the course design method reduced or exchanged costs, providing proof of concept for the method. Future work will study the application of this course design method in other course contexts to study the robustness of the method. Future work will also continue to explore how best to improve the course design tools and rubrics and connect faculty more deeply to the motivation research literature.

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