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The Effect of Different Active Learning Environments on Student Outcomes Related to Lifelong Learning*

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Calls for educational reform emphasize the need for students to develop a capacity for lifelong learning. Lifelong learners may be characterized as curious, motivated, reflective, analytical, persistent, flexible, and independent—traits that are critical for success in today's globalized economy. Stakeholders in engineering education recognize that students' development of the capacity for lifelong learning is vital for their success and that instructors play a critical role in influencing such outcomes. However, there is a critical lack of research in this area. This research investigates how instructor choices of active learning pedagogies affect student outcomes related to their development as lifelong learners at four institutions. We measure student self-regulated learning (SRL) in response to a range of active learning pedagogies and suggest that SRL is a proxy for lifelong learning in the context of the formal classroom. We consider the research question 'In what ways do pedagogical choices made by engineering instructors assist students to develop attitudes and behaviors associated with self-regulated learners?' The results of this mixed-method design suggest that students' development as self-regulated learners involves a complex interplay between many factors that are influenced by faculty choices in the course design.

Keywords: autonomy; lifelong learning; self-regulated learning; self-directed learning

1. Introduction

Calls for reform in engineering education emphasize the need for student-centered learning approaches that aid development of broader skills such as a capacity for lifelong learning [1–5]. In its call to action, the National Research Council's Board on Engineering Education asked educators to 'instill in students a desire for continuous and lifelong learning to promote professional achievement and personal enrichment' [2]. The National Academies, the American Society for Engineering Education, the National Science Foundation, and ABET assert that students must develop the skills and attitudes that foster continuous learning in order to succeed in our accelerating global environment [1, 3, 4]. As the accreditation board for engineering programs, ABET essentially challenged engineering educators to teach not only engineering content but a way of sustaining professional development after students no longer have the benefit of a formally structured college curriculum.

Lifelong learners are autonomous, self-motivated managers of their own learning processes. They are able to identify their learning needs and initiate, monitor, control, and evaluate learning strategies to address these needs [6]. Achieving the long-term outcome of lifelong learning requires that learners gain increasing ability and motivation to direct their own learning processes while they are still in a structured classroom environment [7]. Gaining this competence demands instructor guidance, encouragement, assistance, and challenge along the way. To effectively foster students' propensity toward lifelong learning, faculty need to be aware of the role that classroom environment can play in aiding students to emerge as lifelong learners well before they graduate.

One way instructors play a key role in supporting lifelong learning is through their choice of pedagogy. Student-centered pedagogies have been found to support the development of a range of skills and attitudes associated with lifelong learning [8–11] Such pedagogies offer students opportunities to exercise choice [12]. Student-centered environments are not all equivalent, however, and few studies have examined how different student-centered environments may affect outcomes related to lifelong learning.

This investigation examines how instructor choices in course design affect a range of student outcomes related to their development as lifelong learners. Using a theoretical basis in self-regulated learning (SRL) theory [13], we measure behavioral

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and affective outcomes of undergraduate engineering students at four different institutions throughout the U.S. We propose that in order to be a 'lifelong learner,' one must first be a 'self-regulated learner,' and that the capacity for self-regulated learning must be nurtured in much the same way as one's content knowledge is nurtured. Self-regulated learners do not easily emerge in environments that do not support autonomy and growth of the student [14–17]. Our study therefore focuses on courses that make use of student-centered pedagogies and that offer varying levels of autonomy support and student self-regulation of learning. We examine courses that fall into two distinct groups based on their position within the active learning continuum (Fig. 1). Courses in the first group use simple active learning techniques combined with lectures while courses in the second group employ problem- and project-based learning approaches. We examine the effect of these different learning environments on proxies for lifelong learning such as self-regulated learning attitudes and strategy use.

2. Research base

2.1 Defining self-regulated learning

Self-regulated learning has been defined by Boekaerts as 'a complex, interactive process involving not only cognitive self-regulation but also motivational self-regulation' [18, p.161]. Pintrich [19] defines four assumptions of self-regulated learning (SRL) models. He suggests that SRL means that learners participate in their own learning, control and regulate their thinking, motivation, behavior and environment, monitor their progress toward their goal, and that these mechanisms mediate between the person, the context, and achievement (pp. 387–388). Zimmerman emphasizes that in addition to metacognitive skill, students need a sense of self-efficacy and personal agency for success in self-directed environments [20].

Based on this description of self-regulated learning, successful development of students as self-regulated learners requires a careful balancing of motivational, cognitive, behavioral, and contextual factors in the classroom. To effectively support development in all of these areas, instructors must guide their students through an increasingly autonomous process of planning, self-monitoring, and reflection.

2.2 Role of instructor in self-regulated learning

Instructors are well positioned to aid students' transition from controlled to autonomous learning through creation of classroom climates and support structures for student self-regulation [21, 22]. In an overview of the literature, Vermunt and Vermetten [12] found that with regard to influencing students' regulation strategies, the greatest distinguishing factor was the dimension of internal versus external control of the learning process, or the amount of autonomy instructors provide to students with regard to learning processes.

Vermunt and Vermetten suggest that different teaching strategies can be distinguished, and they range from 'strongly teacher-regulated to shared regulation to loosely teacher-regulated' (p. 363). The more loosely teacher-regulated the context is, the more the student needs to regulate; the more strongly teacher-regulated the context, the less need for student regulation. However, how a student navigates this complex of internal and external regulation may depend on both the instructor's teaching strategies and the student's learning strategies [12]. Where they complement each other, a state of congruence exists; when they are not compatible, Vermunt and Verloop [23] describe the outcome as 'friction', which can have the positive outcome of the student learning new approaches to thinking and learning or conversely in the negative outcome of decreasing student engagement and motivation to learn. The teacher who intends to help students internalize self-regulatory behaviors needs to be cognizant of the students' affective and cognitive states and monitor the effect of the instructional context on the students, adjusting and adapting when needed.

Clearly, the importance of transferring ownership of the learning process to students is essential if students are to feel confident in their abilities to operate independently as learners over time. Ryan and Deci [24] refer to this as the psychological need for autonomy. Students exercise autonomy when they make choices and act on those choices. Teachers support student autonomy when they recognize the student's perspective and goals, and when they allow students to make choices that are in concert with those perspectives and facilitative of the students' goals. The degree to which individuals feel competent to make those decisions rests in part on being in an autonomy supportive environment. Black and Deci, in their investigation of undergraduate students in organic chemistry, revealed that students' perceived instructor support of autonomy related to improved perceptions of their own competence, interest and enjoyment, and ability to self-regulate [25].

Stefanou, Perencevich, DiCintio, and Turner [26] proposed that it is possible to differentiate ways that teachers support autonomy in the classroom, suggesting three different forms of autonomy support are evident in classrooms: organizational, procedural, and cognitive. According to Stefanou et al. [26], it is the support of cognitive autonomy, defined as 'encouraging student ownership of learning' (p. 101), that leads to deep psychological and emotional involvement and investment in learning that is characterized by Ryan and Deci [24] as self-determined behavior. Of the many factors that contribute to the student response in autonomous learning environments, perhaps the least explored are the contextual or environmental factors. In 2000, Pintrich noted that 'there is a clear need for more descriptive, ethnographic, and observational research on how different features of the context can shape, facilitate, and constrain self-regulated learning' [27, p. 493]. Studies have shown that students' positive perceptions of their assigned tasks and instructors' autonomy support can lead to increases in intrinsic motivation, self-regulation, perceived competence, interest, engagement, and academic performance [21, 28, 29], but the connections between these student perceptions and the instructors' choices in course design and classroom environments remain unclear.

2.3 Active learning instructional practices

Active learning is an umbrella term that encompasses a wide variety of instructional practices. It refers to anything a faculty member asks students to do in class, other than listening and taking notes, so long as that activity is related to the desired learning [30, 31]. As such, it spans a range of instructional approaches. Fig. 1 provides a representation of the active learning continuum. On one end of the continuum are simple, short activities that faculty can easily integrate into a traditional lecture class with the goal of making it more engaging and educationally effective. These include such things as 'think-pair-share' activities, one-minute papers and brainstorming activities [30, 32, 33]. In these types of activities, the instructor generally establishes the learning goals and provides a clear structure for the learning tasks, yet students will typically experience some autonomy in the learning process. For example, students may choose specific strategies to approach a problem, explore multiple solutions, connect the activities to their own interests, and manage their interactions with classmates.

On the other end of the active learning continuum are approaches such as project-based (PjBL) and problem-based learning (PBL). While some studies highlight differences between problem-based and project-based learning, an overview of the literature suggests that they are more alike than different, and in fact are often difficult to differentiate in practice [31, 34, 35]. In both PjBL and PBL, students are confronted with realistic, open-ended problems that drive the desired learning. In addition, both PBL and PjBL place significantly more responsibility on students to become active drivers of their own learning, requiring them to identify the problem, set goals, locate appropriate educational resources, determine their own methodology for solving the problem, manage timelines and teaming interactions, and self-assess their progress. The following section examines how the different student-centered learning environments, from simple active learning with interactive lectures to those of PBL and PjBL, may influence students' development as self-regulated learners.

2.4 The effect of student-centered instruction on self-regulated learning

A number of environmental and personal factors influence students' development as self-regulated learners [36–38]. Zimmerman [39] suggests that the most important social/environmental elements affecting self-regulated learning are those related to students' interactions with teachers. Butler and Winne [40] suggest that teachers who adopt student-centered instruction are more likely to promote self-regulated learning. They developed a model for SRL that emphasizes the type of monitoring and formative feedback steps that are an integral part of many active learning environments. For example, one-minute papers [41] stimulate students to monitor their learning. Many other classroom assess-

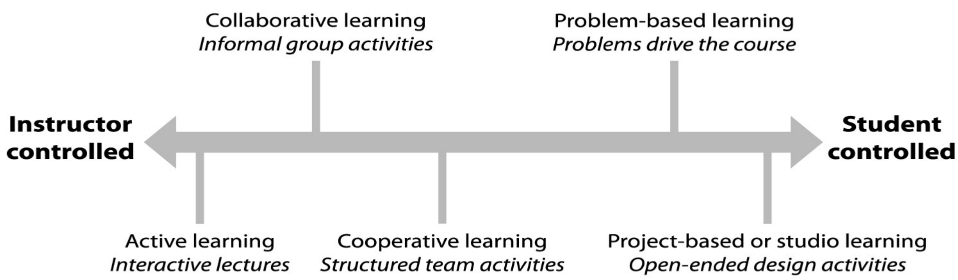

Fig. 1. The active learning continuum.

ment techniques employed in active learning provide frequent and timely formative feedback to students [30–33, 41].

Similar assertions that active learning can promote SRL are echoed by other researchers. Ng et al. [9] show that student-teacher interactions emphasizing active learning (student-centered learning, feedback provided by teachers and strategy instruction) correlated with gains in self-regulated learning outcomes. Bose and Rengel [42] also suggest that student-centered instruction promotes self-regulated learning, emphasizing the role of formative assessment in developing self-regulatory behavior. They also consider that peer feedback and self-reflection, both often a part of active learning classes, should help develop self-regulated learning.

While these studies emphasize the connection between active learning and SRL, more student-centered forms of active learning such as PBL and PjBL have received special attention. Several authors have suggested that problem-based learning has the potential to develop skills and attitudes related to self-regulated learning because of the responsibility that it places on students with respect to the learning process [43–45]. Sungur and Tekkaya [10] found that PBL promoted gains relative to traditional instruction for 10th grade biology students in several outcomes related to self-regulated learning, including intrinsic goal orientation, task value, use of elaboration as a learning strategy, critical thinking, metacognitive self-regulation, effort regulation and peer learning. Galand et al. [11] examined the impact of a new two-year PBL curriculum on engineering students relative to the previous traditional program and found that PBL students reported using more adaptive self-regulation strategies and more deep-processing learning strategies while devoting greater effort, but found no significant difference between cohorts on motivational beliefs.

We note that there appears to be a need to add to these limited empirical studies regarding the effect of active learning on students' self-regulated learning. Few studies provide empirical data on the impact of various forms of active learning techniques on outcomes related to self-regulation, especially with engineering students, with little or no existing empirical research with engineering students on the effect of PBL/PjBL on self-regulated learning compared to other active learning strategies. Since designing problem- and project-based learning environments requires a more significant change from traditional instruction than other active learning techniques, they are more difficult for faculty to adopt. Therefore, it seems worthwhile to examine whether PBL/PjBl lives up to its promise to enhance self-regulated learning not only compared to traditional instruction but relative to other student-centered, active learning strategies.

3. Methods

In this study, we employed a mixed-method triangulation research design where both qualitative and quantitative data were collected during a defined research period and analyzed simultaneously. A case study design constituted the qualitative methodology; a non-experimental comparative design defined the quantitative methodology. Sampling of students was a sample of convenience in that students who were enrolled in the courses were invited to participate. Sampling of courses was purposeful in that particular courses were chosen because they exemplified a specific type of pedagogy along the active learning continuum in Fig. 1. In this section, we explain our methods, summarize the courses examined, and describe the survey instruments. Quantitative and qualitative analysis will follow in Sections 4 and 5, respectively.

Quantitative data consisted of student responses to the Motivated Strategies for Learning Questionnaire (MSLQ), a measure of motivation and learning strategy usage, within the first week of classes and again at the end of the term, and the Learning Climate Questionnaire (LCQ), a measure of perceived teacher support of student autonomy at the end of the term.

Qualitative data consisted of transcribed recordings of student-instructor interaction during class sessions and recordings of student-student interaction within and outside of class.

3.1 Participants and courses

Participants in this study included four engineering faculty and 176 undergraduate students enrolled in 10 courses in the 2009–2010 and 2010–2011 academic years at four different institutions. The institutions include a small, private specialty engineering school with a gender balanced student body and small student-to-faculty ratios, two small private liberal arts institutions with typical engineering gender ratios and small student-to-faculty ratios, one with a College of Engineering and the other with a Department of Engineering, and a large, public university with a College of Engineering and a gender and student-to-faculty ratio typical of large engineering programs. The faculty teach in various areas of engineering including mechanical, chemical, electrical, and materials science.

The courses involved in this study are summarized in Table 1. We distinguish PBL and PjBL in terms of their overall goal being mainly to learn new content (PBL) or to integrate existing knowledge

Table 1. Course information and demographics for student participants in this study

		Student participants						
Course title	**Pedagogy***	**Male**	**Female**	**First year**	**Soph**	**Junior**	**Senior**	**Total**
Heat transfer	PBL	12	4		0	16	0	16
Thermodynamics	Lec/Active	18	2		0	0	20	20
Failure analysis	PjBL	1	9		3	5	2	10
Metals and alloys	PjBL	3	6		3	1	5	9
Statics	Lec/Active	10	8		14	3	1	18
Circuits	Lec/Active	10	6		14	2	0	16
Materials science	Lec/Active	11	11		8	12	2	22
Failure analysis	PjBL	6	9		10	4	1	15
Senior design	PjBL	12	4		0	0	16	16
Statics	Lec/Active	15	8	1	22	0	0	23
Materials science	PBL	5	6	3	0	4	4	11
		103	**73**	**4**	**74**	**47**	**51**	**176**

* PBL: Problem-based learning PjBL: project-based learning Lec/Active: lectures with active learning.

(PjBL). The lectures with active learning (Lec/Active) included activities in the classroom such as think-pair-share, using clickers to answer and discuss conceptual questions, and having students work on problems in ad-hoc teams. In general, the Lec/Active courses are more teacher-directed than the PBL or PjBL courses.

3.2 Instruments

3.2.1 Motivated Strategies for Learning Questionnaire (MSLQ)

The MSLQ [46] is a Likert-scaled self-report instrument used to measure college students' motivational orientations and use of different learning strategies. Scores range from 1 to 7 with 1 meaning 'not at all true of me' and 7 meaning 'very true of me'. Mean scores on 15 subscales are reported. Six of these address motivation: intrinsic motivation, extrinsic motivation, task value, control of learning beliefs, self-efficacy, and test anxiety. Nine are learning strategies: rehearsal, elaboration, organization, critical thinking, self-regulation, time and study environment, effort regulation, peer learning, and help seeking. The MSLQ is designed to be used in whole or in part. For this study, the text anxiety subscale was eliminated because tests were not given in all courses. Also, the wording in several items was modified to better reflect the learning environments of the courses. Specifically, references to 'study' were replaced with 'prepare,' and 'lecture' with 'class discussion.' Students completed the 76-item MSLQ survey at the beginning and end of the term using a web-based survey system. The MSLQ has high internal consistency, reliability, and predictive validity [47, 48]. Internal reliability estimates, similar in strength to those reported in the MSLQ manual, were found on the basis of the data included in this study, ranging from 0.7 to 0.9 for all but two subscales which were only slightly lower.

3.2.2 Learning climate questionnaire (LCQ)

The LCQ [49] was used to characterize the degree of autonomy support students perceived in the learning environment in each class. The LCQ is a 15-item, 7-point Likert self-report scale that is one of the Perceived Autonomy-Supportive Climate Questionnaires developed by Ryan and Deci based on self-determination theory (SDT) [24]. The LCQ is typically used to describe the learning environment in a particular class at the university level as autonomy-supportive or controlling. Students responded using a web-based survey system at the end of the term. Scores range from 1 to 7 with 1 meaning 'strongly disagree' and 7 meaning 'strongly agree'. A higher average score represents a higher perception of autonomy support. The Cronbach alpha internal reliability estimate for the LCQ was 0.94.

4. Quantitative analysis

Paired sample t tests were used to test for significant changes among students' self-reported motivation and use of learning strategies over the course of the term within each of the active learning environments. A one-way analysis of variance was used to test for differences among students' reported motivation and use of learning strategies between the learning environments at the end of the term. Analysis of covariance was used to control for pre-test difference when found. Students in each learning environment were asked to provide an indication of the autonomy support they perceived from their instructors using the Learning Climate Questionnaire (LCQ) and their responses were compared at the end of the course using an independent groups t test.

Analysis of the MSLQ results at pre-and post-course show significant temporal differences for student outcomes on several subscales of the

Table 2. Statistically significant pre- to post-course MSLQ results for PBL/PjBL (N = 77)

	Pre (start of term)		Post (end of term)		
MSLQ subscale	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**p-value**
Metacognitive self-regulation	4.39	0.78	4.54	0.80	0.049
Peer learning	4.22	1.01	4.51	1.22	0.022
Time/study environment	5.26	0.73	5.04	0.79	0.004

Italics indicate that the subscale's values were higher for post-course. Note that no statistically significant pre/post-course MLSQ results were obtained for Lec/Active courses.

Table 3. Statistically significant post-course (end-of-term) MSLQ results for PBL/PjBL vs. Lec/Active pedagogies

	PBL/PjBL (N = 77)		Lec/Active (N = 99)		
MSLQ subscale	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**p-value**
*Help seeking**	5.14	0.88	4.47	1.22	0.001
Elaboration	4.99	0.85	4.64	0.97	0.013
*Critical thinking**	4.63	0.99	3.88	1.24	0.037
Time/study environment	5.04	0.79	5.32	0.86	0.032
Extrinsic goal orientation*	3.79	1.42	5.27	0.91	0.008

* Pre-course differences observed, so ANCOVA was used to compute post-course differences. For others, ANOVA was used to compute post-course differences.
Italics indicate that the values were higher for PBL/PjBL courses.

MSLQ for those students in PBL/PjBL courses. Those pre-post differences that were statistically significant are shown in Table 2. No statistically significant differences were found for students in the Lec/Active courses on any other subscales or for any other subscale for those in the PBL/PjBL courses. Note that students in PBL/PjBL courses showed an increase in metacognitive self-regulation and peer learning and a decrease in time/study environment.

End-of-term student responses on the MSLQ and LCQ were compared for PBL/PjBL and Lec/Active courses using Analysis of Variance (ANOVA). The statistically significant MSLQ results are summarized in Table 3. Analysis of Covariance (ANCOVA) was used to control for differences present in student responses on specific MSLQ subscales at the beginning of the term. Subscales that exhibited significant pre-course differences and were consequently compared using ANCOVA are indicated by an asterisk (*) in Table 3. These MSLQ results at post-course show that students in the PBL/PjBL courses reported greater use of the learning strategies of help seeking, elaboration, and critical thinking, while the students in the Lec/Active courses reported higher scores in the MSLQ subscales of time/study environment and extrinsic goal orientation.

Metacognitive self-regulation is a strategy related to the awareness and control of cognition. This involves processes of planning, monitoring, and regulating learning activities. Peer learning refers to learning strategies involving interactions with other students in class. The subscale of time and study environment assesses students' self-reported ability to manage their time and study environment through mechanisms such as scheduling and planning. It also relates to their ability to use study time effectively. Help seeking involves getting support from others, either peers or the instructor, to help one learn. Elaboration is the act of building internal connections between topics. It involves connecting new information with prior knowledge. Critical thinking refers to the students being critical of new information and trying to develop their own ideas to help solve problems. Extrinsic motivation is a goal orientation characterized by a focus on external rewards such as grades, competition or evaluation by others.

Table 4. LCQ results for PBL/PjBL vs. Lec/Active pedagogies at end of term

PBL/PjBL (N = 68)		Lec/Active (N = 98)		
Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**p-value**
6.06	0.98	5.63	1.00	0.006

The means and standard deviations of the LCQ results for this study are summarized in Table 4. Students in the PBL/PjBL courses reported statistically significant higher degrees of autonomy support in these environments.

5. Qualitative analysis

Because our project sought to connect autonomy support and self-regulated learning, the transcriptions are used to highlight instances of autonomy support. The qualitative data collected was used to explore possible explanations for the gains found in specific categories of the MSLQ between PBL/PjBL and Lec/Active courses and in students' perceptions of instructor support for their developing autonomy. In this section, we focus on the key quantitative results, those where there were statistically significant differences between the two types of courses, and use the instructor and student voices to explore why these outcomes might have been achieved with these different pedagogies. Rather than doing an exhaustive analysis of the qualitative data, we focused on specific examples from one PBL/PjBL and one Lec/Active course. Because the transcripts contained language specific to the different engineering disciplines represented in this study, the team determined that the course instructor should do the first coding of the transcripts. Following the initial coding, a second team member coded the same transcript and finally the team discussed the coding to arrive at a consensus.

We provide a description of the course written by the instructor and describe the context for the transcription excerpt presented. We then illustrate what the instructor is trying to accomplish in the course and show examples of how that manifests in instructor comments where appropriate. Samples of student-student interactions are reported that show how the course design might have influenced the MSLQ and LCQ results.

5.1 PBL/PjBL

As shown in Tables 2 and 3, for the PBL/PjBL courses, students reported higher use of metacognitive self-regulation and peer learning at the end of the course and higher use of help seeking, elaboration and critical thinking as compared to the Lec/Active students.

CHEG300 *Heat Transfer* is a required course for Chemical Engineering juniors and is taught in a PBL format. Lectures are 'student driven' meaning that they generally only occur in response to students' posted questions. Therefore, the pattern of class activity is best described as a mix of lectures and group work. On days when there are no questions (or few questions) the bulk of the class period is spent in small-group work, with the instructor acting as a facilitator, responding to student questions or interviewing students about their progress. During these open periods, there is significant faculty-student interaction (either student initiated or faculty initiated) and significant student-student interactions within their groups while they work on the assigned problems. These open sessions were recorded and transcribed as part of the qualitative data collected.

The instructor assigns students to teams of 3 or 4 members. All laboratory and homework assignments are completed in teams, including the open-ended problems that give the course its PBL structure. Students are allowed to identify in advance one student with whom they do not wish to work, based on previous experience working together. Efforts are made to avoid isolating underrepresented groups such as women or minorities within the team.

Students work in teams for the full semester. They write team contracts in the first week that set expectations for teamwork and how to handle any disputes or problems that arise, including how and when they would like the instructor to participate in conflict resolution. Students are formally asked to provide anonymous peer evaluations several times over the course of the semester, with the final input used to adjust individual student grades based on their individual contribution to team efforts.

The instructor also meets periodically with each team individually in laboratory for approximately 30 minutes, answering technical questions and soliciting student feedback on topics such as workload and stress levels. These meetings provide significant, personalized faculty-student interaction. Some of these sessions were also recorded, transcribed and coded, though none are presented in this paper.

5.1.1 Context for transcript

Students have just been given a new design problem that involves designing both a wet and a dry cooling tower for a power plant that will be sited in southern California. Earlier in the semester, they learned the concepts necessary to size a dry cooling tower, so that problem is in essence a review. They have recently received some lectures on evaporative cooling, the mechanism used to provide cooling in a wet cooling tower. They have also been given some external links that provide more specific background information on wet cooling towers, which they are encouraged to read independently. With these resources, they are asked to come up with an appropriate design for both a wet and a dry cooling tower for a given situation, determining for themselves what they need to know and how to acquire that information.

The course is designed to promote self-regulated learning, in part by providing students many opportunities for cognitive autonomy, as illustrated in the session below. A primary feature of the course is the emphasis on cognitive autonomy support, illustrated here by the instructor not providing his solutions to problems but asking students to tell him how *they* would go about solving the problem and then receiving feedback on their own ideas.

Instructor: Ok, what I want to do today is to get you started on the cooling tower design . . . It's not a trivial problem. It has multiple steps. You're asked *to design a dry cooling tower and look at the designs and calculations for a wet cooling tower and to sell your ideas. There are some bonuses available on that project for those people that are interested in pulling your grade up a little bit. What I want to do today is to turn you loose in your groups and kind of circulate around. So, if you would, either pull up the homework assignment on Blackboard or get out a hard copy if you have a hard copy and tell me how you would go about solving this problem.*

Many of the instructor-student interactions are similarly structured to encourage and support the students' cognitive autonomy. In the exchange below, the students are trying to understand what is inside the cooling tower, which is called 'fill'.

Male 2: What's the fill?

Instructor: Sorry?

Male 2: The fill?

Instructor: So you're the designer for the cooling tower and you can fill it with anything that you want but you're trying to do evaporative cooling and this is a classic heat mass transfer or separation problem. If you look in the distillation column downstairs what do you see? Or if you're doing gas absorption or liquid extraction in your ESP [equilibrium stage processes] class what do you fill those columns with?

Male 2: Packing?

Instructor: What's the point of the packing?

Male 2: To create surface interaction.

Instructor: You got it. So all of the separation problems are mass transfer problems. They have something to do with, I have something that is in there and I want to take it out. That happens at a certain rate and the faster that I can make that happen, the smaller, cheaper, more compact my piece of equipment can be. So I'm trying to reduce the surface area for volume. So the point of packing is to distribute the water over a large surface area so it's contacting lots of air so I get lots of evaporative cooling in a small volume.

Male 2: So this would be packing in here?

Instructor: Again, there's lot of ways of doing it and you're the designer. You will pick how you want to design it—but packing is not atypical.

What we see in these interactions is the instructor reminding students that, as designers, they have the choices. There are not one but many solutions to the problem. Rather than dictating a single solution, the instructor refuses to point the students in a single direction but places the responsibility for making choices on the students. In addition to supporting the students' cognitive autonomy, the exchange provides another example of the instructor trying to promote elaboration, by asking the students to see connections between this process and similar processes such as gas absorption and liquid extraction, which are covered in another class that the students are currently taking with another instructor in the department.

Significant class time is provided for students to independently explore the cooling tower problem. This independent exploration is also connected to critical thinking, which on the MSLQ is linked to students developing their own ideas. Some of the student-student interactions are transcribed below. Since the problem has just been introduced, the interactions begin showing that students are not certain about the differences between wet and dry cooling towers.

Male 2: I don't get the difference between dry and wet. What's the difference?

Female 1: Wet you have evaporative cooling instead of just the dry air temperature.

Male 2: Well no but, like, design-wise I don't get what's happening that makes it different? Where's the water?

Female 1: Yeah, I'm still trying to get a visual image too.

Male 2: What's the dry one? How does that one work?

Male 1: Isn't just the dry one that fan?

Male 2: Can we just ask him for a design sketch?

Female 1: Yeah let's do that.

This exchange illustrates how the PBL pedagogy encourages the gains in specific subscales of the MSLQ seen in PBL courses. The exchange above clearly illustrates peer learning or students learning from each other by asking questions. It also illustrates help seeking in that both students recognize the need for help and independently decide to seek that help from the instructor. Finally, the exchange illustrates metacognitive self-regulation, a key component of self-regulated learning. Here the students recognize when they do not understand something—in this case, the difference between wet and dry cooling towers—and they take steps to address that misunderstanding by asking questions. (Note that the students' suggestion to ask the instructor for a 'design sketch' is not the same as asking for the solution, but rather a clarification of the problem in order to help them answer their own questions.)

Another exchange by these same students is shown below and illustrates other interactions that relate to self-regulated learning.

Female 1: Ok, let's just do the wet cooling tower first.

Male 2: For one of my design options I want to do something that they showed us, which was if we put our cooling tower at like the edge of where like a lake or stream is. We can draw water out from the ocean and then the hot water that goes back out we will put into a hot water reservoir which will be in the center of that lake. The only thing is sometimes they might argue, some people might say that it affects the fish or the life cycle because like the water is too warm. However according to the Swedish people, they say that the fish like it and the birds like it, more birds come than normally would come.

Female 1: The fish like it?

Male 2: The fish and birds like it.

Male 2: So for technical design, this is a big problem.

Female 1: Yeah.

Male 2: We have a week to do it. Basically we have to design all of our piping and stuff like we did for the first problem.

Female 1: It's like everything combined.

This exchange illustrates several key features of the learning environment. The second comment (by Male 2) illustrates cognitive autonomy in that the student is choosing the direction to take the project. In addition, it illustrates critical thinking, both in the student bringing their own ideas to address the problem and in reflecting critically on some of the criticisms that have been made about the release of warm water into the environment. Finally, the exchange provides two examples of elaboration or students building connections. Male 2 connects the problem he is working on with some reading that he's done about similar problems in Sweden. Similarly in the final comment, Female 1 draws the appropriate connection between this assignment and material covered throughout the previous weeks of the semester.

This collection of exchanges illustrates why PBL courses such as this might have promoted gains in the MSLQ subscales of metacognitive self-regulation and peer learning and why PBL might be more effective at encouraging students to use the strategies of help seeking, elaboration, and critical thinking compared to the Lec/Active courses. In addition, this exchange highlights elements of cognitive autonomy.

5.2 Lec/Active

For the Lec/Active courses, students reported more effective use of time and study environment and were more extrinsically motivated.

ENGR 311 *Engineering Materials Science* is a junior level class although for this particular offering, about half the students were sophomores. This is a required course for Electrical Engineering (EE) and Industrial and Systems Engineering (ISE) students. This course is taught in an active learning format including in-class problem solving in teams and cooperative learning homework teams [30].

In a typical class period, prepared handouts are projected using a TabletPC and Classroom Presenter [50] software. The instructor writes on the slides and encourages the students to actively participate verbally and by writing in their own notes on these handouts. Most periods include an active learning exercise where the problem statement is included in the handout along with needed supporting information (e.g. data on material properties).

Students are told to 'turn to a helpful neighbor' and work together in ad-hoc groups of 2 or 3 while the instructor walks around the room and checks in with groups, asks questions or answers questions. Some of these class sessions were recorded and transcribed as part of the qualitative data collected.

The instructor assigns students to cooperative learning homework teams of 3–4 students using a similar approach to team formation as described for the PBL course in Section 5.1. As part of the team contract, this instructor requires a specified weekly meeting time. Students are assigned team roles (described on the syllabus) which rotate for each assignment. The recorder must write the entire solution. The checker is in charge of checking the final submission. The instructor explicitly tells the students that she expects that the final solution will be presented clearly with detail on the problem solving process, not just the answer. Some of these homework sessions conducted outside of class were recorded and transcribed as part of the qualitative data collected.

5.2.1 Context for Transcript

During this recording, a group of three male junior EE students are working on their homework outside of class. This is the seventh homework assignment so the students are comfortable with the process and expectations by this point in the semester. For most of this session, the student team is working on a cold work design problem where they need to specify a multistep process to meet certain mechanical requirements such as tensile strength, ductility, and material shape. An important part of this is specifying the percentage cold work that must be done in each step. A similar problem was done as an active learning exercise in class.

Male 1: We need to have that 840 [psi for tensile strength] and it has to be at least 12% [elongation, a measure of ductility].

Male 3: So that would also be like 22% [cold work] or whatever.

Male 1: But that won't get you down to the specified size all in one step. So you have to do separate steps. So what I did was, so I said, I took this 10 as the final and worked backwards. I started with the third thing, so 22% and the one size that we need minus ten and ended up getting that and then the size that you need to go down to that is 11.3 mm. The problem is that you can't go from 15 down to 11.3 in one step without it breaking also. So I basically just did 15 to 13 and then 13 down to 11.3.

Male 2: Why don't you. . .

Male 1: See this is where you get 15 minus 11.32, 43%.

Male 2: Why don't you. . .I don't think that you can choose like N [sic]

Male 1: Yeah you can. As long as you anneal it between every time. It retains the ductility and it just remains that same size.

Male 2: Why don't you like cold work again with 22 [%]?

Male 1: I could have done that. I just picked somewhere intermediate because these two steps, it didn't matter, I guess 24.1 and 29 but it doesn't matter where these get you because these steps are the only steps that get you the tensile strength.

Near the beginning of the session, Male 1 is taking the lead in describing his choices and his solution. His teammates are questioning him and he defends his choices with good reasoning and states that there are other possible solutions. This is evidence of cognitive autonomy.

A little later in the discussion, Male 2 asks for more explanation for the solution.

Male 2: So why didn't you go with the 22% again? I know that like, the final cold work percent but why didn't you just go get it again with 22%? She [the instructor] may ask you.

This displays the extrinsic motivation of the students to meet the instructor's expectations. In this case, the additional explanation is good practice.

The same students go on discussing the solution to the earlier problem in this exchange.

Male 2: If you're doing it in this way, you need 4 steps instead of 3, so that's like one less step.

Male 1: Yeah this is as little steps as you could possibly do with the numbers that I have.

Male 2: Yeah but explain that to her [the instructor], that with the 22% you will get 4.

Male 1: You mean that if you kept doing 22%?

Male 3: I bet that if you did it this way and you got like 24% instead, you know the numbers are going to be pretty similar.

Male 1: I didn't do it by plugging in the percent, I did it by just plugging in some amount that I thought would be safe to get down to.

Male 3: Yeah that's fine.

Male 1: And it says it's as good as it can go because you get here and you know that you can't do this in one step and it needs to be split up into two steps.

Male 2: Yeah let's go for it. Ok, cool.

This exchange displays cognitive autonomy as they explore different ways to solve this problem. Extrinsic goal orientation is also evident in their reference to the need to have good explanations for the instructor. Again, although their motivation is driven by the instructor's expectations, this is helping these students to develop habits of good learning such as engaging with the material, thinking about the problem-solving process and carefully presenting their solution.

This collection of exchanges illustrates why this course might have promoted gains in the MSLQ subscales of extrinsic goal orientation and highlights elements of cognitive autonomy.

6. Discussions

The different student outcomes in these courses suggest that pedagogical design differentially influences development of certain aspects of self-regulated learning and, by extension, lifelong learning. In particular, different pedagogical approaches emphasize or require students to engage in different learning strategies which can lead to promoting different learning outcomes for students. In this section, we discuss the student outcomes that showed a significant change from pre- to post-course in the PBL/PjBL courses (Table 2), student outcomes that were different in the two types of active learning course environments (Table 3), and student perceptions of autonomy support (Table 4). Finally, we interpret the findings in light of existing educational theory and prior empirical findings.

As noted in Section 4, SRL-related outcomes measured by the MSLQ subscales were relatively stable over one academic term. The Lec/Active courses showed no significant changes from pre- to post-course, while the PBL/PjBL courses showed significant temporal increases in metacognitive self-regulation and peer learning, and a significant temporal decrease in time/study environment. The relative stability of student motivations and cognitive/behavioral strategy use over one academic term may be explained in part by the short time over which the student outcomes are measured in this study, and by considering the framing of the MSLQ survey prompts. The MSLQ instrument is designed to measure motivational orientations and the use of learning strategies at the course level, and it asks students to consider the course as a whole when responding to the survey prompts. It may be the case that students adopt certain motivations and cognitive/behavioral strategies at the start of the term that are based on their past experiences at the institution, with the particular instructor, or in courses that share a similar structure or approach to those examined in this study. For example, previous research indicates that environmental cues may activate particular motivational responses [51]. Students in either the Lec/Active or PBL/PjBL courses may adopt motivational (or cognitive or behavioral) strategies in response to recognizable features of the environment. A student in a lecture course, for example, may examine the course structure, instructor expectations, and pedagogical practices, and adopt strategies that have proven effective in similar settings in the past. Unless something in the course environment causes an incompatibility or sufficient 'friction' with a strategy that worked in the past, students do not need to change their learning approaches [23].

In contrast, the PBL/PjBL courses do appear to have provided enough friction with regard to learning approaches to spark some significant changes in students' cognitive and behavioral strategy use. The pre-post increases in metacognitive self-regulation and peer learning in the PBL/PjBL courses may reflect the higher demands on students to self-regulate their learning in these non-traditional settings compared to what they typically see in their undergraduate courses. In the PBL/PjBL courses, students are expected to continually reflect on their thinking and identify what they do not know, and to seek out help from peers and from the instructor to make progress on open-ended problems. In that context, more gains in certain self-regulatory strategies might be expected.

In addition to these gains, however, students in the PBL/PjBL courses also show a decrease in their use of time and study environment regulatory strategies, likely due to the nature of 'studying' in a PBL/PjBL course, as discussed below. This study also revealed several significant post-course differences between the Lec/Active courses and the PBL/PjBL courses. Students in the Lec/Active courses reported higher time and study environment management and higher extrinsic goal orientation than students in the PBL/PjBL courses. Students in the PBL/PjBL courses, on the other hand, reported higher use of the help seeking, elaboration, and critical thinking strategies compared to students in the Lec/Active courses. The potential impacts of course design on each of these outcomes are discussed in the following paragraphs.

Time and study environment. In the Lec/Active learning courses, students have weekly homework assignments which force them to develop a weekly routine of engaging with the material for such courses. They likely considered this when responding to the MSLQ questions such as 'I have a regular place set aside for studying,' 'I make sure I keep up with the weekly readings and assignments for this course' and 'I often find that I don't spend very much time on this course because of other activities (reversed).' In fact, in the Lec/Active learning course discussed in Section 5.2, the students were asked to specifically designate a weekly meeting time. The instructor's motivation for establishing this mandatory weekly meeting time is that finding a time to meet is the most often cited problem for students doing group work [52]. In addition, the structure provided in a Lec/Active course by the cooperative learning homework teams, active learning exercises in class, and instructor's expectations, may also contribute to gains on the time and study environment subscale. Helping students develop good study habits and skills assists them in their development as independent learners [16].

It may initially seem surprising that students self-report lower scores regarding time and study environment in PBL/PjBL classes. Since time and study environment refers to students' ability to plan and manage their time to solve open-ended problems, one might expect these scores to increase. However, we believe that this observed decline is related to the phrasing of the questions on this subscale of the MSLQ. For example, many PBL/PjBL courses have no weekly readings, assignments, or, in some cases, even exams. Thus questions that refer to these activities would likely be rated low by the students. It would be interesting in future analyses to examine item-by-item responses on this subscale to determine if the observed pattern could be explained in this way.

Extrinsic goal orientation. Extrinsic goal orientation refers to student participation in learning tasks for reasons such as rewards, grades, performance, evaluation by others, and competition [46, 47]. When students adopt extrinsic goals, their behaviors are externally regulated to attain rewards or to avoid negative consequences such as low grades or feelings of guilt or shame in front of their instructor, parents, or peers. As expected, students in the PBL/PjBL reported significantly lower extrinsic goal orientation than students in the Lec/Active courses. These findings are consistent with motivation theory, which predicts that increases in student control will provide for a decrease in externally controlled behaviors [53]. As noted above, students in the PBL/PjBL courses have significant control over their learning processes. In some of these courses, for example, individuals articulate personal learning goals and the project teams identify the research questions they wish to answer for each project. Further, the use of contextually rich problems and projects in the PBL/PjBL courses adds a layer of authenticity to the experience through which these students construct understanding [54]. Authentic activity is considered a critical component in instruction in helping students become less focused on external reasons for participation and more focused on intrinsic reasons. In the Lec/Active courses, the instructor's expectations help students develop valuable skills in organization, presentation, and explanation which enhance their ability to learn on their own. Additionally, it is important to remember that the path along the self-determination continuum is a developmental journey [16]. Students can be expected to first be motivated by external consequences, then move to identification with their instructor's values, and finally to accept those values as their own. Perhaps the PBL/PjBL course structure simply pushes students along this continuum at a faster pace.

Help seeking. Both the Lec/Active and PBL/PjBL courses emphasize peer learning through a range of mechanisms, such as class discussions, project presentations, formal study groups, and think pair-share activities.

The PBL/PjBL courses, however, also provide a learning environment in which the use of active help seeking strategies is essential for success in the courses. In the PBL/PjBL courses, students are faced with open-ended problems that require technical knowledge or conceptual understanding that is well beyond the information available in textbooks or lecture notes. For example, to learn about a complex analytical technique, a PBL team may need to interview a disciplinary expert, e.g., a faculty member from another department, or find other students on campus with prior experience with the technique. To acquire materials, understand a manufacturing process, or clarify design constraints, a PBL/PjBL team may need to directly contact vendors or glean information from a corporate liaison. In these situations, students must quickly develop mechanisms for identifying and communicating with appropriate external constituencies who may offer help. Such learning environments contain many of the features of cognitive apprenticeships where scaffolding, mentoring, and the assistance of slightly more able peers are key features [55].

Elaboration and critical thinking. Students in the PBL/PjBL courses reported higher use of elaboration and critical thinking strategies than students in the Lec/Active courses. The MSLQ's elaboration subscale emphasizes the building of connections among various sources of information, relating course material to prior knowledge, apply concepts to other courses, and using strategies such as paraphrasing, summarizing, creating analogies, and generative note-taking. The critical thinking MSLQ subscale refers to 'applying previous knowledge to new situations in order to solve problems, reach decisions, or make critical evaluations with respect to standards of excellence.' In the PBL/PjBL courses, students frequently find it necessary to apply new knowledge directly to hands-on projects, or to draw on knowledge or skills they developed in previous courses to solve open-ended problems. For example, the examinations in one of the PBL courses in this study ask students to apply technical concepts from the textbook readings directly to their chosen project topic. The design or analytical tasks in other PBL courses require student teams to integrate technical theory with empirical data from lab experiments, output from quantitative analytical models, and input from user interviews and discussions with faculty or industry professionals. Once they integrate this information, students need to apply it to reach design decisions or to choose an analytical approach. PBL/PjBL courses provide the opportunity to apply abstract concepts and principles which, according to Billing [56], facilitates the transfer of skills beyond the demands of the inert environment of traditional teacher-centered classrooms. Elaboration and critical thinking strategies are a necessary part of this process.

Metacognitive self-regulation. The MSLQ's metacognitive self-regulation subscale focuses on the planning, monitoring, and regulating of cognition—processes that are explicitly emphasized in many of the PBL/PjBL course environments. As such, a greater use of metacognitive self-regulatory strategies in the PBL/PjBL courses compared to the Lec/Active courses is expected. Many of the PBL/PjBL courses examined in this study include personal or team-based goal setting, as well as monitoring and reporting of progress on the project task.

These courses also require students to conduct periodic self-evaluations and peer-evaluations, and to submit mid-term and end-of-term written self-reflections on their learning goals, processes and outcomes. These assignments are intended to trigger metacognitive awareness through continual monitoring and adjusting of the learning process.

Learning climate. In addition to the differential reporting of motivational, cognitive, and behavioral outcomes on the MSLQ subscales, the Lec/Active and PBL/PjBL courses also showed significant differences in students' perceptions of the autonomy supportiveness of the learning environment as measured by the LCQ. The LCQ includes a number of prompts that relate to the instructor's provision of autonomy (e.g., *I feel that my instructor provides me choices and options.*), and to the instructor's ability to interact with students in an motivationally and emotionally supportive manner (e.g., *My instructor conveyed confidence in my ability to do well in the course.* and *I feel that my instructor cares about me as a person.*). The PBL/PjBL settings offer more choices and student control than the Lec/Active courses, and thus their higher LCQ scores are not surprising [16]. Although statistical analyses indicate a difference in students' perceptions of the autonomy supportiveness of PBL/PjBL versus Lec/Active learning environments, we note that the LCQ scores were generally high for both types of course environments. This indicates that, regardless of pedagogy, the learning environments in all courses examined in this study effectively promote a sense of autonomy support among students.

Limitations. In interpreting the findings of this study, several limitations must be considered. First, samples of convenience were used for both the courses and for the students. Future work should consider the benefits to be gained by using random samples of engineering courses and engineering undergraduate students. Second, while the Motivated Strategies for Learning Questionnaire is one of the most heavily used instruments for measuring college student self-regulated learning behaviors, the instrument does not seem to adequately address student-centered pedagogies such as those employed in this study and is particularly problematic for problem-based and project-based learning. Attention could be given to developing instruments that better reflect these emerging pedagogies. Third, student report may not provide a complete picture of student behavior. While qualitative analyses in this study attempted to provide examples of evidence of self-regulated learning behaviors and autonomy, direct observations of student behavior and interviews of the students following those observations might yield information that will inform practice more directly. Finally, the coding of classroom transcripts was focused only on the significant findings from the quantitative analyses of MSLQ survey data. Future work would benefit from the development of a more formal coding system through which the transcripts can be evaluated for instances of student self-regulated behaviors and teacher support of autonomy.

7. Conclusions

We investigated student outcomes for a variety of active learning pedagogies in ten courses taught by four different instructors. Students in the PBL/PjBL courses showed temporal increases in metacognitive self-regulation, a key characteristic associated with life-long learning. Students in the PBL/PjBL courses also showed increases in peer learning and a decrease in time/study environment.

Looking at statistically significant differences at post-course between PBL/PjBL and Lec/Active courses, PBL/PjBL pedagogies tend to promote more critical thinking, help seeking and elaboration as strategies for learning while Lec/Active pedagogies tend to promote more effective use of time and study environment. At the end of the terms, students in the Lec/Active courses were more extrinsically motivated. The higher post-course scores in critical thinking, help seeking, and elaboration in PBL/PjBL courses correlate with higher autonomy support as measured by the LCQ. These outcomes may also be considered to be consistent with the goals of the specific pedagogies used (problem and project-based learning). Further evidence for these gains can be seen in the analysis of the qualitative data from students' conversations with instructors and among themselves.

The work presented here is part of a larger study. Future quantitative analysis will also consider variables such as gender and student's school level. More detailed analysis of the qualitative data is underway with the goal of integrating these results more fully with the quantitative data presented here. This mixed-methods approach should provide for rich, contextualized descriptions of what instructors and learners do, how instructors and students relate to each other, and how students view their classrooms. Analysis of these results can help inform other engineering educators about effective ways to help students develop as lifelong learners.

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