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Can Disciplinary Integration Promote Students' Lifelong Learning Attitudes and Skills in Project-Based Engineering Courses? *

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Today's engineering graduates face an evolution of global priorities that places a greater emphasis upon sustainability, community, and well being. Overcoming the complex challenges of this shift will require engineers to display agility, resilience, intrinsic drive, and an ability to continually grow and develop—capacities that are currently underemphasized in engineering degree programs. Despite a growing recognition of the importance of socially responsible technological development, many engineering programs continue to prioritize decontextualized technical content learning over broad competency development. As a result, students may have difficulty identifying either personal or societal value in their engineering activities. We suggest that the integration of engineering and humanities perspectives can help students situate their technical studies within the larger human system while simultaneously offering measurable improvements in students' motivations and lifelong learning skills. In this paper, we report findings from an investigation of the effects of disciplinary integration on student motivation and learning engagement in introductory materials science courses. The quantitative results show that integrating materials science with humanities through a project-based course effectively supports increased student motivation and engagement in self-regulated learning strategies. Compared to students in non-integrated project-based courses, students in integrated project-based courses show higher intrinsic motivation and task value. Students in the integrated materials science-history course also report significantly higher use of critical thinking strategies in their project work, indicating that an emphasis on societal context may help students cognitively engage in their engineering studies. Findings also indicate that disciplinary integration offers particular benefits to women engineering students. Compared with the non-integrated course, women in the integrated course report more significant motivational and self-regulated learning gains. This research suggests that putting human contexts at the center of engineering learning can help all engineering students, and especially women engineering students, build a sense of societal relatedness that promotes better learning.

Keywords: motivation; self-regulated learning; lifelong learning; project-based learning; disciplinary integration; self-directed learning

1. Introduction

Foreshadowing more recent calls to action in engineering education, Abraham Maslow argued in 1971 that "we must teach and train engineers not in the old and standard sense," but in a manner that enables them to confront novelty, improvise, and gain comfort with change [1]. This was essentially a call for engineers who are self-regulated, lifelong learners—individuals with agility, intrinsic drive, curiosity, persistence, and metacognitive awareness [2, 3]. Coupled with broad competence in teamwork, communication, systems thinking, creativity, contextual understanding, and ethical decision making [4–8], lifelong learning skills would equip graduates with "the tools needed for the world as it will be, not as it is today" [2].

Governing bodies around the world have encouraged instructors to support students' development as lifelong learners. The U.S. National Academies, for example, challenged educators to "instill in students a desire for continuous and lifelong learning to promote professional achievement and personal enrichment" [9]. ABET went so far as to *require* engineering programs to demonstrate that their graduates have the ability to engage in lifelong learning [10]. The engineering educational community has responded with significant changes in its curricular and pedagogical approaches. Engineering programs increasingly include student-centered pedagogies, such as problem-based and project-based learning, aimed at development of broad competencies including lifelong learning. Prior research suggests problem- and project-based approaches may indeed promote engagement and the growth of lifelong learning-relevant attitudes and skills among engineering students [11].

Despite clear progress in the engineering educational community's understanding of student learning in recent years, we suggest that instructors could do more to support personal engagement and lifelong learning among engineering students. Specifically, we argue that improving cross-disciplinary connections between technical studies and societal contexts may help spark the type of student engagement that leads to long-term growth. Unfortu-

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nately, the prevailing focus of many curriculum redesign efforts remains the technical content of the curriculum [4], and not the promotion of meaningful cross-disciplinary interaction [12]. Engineering programs could enable students to build strong connections between their engineering studies and the larger societal context, yet our curricula often present technical topics in a completely decontextualized manner. As a result, students may have difficulty identifying either personal or societal value in their learning tasks. Rather than connecting their work with socially beneficial and personally relevant outcomes such as solving significant problems and improving lives, students may connect engineering with abstract technical content and unknown applications [13]. Without a sense of personal relevance and broader value, student motivation declines, and engagement in deep learning strategies suffers. In addition, students' difficulties in identifying relevance and value in their technical coursework may contribute to low student retention in undergraduate engineering programs.

We suggest that integrated learning experiences that reflect the interconnected nature of our modern world and enable students to relate *personally* to the societal contexts of technologies may enhance student motivation and the development of lifelong learning skills. The investigation described in this paper explores the connections among motivation, engagement, and pedagogy in undergraduate materials science classrooms. Leveraging self-determination and self-regulated learning theories, we gauge the ways in which projects with varying degrees of disciplinary integration support different motivational orientations and learning outcomes among engineering undergraduates.

2. Research base

Our study draws on prior research in student motivation and self-regulated learning to examine the impact of disciplinary integration on a range of student outcomes associated with lifelong learning. The UNESCO Institute for Education notes that lifelong education is "dependent for its successful implementation on people's increasing ability and motivation to engage in self-directed learning activities" [14]. That is, in order to become lifelong learners, students must first develop the ability to direct their own learning process (self-regulation), as well as the personal agency and intrinsic drive to continually engage in learning (motivation). Prior research suggests that the contextualization that comes from disciplinary integration could play an important role in both self-regulatory and motivational processes. In this section, we provide a brief overview of relevant self-regulated learning and motivation theory, and illustrate how disciplinary integration connects to both.

2.1 Self-regulated learning: definitions and key processes

Self-regulated learners are autonomous, self-motivated managers of their own learning processes, able to identify their learning needs and initiate, monitor, control, and evaluate learning strategies to address these needs [15]. Most current models for self-regulated learning (SRL) have their basis in Bandura's social cognitive theory [16], and all recent SRL models emphasize the importance of both *cognitive/metacognitive* and *motivational* processes that individuals deploy in a learning context [17]. Boekaerts, for example, defines self-regulated learning as "a complex, interactive process involving not only cognitive self-regulation but also motivational self-regulation" [18, p.161]. Zimmerman defines SRL as ". . . self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals" [19, p.14]. Zimmerman [20] emphasizes that in addition to metacognitive skill, students need a sense of self-efficacy and personal agency (i.e., motivation) for success in self-directed environments. In short, SRL requires that individuals develop a set of cognitive/metacognitive skills that they may readily deploy in learning settings, as well as the motivation to engage in learning and the self-efficacy to apply strategies that lead to success.

The cognitive skills required in self-regulated learning involve strategies such as critical thinking and problem solving. Metacognition includes both the self-awareness that enables learners to understand and monitor their own learning processes, and a set of practical skills that equip learners to control their processes in different learning environments [17]. Zimmerman [21] and Pintrich [22] describe SRL in terms of active processes such as planning and forethought, monitoring and controlling, and reaction and reflection. Specific metacognitive strategies important to SRL include recognition of learning needs, development of learning goals and strategies, estimations of task difficulty, self-monitoring and adjustment of learning approaches, time and effort planning and management, attention focusing, self-evaluation of performance, and reflecting on learning processes [19, 23, 24]. In a course context, individuals may also need to manage peer relationships [25] and physical resources [19], and respond to different instructor styles and requirements [26, 27].

Monitoring and controlling one's learning is an effortful process that requires more than metacognitive knowledge and skills—it requires *motivation* [19, 28]. Prior research shows that self-regulated learners have adaptive motivational beliefs, a sense of personal agency [21, 25], and the psychological drive necessary for cognitive engagement and academic achievement [29, 30–32]. Self-regulated learners adopt intrinsic motivational orientations that lead to high self-efficacy, a sense of control, task interest, and positive emotions [33–35]. Self-regulated learners also tend to adopt mastery goal orientations—as opposed to performance goal orientations—that enable them to question their existing mental models and integrate new information in a way that leads to conceptual change [36]. To understand how learners may develop the intrinsic motivation necessary for self-regulated (and eventually lifelong) learning, we turn to self-determination theory.

2.2 Self-determination theory and student motivation

Self-determination theory (SDT) is a needs-based model for motivation that has proved both flexible and insightful over the past few decades [37–39]. SDT proposes that actions, such as engagement in learning, may be described as a continuum that ranges from internal to external or autonomous to controlled, motivations [40]. At one extreme is intrinsic motivation, a state described by interest, enjoyment, inherent satisfaction, and personally endorsed goals. At the other extreme of the continuum is amotivation, a condition that occurs when learners find no value in the learning activity and expect no desirable outcomes. Between the two extremes lies extrinsic motivation, a state in which initiative and regulation of action may be prompted by a range of inputs, from external rewards and punishments (external regulation) to an identification of value in the learning activity (identified regulation). Research shows that not all types of motivation are equally effective for learning [e.g., 39–42]. For example, students with high intrinsic motivation and identified regulation also show enhanced learning engagement, improved self-regulation, more persistence, better performance, and healthier development [e.g., 34, 41–47]. Conversely, desirable learning outcomes often correlate negatively with external regulation and amotivation [42, 48].

SDT posits that individuals will fully engage in learning when three basic needs are satisfied: competence, the development of a sense of mastery or self-efficacy; autonomy, the feeling of choice and control; and relatedness, the building of social connections [39]. Meeting these needs enables students to more easily internalize learning goals and shift their motivations from extrinsic to intrinsic [49]. When students internalize learning goals, they see the value in these goals and gradually accept them as their own. Over time, the learning goals become part of their own identity, and thus much easier to maintain and endorse [40].

Prior research illustrates that motivations are inextricably linked to self-regulated learning strategies [19, 30, 34] and that supporting intrinsic motivation may boost both cognitive and behavioral engagement [34, 50–52]. In essence, meeting motivational needs for autonomy, competence, and relatedness underlies the development of adaptive, lifelong learning skills [53]. Given the well-documented linkage between motivation and desirable learning outcomes, instructors are well served by considering students' psychological needs for competence, autonomy, and relatedness in the classroom. Students gain a sense of competence, and a corresponding boost in motivation and performance, when they see that they are making progress toward learning goals, when they perceive tasks as both challenging and meaningful, and when they receive positive feedback on their work [54]. Students feel autonomous when they have choice, control, and ownership in learning; and this sense of autonomy leads to increased intrinsic motivation, enhanced engagement, improved self-regulation, and better performance [38–40, 47, 48]. Students build a sense of relatedness when they feel an authentic, caring, and respectful connection to others [40]. This sense of relatedness is key to development of the autonomous motivations necessary for self-regulated learning [38–40]. A learning environment oriented at the three goals of competence, autonomy, and relatedness will most effectively foster student self-direction and intrinsic motivation. Within the field of engineering, the goal of relatedness calls out for increased attention because of the dramatic challenges and rewards of successfully connecting technical skills and experiences to personal and social contexts.

2.3 Disciplinary integration and learners' need for relatedness

Engineering students may develop their sense of relatedness both within and outside of the classroom setting. Relatedness is derived from positive connections to other people, so any supportive interaction can help students find meaning in their work [55]. Education research reveals that supportive and collaborative classroom interactions contribute to a students' sense of community and relatedness [24, 56–60]. Connections between learning and the broader societal context can help students identify with a larger community and purpose, which provides positive impacts on individual motivation, engagement, and learning [49, 61–63]. Ford and Smith describe social purpose as an "amplifier" for motivation [64]; and Coyle et al.

highlight how connections of technical studies to broader societal contexts can benefit engineering students [65]. When students engage in engineering tasks with a sense of community and purpose, their motivations become more internalized, and more intrinsic.

Promoting a sense of relatedness through societal connections is particularly important in today's engineering environment [12]. The Grand Challenges for Engineering point to broad human concerns—sustainability, health, and joy of living—and human connectivity as the future of engineering problem solving [66]. Situating engineering studies in a meaningful societal context may also be key to the engagement and retention of women in engineering. Adelman reports that a larger percentage of women students express a need to make a positive societal impact in the practice of engineering compared to their male counterparts [67]; and data from the Academic Pathways Study (APS) show that women in engineering think more globally and broadly about technical information, such as considerations of social and environmental impacts, than their male counterparts [68]. Designing courses that enable students to integrate technical learning with societal contexts could play an important role in diversifying our engineering programs.

Unfortunately, the prevailing focus of many curriculum redesign efforts is the technical content of the curriculum [4], not on meaningful cross-disciplinary interaction [12]. Engineers often focus on disciplinary technical learning and leave societal connections to courses and experiences outside of the engineering core. It is easy to assume that students' general education courses, or even their professional experiences [69], will provide broader context. The arts, humanities, and social sciences offer excellent opportunities for linkages to engineering, but engineers often overlook or fail to productively exploit these opportunities. Non-traditional pedagogies such as project-based learning also provide good opportunities for contextualization, but engineering instructors often focus project work on improving technical and professional skills, not on situating technical studies in the broader societal context. If project work is not effectively contextualized, it may remain difficult for students to find connections between the technical discipline and their individual goals or societal concerns. Jamieson and Lohmann suggest that "providing more relevant learning experiences requires reaching beyond the resources within engineering, science, and mathematics to embrace the practice of engineering in a global context" [12, p. 19]. Sheppard et al. add, "it would be naïve to treat technical and non-technical challenges and opportunities as separable . . . Technical and non-technical issues are inextricably and increasingly linked" [70, p. 231].

This paper presents one approach to connecting students' personal goals with technical studies and broader societal context. We examine a project-based integrated materials science and history of technology course designed to promote strong linkages between technical topics and societal context, and to encourage undergraduate engineering students to view themselves as a part of the larger societal and technological system.

3. Methods

This study examined the motivations, cognitions, and behaviors of undergraduate engineering students in two different project-based, introductory materials science courses. This study was driven by questions regarding the potential benefits of disciplinary integration for a broad range of student outcomes, including motivational orientations, self-regulated learning outcomes, and academic performance. In addition, we wished to examine if integrated projects provide gender-specific benefits that are not realized with non-integrated project-based approaches. To address these questions, we developed several hypotheses:

1. Project-based materials science courses that offer disciplinary integration (via history of technology) would support increases in student motivations and use of self-regulated learning strategies.
2. Compared to non-integrated project-based courses, integrated project-based courses would promote better student motivations and the use of self-regulated learning strategies.
3. Compared to non-integrated project-based courses, integrated project-based courses would provide motivational and self-regulated learning benefits to women students.

3.1 Participants

Our study participants were 114 total undergraduate students enrolled in introductory materials science courses at a small, private, predominantly undergraduate institution in the northeastern U.S. Participants included 63 men (55%) and 51 women (45%) in eight different project-based course sections offered over a three-year period. The group comprised 28 first-year students, 54 sophomores, 20 juniors, and 12 seniors from multiple engineering majors.

3.2 Course environments

The introductory materials science courses were offered in two modes: integrated project based, and non-integrated project based. The integrated course is treated as a single double-sized course from a registration standpoint. One male professor of engineering and one male professor of history served as instructors in the integrated materials science course. The same engineering instructor who taught in the integrated project-based course also served as the instructor in the project-based materials science sections examined in this study.

The integrated and non-integrated course offerings shared the same structure and project-based learning pedagogy. Both project-based materials science courses were divided into three approximately five-week phases, each defined by a major team-based project with a different theme. Projects served as the primary mechanism for learning; and supplemental readings, in-class discussions, presentations, open-ended problems, and other weekly assignments supported the ongoing project work. The succession of three projects provided students in both courses with gradually increasing control over their use of time, selection of resources, and use of learning strategies. The instructors shaped the project constraints in order to introduce basic knowledge, skills, and attitudes in a more structured manner before initiating increasingly open-ended activities as the semester progressed. In all sections of the project-based courses, student work was assessed according to competency-based metrics such as communication, qualitative and quantitative analysis, contextual understanding, teaming, and lifelong learning. In all sections, students engaged in personal goal setting and periodic self-reflection on their learning strategies, motivations, interactions, and outcomes. In addition to their common structure and pedagogy, the integrated and non-integrated courses used the same physical classroom space, a project-based learning studio/laboratory.

The non-integrated courses emphasized technical learning in a real-world context through the study of modern consumer products and processes, while the integrated courses took the contextualization a step further by combining materials science with a humanities and social science course in the discipline of the history of technology. For example, the first project in the non-integrated course asks students to select a modern consumer product (e.g., tools, sporting goods, toys, electronics, household item, apparel), and explore the relationships among material composition, structure, properties, and intended function or performance of the product. In the integrated history-materials science course, students conduct the same modern product analyses, but they also study the material and societal aspects of an ancient civilization's (e.g., Mesopotamia, Egypt, Maya, Greece) counterpart to this product and finish their project with a student presentation in a local art museum. In carrying out a challenging interdisciplinary research project, students in the integrated course develop a foundation of both technical and historical knowledge and skills. In the second project, students in the non-integrated course study structure-processing-property relationships of modern metal alloys. In the integrated history-materials course, teams combine their investigation of alloys with the study of Paul Revere, a well-known American patriot who also aided his country through his silver working, iron casting, bronze bell and cannon casting, and copper sheet rolling endeavors. Students use their growing knowledge of material properties and analytical techniques to reproduce some of Revere's work, examine the efficiency of his processes, and examine the social context of one of his metallurgical endeavors. Students in both courses conclude the semester with a study of present-day materials and their social, ethical, and environmental contexts. Compared to the non-integrated course, however, the integrated course offers more time for deep analysis of the historical context and societal impacts of modern materials technologies.

3.3 Data collection and analyses

This study made use of two survey instruments. The Situational Motivation Scale (SIMS) was used to gauge student motivations at the *activity or task level* periodically throughout the semester. The Motivated Strategies for Learning Questionnaire (MSLQ) was used to gauge students' *course-level* motivational orientations and self-regulatory strategy use near the start (pretest) and end (posttest) of the academic term. The SIMS is a 16-item, Likert-scaled instrument composed of four subscales based on self-determination theory: intrinsic motivation, identified regulation, external regulation, and amotivation [71]. The MSLQ is an 81-item, 7-point Likert scaled, self-report questionnaire designed to measure motivational orientations and the use of learning strategies in college students [72–74]. The MSLQ provides subscale scores in 15 areas. Survey responses are mapped to three sets of subscales: motivational subscales of intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, self-efficacy, and test anxiety; cognitive and metacognitive strategy subscales of rehearsal, organization, elaboration, critical thinking, and metacognitive self-regulation; and resource management strategy subscales of time and study environment, effort regulation, peer learning, and help seeking.

Since both the SIMS and the MSLQ are described as "situational" instruments, several of the SIMS and MSLQ motivation subscales are expected to correlate positively [40, 73]. For example, the MSLQ intrinsic goal orientation, which deals with challenge, curiosity, and mastery, is expected to map to intrinsic motivation (fun, interesting, pleasant) and identified regulation (important, valuable, good to do) on the self-determination continuum. Extrinsic goal orientation should map to external regulation on the self-determination continuum. The MSLQ task value subscale includes aspects of both intrinsic motivation and identified regulation on the self-determination continuum, and the MSLQ control of learning beliefs construct is the opposite of the amotivation orientation described by self-determination theory. The SIMS surveys do differ, however, in their level of generality. The SIMS asks students to consider why they are engaged in a particular *activity*, while the MSLQ asks students to consider their motivational orientations in a *college course.*

The course-level MSLQ data were analyzed via means and standard deviations at pretest and posttest. Overall means and standard deviations for the activity-level SIMS subscales were calculated based on week-to-week data collected throughout the academic term. Within-group temporal changes in MSLQ subscale means were measured using paired samples t-tests. For the posttest MSLQ scores and overall SIMS scores, independent samples t-tests were used to determine differences between the integrated and non-integrated project-based course groups. Gender-specific outcomes within each course were determined based on paired samples t-tests; and gender-based differences between the integrated and non-integrated courses were determined via independent samples t-tests.

Following the procedure commonly used in self-determination research [75], SIMS subscale scores were weighed according to their position on the self-determination continuum and summed to form a self-determination index (SDI) of situational motivation using the following formula: SDI = 2 × (intrinsic motivation) + 1 × (identified regulation) – 1 × (external regulation) – 2 × (amotivation). The SDI values represents students' relative levels of autonomous versus controlled types of academic motivation in the course activities. The range of possible SDI scores is –18 to +18, with higher scores indicative of greater self-determination toward the learning activities. The SDI has been applied in a number of motivation investigations [75–78].

4. Results

This study provided a detailed look at the motivational and self-regulatory strategies of engineering undergraduates in integrated and non-integrated project-based introductory engineering courses. In this section, we present the quantitative findings, and we discuss the results in light of existing educational theory and course design. Tables 1–2 present results for the start-of-term (pretest) and end-of-term (posttest) measures on the MSLQ subscales. Table 3 highlights significant posttest MSLQ differences between the two courses. Table 4 presents the means and standard deviations for the mean SIMS subscale values throughout the entire semester. Results from the gender-based analyses of MSLQ and SIMS responses are shown in Tables 5–7, and significant gender-based results are highlighted in Fig. 3.

Table 1. Descriptive statistics for, and comparisons between, the pretest (start-of-term) and posttest (end-of-term) MSLQ subscale data for the non-integrated course. N = 38

	Start-of-term (pretest)		**End-of-term (posttest)**		
Instrument and Subscale	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**t (pretest vs. posttest)**
MOTIVATIONS					
Intrinsic Goal Orientation	5.14	0.91	5.42	0.97	–2.22*
Extrinsic Goal Orientation	3.32	1.13	3.19	1.18	1.79*
Task Value	5.43	1.08	5.35	1.14	ns
Control of Learning Beliefs	5.57	0.83	5.57	0.73	ns
Self-Efficacy	5.09	1.00	5.30	0.91	–2.00*
Test Anxiety	3.41	1.42	3.22	1.39	ns
COGNITIONS					
Rehearsal	2.92	1.23	2.77	1.05	ns
Organization	3.79	1.30	3.55	1.34	ns
Elaboration	4.95	0.87	4.84	0.84	ns
Critical Thinking	3.93	1.09	4.08	0.98	ns
Metacognitive Self-Regulation	4.30	0.71	4.26	0.83	ns
RESOURCE MANAGEMENT					
Time and Study Environment	4.99	0.80	4.81	0.67	ns
Effort Regulation	5.03	0.94	5.02	1.10	ns
Peer Learning	3.49	1.05	3.88	1.00	ns
Help Seeking	4.64	0.78	4.74	0.88	ns

Table 2. Descriptive statistics for, and comparisons between, the pretest (start-of-term) and posttest (end-of-term) MSLQ subscale data for the integrated materials-history course. N = 76

	Start-of-term (pretest)		End-of-term (posttest)		
Instrument and Subscale	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**t (pretest vs. posttest)**
MOTIVATIONS					
Intrinsic Goal Orientation	5.50	0.80	5.66	0.77	ns
Extrinsic Goal Orientation	3.52	1.38	3.42	1.20	1.76*
Task Value	5.70	0.97	5.80	0.96	ns
Control of Learning Beliefs	5.69	0.89	5.88	0.84	ns
Self-Efficacy	5.33	0.88	5.58	0.80	–2.28*
Test Anxiety	3.21	1.28	3.02	1.38	ns
COGNITIONS					
Rehearsal	2.39	1.00	2.42	1.11	ns
Organization	3.34	1.22	3.40	1.22	ns
Elaboration	4.72	0.85	4.96	0.80	ns
Critical Thinking	4.48	1.11	4.55	1.18	ns
Metacognitive Self-Regulation	4.12	0.64	4.46	0.73	–4.38***
RESOURCE MANAGEMENT					
Time and Study Environment	5.01	1.06	5.09	0.80	ns
Effort Regulation	5.42	0.93	5.31	0.93	ns
Peer Learning	3.20	1.27	3.87	1.26	–4.11***
Help Seeking	4.32	1.14	4.80	1.18	–2.91**

$*p < 0.05$, $**p < 0.01$, $***p < 0.001$, ns = not significant.

Table 3. Descriptive statistics for significant posttest differences between the non-integrated and integrated project-based courses

	Non-Integrated		Integrated		
Instrument and Subscale	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**t**
Task Value	5.35	1.14	5.80	0.96	–2.01*
Critical Thinking	4.08	0.98	4.55	1.18	–2.11*

$*p < 0.05$.

4.1 Student motivations

Within-group analysis of the MSLQ data showed that students in the non-integrated course report significant increases in intrinsic goal orientation and self-efficacy, and significant decreases in their extrinsic goal orientations (Table 1). In the integrated project-based course (Table 2), students report significant increases in self-efficacy, and significant decreases in extrinsic goal orientations. Although students in the integrated course do not report a significant shift in intrinsic goal orientations over time, their intrinsic goal orientations begin quite high (pretest $M = 5.50$, $SD = 0.80$) and remain high (posttest $M = 5.66$, $SD = 0.77$) at the end of the term.

Between groups analysis of the posttest MSLQ responses (Table 3 and Fig. 1) revealed only one significant motivational difference between the integrated and non-integrated courses: task value. Consistent with our hypothesis regarding the potential benefits of disciplinary integration on motivation, students in the integrated project-based course report higher task value at posttest compared to students in the non-integrated course. Examination of the *activity-level* SIMS motivation data (Table 4) reveals several small but significant differences between the two course settings. Students in the integrated materials-history course report higher intrinsic motivation, higher identified regulation, and lower amotivation toward their project activities than students in the non-integrated materials course. External regulation scores are statistically equivalent in the two courses.

Based on the quantitative data, we may draw several conclusions regarding student motivation. First, it appears that both the integrated and non-integrated project-based courses engender the type of motivational responses that we hope students will demonstrate in our learning environments, i.e., high intrinsic motivation and low extrinsic motivation (Fig. 1). It is not surprising that students in these project-based courses show strong internalized drive, given that the instructors designed the courses to help build students' sense of autonomy, relatedness, and competence—key conditions for intrinsic motivation [39, 40]. The highly autonomous motivational responses are apparent at both the activity-level (SIMS) and the course-level (MSLQ). High

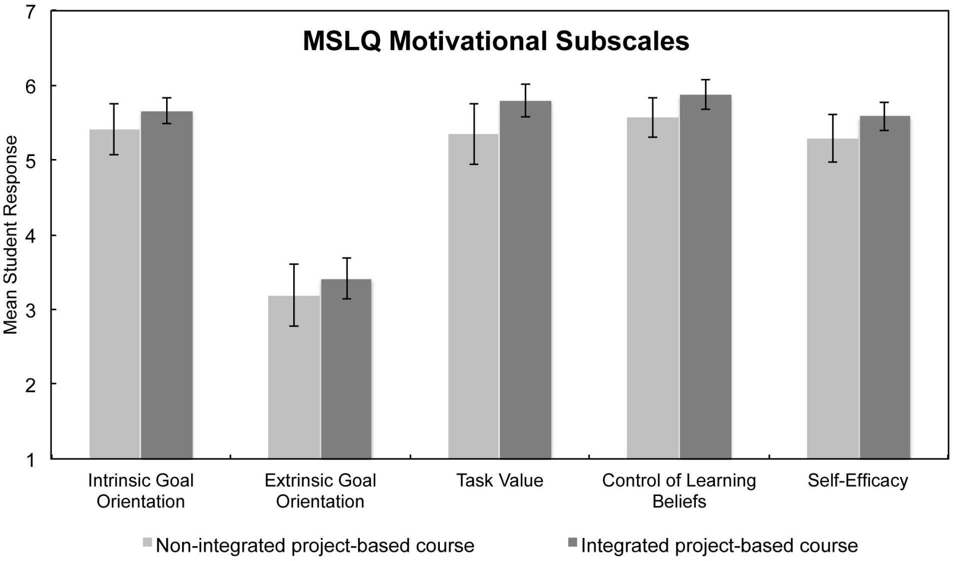

Fig. 1. MSLQ motivational subscale data for the non-integrated project-based and integrated project-based courses. N = 38 for the non-integrated project-based course, and N = 76 for the integrated project-based course. Error bars show 95% confidence intervals.

intrinsic and low extrinsic scores on the MSLQ indicate that students are adopting internalized goals toward the courses *as a whole*. It is possible that environmental cues, past experiences, and learning culture at the small private college may have contributed to the high intrinsic goal orientations at pretest in the project-based courses [76, 79, 80]. Students in the project-based courses could have adopted their high intrinsic goal orientations in response to recognizable course features [79], e.g., a student may say *this is a project-based course, and I know I enjoy this type of learning*, or *this course lets me choose goals and applications that interest me, so I think I'll get a lot out of it*. As early as their first semester, students at the small private college participate in project-based courses that enable them to shape their work around personal interests and goals. By the time they reach the materials science course described here, students have had several experiences with intrinsically driven projects and personalized goal setting; and this may serve to boost intrinsic motivations at pretest.

Maintaining or increasing intrinsic goal orientation scores from pretest to posttest, however, indicates that the learning activities in the project-based courses effectively supported the initially high intrinsic motivation values throughout the academic term.

The SIMS data indicate that when considering the specific course activities during the semester, students' intrinsic motivation and identified regulation are quite high. High scores on the intrinsic motivation subscale of the SIMS instrument indicate that students are engaged in the course because they think the *course activities* are interesting, pleasant, and fun, and because they feel good when doing the activity; while positive SIMS identified regulation values show that students think the course activities are valuable, useful, or important. Coupled to the high intrinsic motivation and identified regulation values are low external regulation and amotivation values. Combining the subscale values provides for a relatively high overall self-determination index (SDI) in both course settings. High SDI values are expected, given the project-based course design aimed at supporting autonomy, competence, and relatedness. Autonomy appears in both courses as increasing student choice, control,

Table 4. Descriptive statistics for, and comparisons between, the SIMS subscale data and self-determination index (SDI) for the integrated and non-integrated courses over the entire semester

	Non-Integrated		Integrated		
SIMS Subscale	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**t**
Intrinsic Motivation	4.91	1.06	5.06	1.10	–2.04*
Identified Regulation	4.87	0.95	4.98	1.00	–1.66*
External Regulation	3.26	1.27	3.34	1.31	ns
Amotivation	1.73	0.84	1.63	0.77	1.85*
Self-Determination Index (SDI)	7.97	4.71	8.49	4.29	–1.69*

and ownership of the project work as the semester progresses. In the first project, for example, students set personal goals, choose a project topic and outline questions to answer, identify strategies to answer their questions, and reflect on their learning progress. In the third course project, students have increased autonomy in selecting resources (materials, supplies, books, articles), establishing a project timeline, and specifying the type of final project deliverable. Several course features contribute to students' sense of competence. Students focus on broad competency development (analysis, communication, contextual understanding) defined by the projects, as opposed to exam performance; and they receive detailed competency-based feedback from their instructors on each assignment. In addition, the complex and open-ended nature of the project tasks likely contributes to competence building: students test and analyze real world products using professional laboratory equipment. Finally, students' sense of relatedness is supported in the project-based courses through close peer and instructor interactions, as well as the real world application of technical topics. Most of the learning in the project-based courses is collaborative: students work with their peers on team projects, and they use their instructors as consultants and coaches. Since every materials science investigation is based in real-world products and processes, students are able to consider technical topics from the perspective of engineering applications. All of these course features serve to make the project activities interesting, fun, and valuable.

A second conclusion from the motivation data pertains to the increases in student self-efficacy in both the integrated and non-integrated project-based courses. Several personal and situational factors emphasized in the project-based classrooms may have influenced the self-efficacy shift [55]. Autonomy afforded by the projects, particularly the personal goal setting and self-reflection, may have encouraged students' perceptions of control over their learning [36, 55, 81]. The gradual shift from instructor-scaffolded projects at the start of term, to student-directed projects near the end of term, may have helped build students' sense of competence in project design and management. Instructors' emphasis on collaborative processes, competency-based assessments, and formative feedback may have quelled fears of failure and built expectancies for success. To improve self-efficacy, students need to be able to view mistakes and errors as a natural part of the learning process, not an indication of incompetence [64]. In the project-based courses, this need may have been satisfied through opportunities to iterate on experimental and analytical tasks, and to edit and re-submit project deliverables for a revised grade. Finally, available "models" for success may have helped to promote self-efficacy [55]. Students in the project-based course had access to posters and videos that provided examples of prior project work; and instructors facilitated informal, in-class critiques of prior student work to help teams design their new deliverables.

Finally, the between-groups analyses support our hypothesis regarding the positive impacts of multidisciplinary integration on student motivation. We expected the contextualization that comes from disciplinary integration of the technical topics to provide an important boost to intrinsic motivation (*the work is interesting and fun*) and identified regulation (*the work is important or valuable*) on the SIMS, and to intrinsic goal orientation and task value on the MSLQ. The education literature indicates that when students are able to see the societal relatedness of their studies, as they do in the integrated course through explicit linking of technology and context, they are more inclined to pursue learning for intrinsically motivated reasons [65]. Small yet statistically significant differences between the integrated and non-integrated courses are apparent on the SIMS subscales, as well as on the MSLQ task value measure. The relatively small differences in student motivation between the integrated and non-integrated courses are likely due to the shared design features across these two project-based environments. Both courses are based on pedagogically sound methods of supporting positive motivations. As described above, students in both the integrated and non-integrated project-based courses have substantial choice and control (autonomy) over their learning topics and processes. In addition, students in both courses are able to identify the practical relevance of their work, as they examine materials in the context of product design, manufacturing, use, and disposal.

Our findings may indicate that applications-centered project work alone can provide high enough levels of autonomy, competence, and relatedness to promote intrinsic motivation. The between-groups analysis of the course-level task value measure and the activity-level SIMS data suggest, however, that engineering students do realize increased personal interest and value in considering technology in context. As prior research suggests, satisfying the need for relatedness is critical for motivation and engagement, and connecting learning to a broader context can have significant positive impacts on motivation, engagement, and learning [38, 40, 64–66]. The tight coupling of technical and contextual analysis found in the integrated projects probably better addressed students' need for relatedness than the non-integrated projects, and thus amplified their intrinsic drive and sense of value and purpose in the learning tasks [65].

4.2 Student engagement in cognitive, behavioral, and contextual self-regulation

Students' engagement in higher-level thinking is a notable and well-documented strength of active learning. Both theoretical and empirical research across many disciplines illustrates that pedagogies such as problem-based learning and project-based learning can help students build important cognitive skills such as problem solving, analysis, and critical thinking [82–84]. Problem-based curricula help students define problems, generate more coherent explanations, think critically, and more effectively transfer their cognitive strategies to new problems [85–90]. In problem- and project-based classrooms, learners actively engage complex and authentic problems, and this overt engagement demands the use of high-level cognitive and metacognitive strategies [91]. In addition, students in PBL and PjBL environments discuss their thinking with others, observe and learn from peer and instructor modeling, and collaboratively create new understandings. These situated social interactions are expected to enhance cognitions in ways that are difficult to achieve in isolated learning activities [92, 93].

Based on the prior research in problem- and project-based learning, and the well-established links between intrinsic motivation and higher-level cognitions [e.g., 34, 35], we hypothesized that students in both project-based course formats would show frequent use of the higher-level cognitive strategies associated with self-regulated learning (elaboration, critical thinking, and metacognitive self-regulation). In addition, we anticipated a reported increase in students' use of higher-level cognitive strategies from pretest to posttest in both courses. In the non-integrated course (Table 1), students reported little use of the lower-level cognitive strategy of rehearsal; moderate use of organization, critical thinking, and metacognitive self-regulation strategies; and relatively high use of elaboration strategies. In the integrated course (Table 2), students reported little use of rehearsal; moderate use of organization and metacognitive self-regulation strategies; and relatively high use of elaboration and critical thinking strategies. While it is the case that students reported more use of higher-level cognitive strategies than lower-level cognitive strategies, the within-course analyses indicated little change in cognitive strategy use from pretest to posttest. In fact, the pretest-posttest MSLQ responses revealed only one difference between the integrated and non-integrated courses on the cognitive and metacognitive subscales. While students in the non-integrated course reported no significant changes in their use of cognitive and metacognitive self-regulatory strategies, students in the integrated course reported an increase in their use of metacognitive self-regulation strategies over time. The positive shift in metacognitive strategy use supports our hypothesis regarding the potential benefits of disciplinary integration to students' development of self-regulated and lifelong learning skills. The integrated course, with its synthesis of multidisciplinary approaches to problem solving, may have prompted the undergraduate engineering students to question more of their own assumptions, consider a broader range of learning strategies, and wrestle with the meaning and significance of their technical efforts.

Between-groups analysis of the posttest subscale means (Fig. 2) revealed higher use of critical thinking skills at posttest in the integrated course compared to the non-integrated course (Table 3). This indicates that the integrated projects prompted more use of strategies that involve applying previous knowledge to new situations, making decisions, playing with ideas and developing new concepts, critically evaluating evidence, assertions, and conclusions [73].

On the resource management strategy subscales, students in the non-integrated course report no significant pretest-posttest differences, while students in the integrated course report significant increases in their use of peer learning and help seeking strategies. Increased peer learning and help seeking in the integrated course may result from increased time shared among students and instructors: the team-based projects in the integrated course are twice the size of those in the non-integrated course.

The increases in metacognition, peer learning, and help seeking in the integrated course support our hypothesis that disciplinary integration provides benefits to students' development of self-directed learning skills. The significantly higher use of critical thinking skills at posttest also indicates that disciplinary integration is serving an important role in prompting high-level cognitive strategy use. At the start of this study, however, we also expected to see additional differences between the integrated and non-integrated courses on the cognitive and resource management subscales. One explanation for the similarities in the use of rehearsal, organization, elaboration, effort regulation, and time and study environmental regulation strategies may lie in the similar designs of the two project-based courses. The same materials science instructor who designed the integrated course also designed the non-integrated course, using the organization and goals of integrated course as a model. The two courses share the same three-project structure, the same technical analysis goals, and identical physical environment. Differences lie in the non-integrated course's reduced emphasis on written communication, rigorous contextual analysis, framing context-related questions, and collection and analysis of historical evidence. It may be that the cognitive and behavioral demands of the two project-based are sufficiently matched to require the development and application of similar cognitive and behavioral strategies. The additional high-level analytical requirements of the integrated course, such as finding and evaluating historical evidence to support an integrated thesis, may be responsible for the higher critical thinking at posttest, as well as the significant temporal increase in metacognitive self-regulation.

4.3 Gender-specific effects

Given the underrepresentation of women in many STEM disciplines, we examined the role of gender in this study of student motivations and self-regulated learning strategies in engineering classrooms. Gender is one of the personal variables that have been related to differences found in attitudes, expectations, motivations, goals, attributions of success and failure, and self-regulation [94, 95]. Prior studies have shown differences in the motivational orientations and responses of women and men, but the patterns of motivation results are inconsistent [96–100]. Some suggest that situating engineering studies in a meaningful societal context may be key to the engagement and retention of women in engineering. Based on prior work in engineering [68–69], we hypothesized that integration of the materials science course with a humanities course in the field of the history of technology would provide some measurable benefits to women undergraduate engineers.

Results from the gender-based analyses are provided in Tables 5–7. Table 5 shows the overall SIMS motivational responses by gender. Table 6 shows the significant MSLQ pretest to posttest changes for men and women within each course setting. Table 7 shows significant differences in women and men's MSLQ posttest scores between the integrated and non-integrated courses.

A comparison of the SIMS situational motivations over the entire term (Table 5) indicates that women are generally more self-determined in their motivations than men in both project-based course settings. The gender-based differences are more pronounced in the integrated history-materials science course, however. In the integrated course, women show significantly higher intrinsic motivation and identified regulation than men in the same course, as well as a significantly lower amotivational response than men. Despite the fact that women also adopt higher external regulation than men in the integrated course, the differences in intrinsic motivation, identified regulation, and amotivation contribute to a significantly higher SDI value for women compared to men.

As shown in the pretest-posttest analysis of MSLQ data (Table 6), women in the integrated project-based course reported significant gains in self-efficacy, elaboration, metacognitive self-regulation, peer learning, and help seeking. Women in the non-integrated version of the course only showed significant increases in their use of critical thinking strategies. Differential outcomes for men and women in each course are also apparent in the

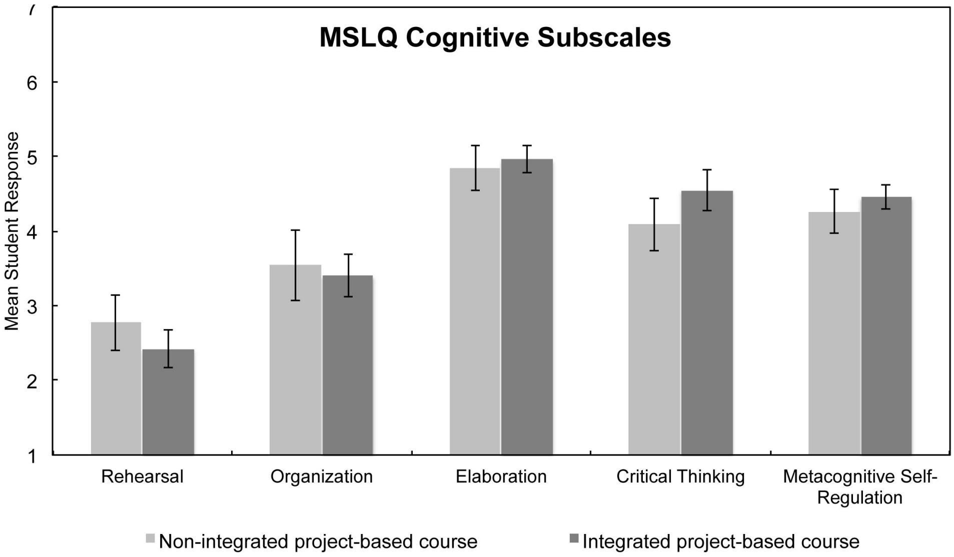

Fig. 2. MSLQ cognitive subscale data for the non-integrated project-based and integrated project-based courses. N=38 for the non-integrated project-based course, and N=76 for the integrated project-based course. Error bars show 95% confidence intervals.

Table 5. Descriptive statistics for SIMS subscale means and self-determination index (SDI) over the entire semester for women and men in the non-integrated and integrated materials science course

Course Format and SIMS Subscale	**WOMEN**		**MEN**		
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**t**
NON-INTEGRATED COURSE					
Intrinsic Motivation	5.02	1.03	4.73	1.08	2.43*
Identified Regulation	4.86	0.91	4.90	1.03	ns
External Regulation	3.27	1.22	3.29	1.37	ns
Amotivation	1.63	0.71	1.92	1.01	–2.84
Self-Determination Index (SDI)	8.35	4.14	7.28	5.54	ns
INTEGRATED					
Intrinsic Motivation	5.24	1.07	4.95	1.10	3.34***
Identified Regulation	5.09	0.87	4.91	1.07	2.27*
External Regulation	3.51	1.24	3.23	1.34	2.65**
Amotivation	1.48	0.64	1.73	0.83	–4.32***
Self-Determination Index (SDI)	9.09	3.80	8.10	4.54	2.98**

*p < 0.05, **p < 0.01, ***p < 0.001, ns = not significant.

pretest-posttest findings. In the integrated project-based course, men report increased use of metacognitive self-regulation and peer learning strategies, while in the non-integrated course men report *decreases* in metacognitive self-regulation and rehearsal strategies. A between-groups, gender-based analysis of the significant posttest differences (Table 7 and Fig. 3) shows that women in the integrated course report higher task value, self-efficacy, and critical thinking strategy use compared to women in the non-integrated course. Men in the two courses, however, show no significant posttest differences on the MSLQ subscales. In short, the gender-based analyses support our hypothesis regarding the benefits that contextualization through integrated course approaches can provide to women in engineering.

4.4 Limitations and future research directions

The results of this investigation highlight several measurable differences between integrated and non-integrated courses. In interpreting the findings of this study, however, some limitations should be considered. First, although the sample sizes in this study allowed for identification of statistically significant trends within and between the two course formats, these results are nonetheless limited to two project-based courses in a single institutional setting. An expansion of this research to other integrated and project-based courses in additional institutional contexts would reveal whether the findings reported here are idiosyncratic to specific settings, or more broadly generalizable. A second limitation of this study relates to the inability of quantitative analyses to fully capture the complex-

Table 6. Descriptive statistics for the significant pretest to posttest changes in MSLQ subscale means for women and men in the non-integrated and integrated materials science courses

	Start-of-term (pretest)		**End-of-term (posttest)**		
MSLQ Subscale	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**t**
NON-INTEGRATED COURSE					
Women (N = 21)					
Critical Thinking	3.58	0.74	3.91	0.94	–2.40*
Men (N = 11)					
Rehearsal	2.91	1.26	2.30	1.12	2.28*
Metacognitive Self-Regulation	4.39	0.97	3.99	1.06	3.58*
INTEGRATED COURSE					
Women (N = 26)					
Self-Efficacy	5.27	0.88	5.58	0.75	–2.16*
Elaboration	4.49	1.03	4.90	0.70	–2.81**
Metacognitive Self-Regulation	4.00	1.09	4.42	1.03	–3.60***
Peer Learning	3.24	1.12	3.86	1.29	–2.99**
Help Seeking	4.30	1.28	4.78	1.29	–2.53**
Men (N = 40)					
Metacognitive Self-Regulation	4.13	0.64	4.39	0.71	–2.89**
Peer Learning	3.38	1.38	3.89	1.13	–2.81**

*p < 0.05, **p < 0.01, ***p < 0.001, ns = not significant.

Table 7. Descriptive statistics for significant differences between posttest MSLQ subscale means for women and men in the integrated and non-integrated courses

	Non-Integrated (N = 22)		**Integrated (N = 30)**		
MSLQ Subscale	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**t**
Women					
Task Value	5.42	1.13	6.00	0.81	–2.04*
Self-Efficacy	5.13	0.89	5.64	0.72	–2.21*
Critical Thinking	3.95	0.93	4.61	1.12	–2.30*
Men					
(no significant differences)					

*$p < 0.05$.

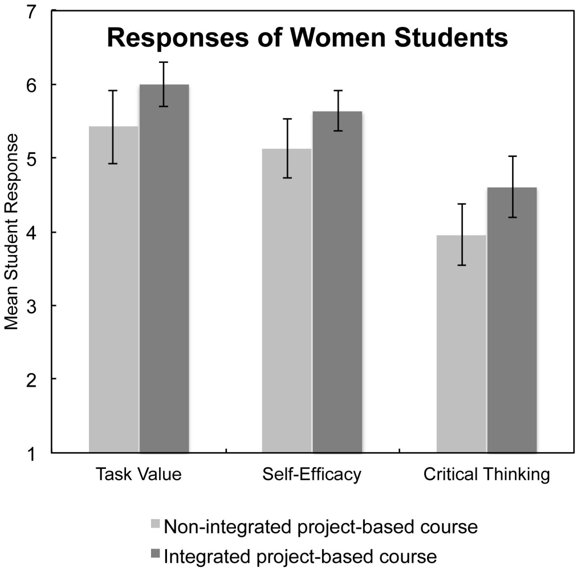

Fig. 3. Significant posttest differences in MSLQ responses for women students in the non-integrated project-based course (N = 22) and integrated project-based course (N = 30). Note that no differences in MSLQ responses were measured for men at posttest in the two courses. Error bars show 95% confidence intervals.

ity of real classroom situations. The quantitative approach enabled us to provide a detailed characterization of motivation and self-regulated learning skills in project-based course environments; and the quantitative findings are generally well supported by existing theoretical models and prior empirical work. To fully understand and explain certain outcomes and to better connect the effects of context-specific variables on motivation and self-regulation, however, further qualitative analyses would be helpful. Of particular interest are the moderate mean scores and lack of significant pretest to posttest increases in some of the MSLQ high-level cognitive outcomes—a finding that is not entirely consistent with educational research that shows high levels of cognitive engagement with student-centered pedagogies. Since the MSLQ survey was designed with more conventional college classrooms in mind, it may be that some of the MSLQ survey prompts are difficult for students to interpret in the context of project-based activities. Examining the specific factors that influence student engagement in high-level cognitive strategy use in the project-based activities could help clarify the role of instructional design in supporting specific self-regulated learning skills.

5. Conclusions

The findings in this study indicate that disciplinary integration offers significant benefits to student motivation and self-directed learning skills. Compared to a non-integrated project-based materials science course, students in an integrated materials science-history of technology course showed higher activity-level intrinsic motivation and identified more value in their learning tasks. Students in the integrated course also reported gains in certain self-regulated learning strategies that were not realized in the non-integrated course, as well as higher use of critical thinking strategies compared to students in a non-integrated course. The gender-based analyses revealed significant differences in the motivational orientations and self-regulatory strategies of women and men in the integrated and non-integrated courses. Compared to the non-integrated project-based course, the integrated project-based experiences appear to support higher self-efficacy and valuing of the learning tasks, as well as improved cognitive and contextual self-regulation, among women.

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