AC 2011-1601: STUDENT LIFELONG LEARNING OUTCOMES FOR DIF-FERENT LEARNING ENVIRONMENTS

Susan M. Lord, University of San Diego

Susan M. Lord received a B.S. from Cornell University and the M.S. and Ph.D. from Stanford University. She is currently Professor and Coordinator of Electrical Engineering at the University of San Diego. Her teaching and research interests include electronics, optoelectronics, materials science, first year engineering courses, feminist and liberative pedagogies, and student autonomy. Dr. Lord served as General Co-Chair of the 2006 Frontiers in Education Conference. She has been awarded NSF CAREER and ILI grants. She is currently working on a collaborative NSF-funded Gender in Science and Engineering project investigating persistence of women in engineering undergraduate programs. Dr. Lord's industrial experience includes AT&T Bell Laboratories, General Motors Laboratories, NASA Goddard Space Flight Center, and SPAWAR Systems Center. She served as the President of the IEEE Education Society in 2009 and 2010.

Candice Stefanou, Bucknell University

Candice is an Associate Professor of Education at Bucknell University. Her teaching interests are in applied measurement and assessment and educational psychology. Her research interests are in motivation and classroom environments.

Dr. Michael J. Prince, Bucknell University
John Chen, California Polytechnic State University

John Chen is an Associate Professor of mechanical engineering at Cal Poly, which he joined in 2008. Prior to that he was on the faculty at Rowan University.

Jonathan D. Stolk, Franklin W. Olin College of Engineering

Student Lifelong Learning Outcomes
For Different Learning Environments

Abstract

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. Engineering educators and ABET recognize that students' development of such aptitudes 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. We are conducting a study investigating how instructor choices affect student outcomes related to their development as lifelong learners. This research examines a variety of undergraduate engineering courses at four different institutions with four different instructors employing a range of active-learning pedagogies. Our theoretical framework comes from the literature on self-regulated learning recognizing the critical need for lifelong learners to be self-regulated. In this paper, we consider the research questions "In what ways do pedagogical choices made by engineering instructors assist students to develop attitudes and behaviors associated with self-regulated learners?" and "What are students' perceptions of the degree to which the different pedagogies support their development as independent learners?" Student outcomes are measured using the Motivated Strategies for Learning Questionnaire (MSLQ), a widely used self-report instrument intended to measure motivation and use of different learning strategies. Dependent groups t-tests were used to compare within-group differences from pre- to post-course. Significant differences were found for student outcomes on several subscales of the MSLQ. The learning environment, specifically the students' perceptions of faculty support for their growth as independent learners, was measured using the Learning Climate Questionnaire (LCQ), and we interpret the MSLQ results in light of these results. The different ways that students change in different courses suggest that different pedagogies influence development of certain behaviors related to lifelong learning. Our preliminary results suggest that students' development as self-regulated learners involves a complex interplay between all these factors.

Introduction

Calls for educational reform emphasize the need for student-centered learning approaches that aid development of broader skills such as a capacity for lifelong learning[1,2,3,4,5]. Engineering educators as well as ABET recognize that students' development of such a capacity is vital for their success in today's global and rapidly changing engineering environment.[4,5,6] However, the current emphasis in the engineering education community is on assessing students' lifelong learning abilities, rather than on understanding the relationship between instructor practices and lifelong learning outcomes. Lifelong learners are autonomous. They are 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. Such learners may be characterized as curious, motivated, reflective, analytical, persistent, flexible, and independent.[7] Designing learning environments that foster students' growth as autonomous, self-motivated managers of their own learning, however, is not a simple task. With its introduction of program outcome (i) "a recognition of the need for, and an ability to engage in lifelong learning," as a requirement for all engineering graduates, 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 formal

educational opportunities on a regular basis. To effectively foster a propensity toward lifelong learning, faculty need to be skillful in facilitating pedagogies that engage students in being self-motivating and self-monitoring, in essence to be self-directed. This requires faculty to be sensitive to and understand student attitudes and behaviors in different educational settings, and be aware of the roles that classroom environments can play in aiding students' development of those skills and attitudes associated with the ability to initiate, monitor and evaluate one's own learning over time.

ABET's challenge to engineering educators to foster the ability of our students to engage in lifelong learning is not one that is easily measured during the time the students are under our guidance. Descriptions of a lifelong learner are consistent in many respects with descriptions in the education literature of a self-regulated learner, with one major difference being in the temporal aspect of where these attitudes and behaviors are exhibited. For the lifelong learner, the curiosity, autonomy, and self-management occur oftentimes in the workplace where the individual is constantly accepting the challenge to learn and stay abreast of current developments in his or her field. The concept of the self-regulated learner is typically associated with someone who is still a student, responding to learning goals set by an instructor. While surveys of alumni provide a litmus test of how engaged engineering graduates are in continuous learning, they do not tell us much about what engineering educators can do that will foster the types of student behaviors in the classroom that may serve as indicators of what lifelong learning looks like after college. With access to such information, engineering educational practices can be more explicitly designed to foster development of the range of behavioral and affective learning outcomes necessary for a disposition toward lifelong learning.

We are in the midst of a study investigating how instructor choices affect a range of student outcomes related to their development as lifelong learners. This study examines a variety of undergraduate engineering courses at four different institutions throughout the U.S. We chose the theoretical basis of self-regulated learning (SRL)[8] as a platform for the linkage between the behavioral and affective outcomes of college student development and development as a lifelong learner because of their shared focus on autonomy and self-management. We suggest that in order to be a "lifelong learner" one must first be a "self-regulated learner", and to be a self-regulated learner one must have opportunities to act autonomously. The propensity to self-initiate, to sustain interest, to seek out challenges or to persist in the face of a challenge, and to evaluate the results of one's efforts must be nurtured in much the same way as one's developing content knowledge base is nurtured. Lifelong learners do not simply emerge. They are guided, encouraged, assisted, and challenged to be autonomous prior to the time when they must be independent. Likewise, self-regulated learners do not easily emerge in environments that do not support autonomy and growth of the student.[9,10,11,12] Student-centered pedagogies support the development of this type of lifelong learning. Such pedagogies offer students opportunities to exercise choice, with such choice occurring on a continuum from a more teacher-controlled classroom to a more student-controlled one.[13] Examining how pedagogies that differ in level of student control affect students' perceptions of their own self-regulated attitudes and behaviors may provide us with insight as to how different course structures can be used to maximum advantage.

In this paper, we seek to add to the knowledge base in engineering education by examining a range of engineering educational environments characterized by their relative focus on being teacher-directed or student-directed, and studying the relationship between these types of classroom environments and proxies for lifelong learning such as self-regulated learning behaviors and attitudes. We propose that in order for graduates to be lifelong learners they must have

opportunities to develop the thinking, behaviors, and motivations that characterize lifelong learners while in the process of becoming an engineer. We believe that opportunities that foster the development of such traits are found in environments that support student ownership of their learning over time. Thus we are conducting an investigation of how pedagogical choices influence student attitudes and behaviors related to self-regulated learning in engineering classrooms.

Research Base

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"[14](p.161). Alternatively, Zimmerman8 defines SRL as "…self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals" (p. 14). Pintrich[15] defined four assumptions of self-regulated learning (SRL) models. The four are (a) learners are active participants in learning, constructing meaning from information available in the environment in combination with what they already know, (b) learners can control and regulate aspects of their thinking, motivation, and behavior and in some instances their environment, (c) learners compares their progress toward a goal against some criterion and this comparison informs the learner of the status of progress toward the goal, and (d) self-regulatory mechanisms mediate between the person, the context, and achievement (pp 387-388). Zimmerman emphasized that in addition to metacognitive skill, students need a sense of self-efficacy and personal agency for success in self-directed environments.[16] From these descriptions, it is clear that self-regulation involves many forms of autonomy.

Based on this description of self-regulated learning, it is clear that 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.

Role of Instructor in Self-Regulated Learning

Clearly, instructors play a critical role in effectively promoting student development through their instructional choices and their interactions with students. Instructors are well positioned to aid students' transition from controlled to autonomous learning in different ways through creation of classroom climates and support structures for student self-direction.[17],[18] Instructors can design learning experiences that include features such as offering students: opportunities to link learning to personal interests and goals, the chance to make choices and be in control, and significant time for self-evaluation and self-reflection. Further, instructors can provide appropriate scaffolding and feedback that helps students progress toward autonomous learning patterns. 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 competence, interest and enjoyment, and ability to self-regulate.[19] Opportunities for individual choice, control, authority, and responsibility appear to be important elements in the academic achievement and the psychological development of students.

Vermunt and Vermetten[13] refer to teaching functions that promote student learning and self-regulation. Their work suggests that different teaching strategies can be distinguished, and they range from "strongly teacher-regulated to shared regulation to loosely-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, according to Vermunt and Vermetten.[13] Where they complement each other, a state of congruence exists; when they are not compatible, Vermunt and Verloop[20] describe the outcome as "friction", which itself has two forms—constructive and destructive. Constructive friction occurs when the incompatibility between teaching and learning strategies results in the student learning new approaches to thinking and learning. Destructive friction can occur when teachers take over for students who are already employing learning strategies the teacher feels will not lead to a positive outcome or when the students do not have the level of self-regulatory skills that the teacher assumes they have. Both situations result in students using thinking and learning strategies on their own, but destructive friction may result in affective responses from students that negatively impact engagement and intrinsic motivation. The teacher who intends to help students internalize self-regulatory behaviors and to know which strategies to use when needs to be cognizant of the students' affective and cognitive states, and constantly monitor the effect of the instructional context on the students, adjusting and adapting when needed.

Ownership of one's own learning is a goal that many instructional contexts hope to activate. The importance of transferring the 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[21] 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 their goals. Who is making decisions about what will be learned, how it will be learned, for what purpose and to what extent it will be learned is at the heart of discussions surrounding autonomy. More specifically, Ryan and Deci's[21] self-determination continuum, which ranges from amotivation to extrinsic regulation (controlled) to intrinsic regulation (autonomous), speaks directly to this experience of "ownership" with regard to motivation to learn. The degree to which individuals internalize the values of their environment depends on how connected and competent they feel, but for the values to become fully a part of the person, support for autonomy is especially important.[22]

Stefanou, Perencevich, DiCintio, and Turner[23] proposed that it was possible to differentiate ways that teachers support autonomy in the classroom. They proposed three different forms of autonomy support evident in classrooms: organizational, procedural, and cognitive. According to Stefanou et al.[23], 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 those whom Deci and Ryan[22] would call self-determined. Their work suggested that perhaps there are different student outcomes depending on the prevailing form of autonomy support, with the most intellectually significant ones perhaps associated with cognitive autonomy support. It is fairly well-established that the more student ownership there is in learning, the more engagement there will be; and the more engagement there is in learning, the deeper the learning.[24] However, creating learning environments that encourage student ownership is a critical issue that continues to confront and challenge teachers from kindergarten through graduate school.

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, Paul R. 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".[15] More than a decade later, the need remains. 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[18,25,26], but the connections between these student perceptions and the instructors' choices in course design and classroom environments remain unclear.

Methods

We are in the midst of a large study investigating how instructor choices affect a range of student outcomes related to their development as lifelong learners. This paper focuses on examining the following research questions:

1. In what ways do pedagogical choices made by engineering instructors assist students to develop attitudes and behaviors associated with self-regulated learners? Are there instructor practices and behaviors that lead students to report greater involvement in and ownership of their own learning and to different choices of learning strategies?

2. What are students' perceptions of the degree to which the different pedagogies support their development as independent learners?

Courses
Participants in this study included four engineering faculty and sixty-two undergraduate students enrolled in four courses in the 2009-2010 academic year 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 gender ratio and a student-to-faculty ratio typical of large engineering programs. These courses are summarized in Table 1. The courses taught by Instructors 1, 2, and 3 are required classes and the course by Instructor 4 is an elective.

Table 1 Courses in this Study

Instructor	Course Title	Student Profile
1	Applied Thermodynamics	20 Senior Mechanical Engineering
2	Electrical Circuits	11 Electrical Engineering (7 Sophomore, 4 Junior) 4 Mechanical Engineering (3 Sophomore, 1 Junior) 1 Sophomore Industrial Engineering
3	Heat Transfer	16 Junior Chemical Engineering
4	Failure Analysis and Prevention	4 Undeclared (3 Sophomore, 1 Junior) 3 Junior Mechanical Engineering 2 Engineering (1 Junior, 1 Senior) 1 Electrical & Computer Engineering Junior

All instructors used active learning strategies. However, these courses exhibited a variety of pedagogical approaches as described by the instructors.

INSTRUCTOR 1

ME-303 *Applied Thermodynamics* is a Junior/Senior-level, required course for mechanical engineering students. The course meets 3 times per week, has no associated laboratory and includes homework sets, quizzes, and midterm and final exam. Collaborative student-centered learning techniques including in-class problem solving using clickers, peer to peer instruction, discussions with student neighbors, calling on students for answers, and handing out partially completed notes are employed. Conceptual questions are included in addition to calculation-based examples. The homework assignments are completed by about half the students in two-person teams, while the rest elect to do them individually. Each time that a homework solution is submitted, the students take an in-class quiz that assesses their knowledge of the homework material.

Classes consist of brief lectures (less than 10 min) and example problems. Students are led by the instructor in solving the problems, with the instructor setting up the problem (describing it, providing known values, etc.) and breaking the problem into small 'chunks' or steps, which are then turned over to the students to solve on their own. Clickers are used for gathering feedback. When there is some confusion as to the correct answer, impromptu two-person teams are formed to discuss the question, and then students are retested. This procedure is repeated until the problem is completed, at which point a new problem is started. The student-student and student-faculty interactions are medium-high or high, relative to a traditional lecture class.

INSTRUCTOR 2

ELEC 201 *Electrical Circuits* is a sophomore level class. This is the first required course in their major for Electrical Engineering students. Industrial and Mechanical Engineering majors may take this course or a different course that includes broader introduction to electrical engineering. There is an associated laboratory but this was taught by a different instructor. The class meets 3 times a week for 55 minutes each and includes weekly homework assignments, two midterm exams, and a final exam. This course is taught in an active learning format including in-class problem solving and cooperative learning homework teams.

Faculty-student interactions occur primarily during class lecture periods. In a typical class period, prepared notes in PowerPoint are projected using a TabletPC and Classroom Presenter[27]. The notes come in a packet for a particular topic so one packet of notes might last from 2 to 6 lecture periods. The notes are intended to provide the outline and structure for the discussion of the topic. There are many spaces where students are encouraged to write in their own notes, answers to questions or solutions to problems. Questions are asked to be sure that the students are following. Students are called on in order going around the room to be sure that everyone is called on. Students are told that they can always pass if they do not know the answer but they need to pass to another student by name. Sometimes volunteers are taken. There is a reasonable amount of faculty-student interaction but little student-student interaction during this time.

Most periods include at least one problem where the problem statement is included in the notes along with whatever supporting information is necessary (e.g. circuit diagrams). A blank space is provided for students to work out solutions. Students are typically told to "turn to a helpful neighbor". Students then 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. During this time,

there is a fair amount of faculty-student interaction (either student initiated or faculty initiated) and student-student interactions within their groups. Depending on the level of difficulty of the problem (and the size of the class), the reporting out is handled in several ways. Sometimes, a volunteer comes to the front and presents the solution. Sometimes, the instructor will work through the solution on the TabletPC with guidance from the students. If all student groups seemed to get the solution easily, it may not be discussed in the larger group.

The instructor assigns students to cooperative learning homework teams of 3-4 students during the first week of the semester. They work in these groups throughout the semester handing in one solution per group. Students are assigned team roles (described on the syllabus) which rotate for each assignment. The recorder must write the entire solution. Early in the semester, students have the option of doing a team expectations assignment. Most groups meet once a week. Significant student-student interaction happens at these times.

There are, of course, other interactions including faculty-student interactions in the instructor's office (during office hours or other times or e-mail communication (asking questions about homework problems). The Engineering lab rooms are open to students when classes are not scheduled so students often meet there.

INSTRUCTOR 3
CHEG300 *Heat Transfer* is a required course for Chemical Engineering Juniors. The course has 3 hours of lecture, 1 hour of recitation and a 2 hour lab each week. The course is taught in a problem-based learning format and includes open-ended homework problems and laboratory assignments. Assessments include graded problem and laboratory assignments, peer assessment of individual student contributions and traditional quizzes and exams.

Only a fraction of the scheduled "lecture" time is devoted to lecturing. 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 students have posted questions, those questions will form the basis for the day's lecture. Lectures employ simple active learning techniques but the primary faculty-student interaction is through the lecture with only modest student-student interaction during the short class activities. 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.

As with the lecture, only a fraction of the scheduled lab time is spent on traditional laboratory work. During formal laboratory work, student teams collect data in the laboratory, primarily under the supervision of a graduate student. There are significant student-student interactions within the team and only minor faculty-student interactions in laboratory. The actual laboratory time typically takes no more than 1 hour. The remaining hour is spent in group meetings. The instructor also meets with every team individually for approximately 30 minutes, answering technical questions and soliciting student feedback on workload, stress levels, etc. These meetings provide significant, personalized faculty-student interaction. On weeks with no physical laboratory students give oral presentations of their laboratory work from the previous week, so there is significant student to faculty communication and some faculty to student communication by way of feedback.

In addition to these "in-class" interactions, there are other interactions including faculty-student interactions through open office hours, extensive e-mail communication and phone conversations. The culture within the department encourages students to "live in" the Engineering building and many hours of student interactions occur there most evenings.

INSTRUCTOR 4
ENGR3820 *Failure Analysis and Prevention* is a project-based, upper-level elective course for engineering students. This course meets for four hours per week and is taught in a project-based learning studio format. There are no exams in the course. Student evaluation is based on project deliverables (case study reports, oral presentations, and posters), team evaluations, and written self-reflections.

Student development in the course is focused on professional-level competencies and application of self-directed learning skills. By organizing and carrying out failure investigations of real-world components and systems, and through analysis of published case studies students "learn failure analysis by doing failure analysis." The student-directed projects emphasize the interdisciplinary nature of failure investigations, and the class devotes significant time to discussions of contextual factors that contribute to engineering decision-making.

Learning in the course is centered on failure analysis projects, and students typically complete 3-4 failure investigations in the semester. All students begin the semester with a 2-week study of the failure mode in paperclips or light bulbs. The goal of this project is to provide students with an opportunity to collect and analyze evidence to test an expert's published hypothesis regarding how paperclips or light bulbs fail. The project also provides an opportunity for students to hone their hands-on materials science laboratory skills.

Subsequent projects in the course involve analysis of real products that have failed in service. Student teams form around common interests (e.g., mechanical failures, electrical failures, corrosion failures), and they select a failed component or system that they wish to analyze. Each project and the relevant technical content is necessarily different, since each team is studying a unique failed product. The teams establish their own project goals, timeline, and investigative strategies. They design their own experiments, and they identify information resources appropriate to their particular project. Most projects culminate in the preparation of a failure analysis case-study style report; some projects end with a poster presentation. Once the report has been submitted, students self-assess their report in several competency areas (e.g., communication, qualitative analysis, diagnosis); they reflect upon their own self-directed learning processes; and they evaluate their teaming behaviors and skills with self- and peer-assessments.

Throughout the projects, the instructor serves as a consultant and a sounding board for the project teams' experimental strategies and data analyses. In the first half of the semester, the instructor provides weekly reading assignments (e.g., case studies, failure analysis methodologies) and facilitates an in-class discussion of these readings. In the second half of the semester, student teams take responsibility for the selection of readings and facilitation of the in-class discussions. The instructor provides grading/self-assessment rubrics, as well as guidelines for the teaming and self-directed learning reflections.

Summary Description of Courses

Overall, the courses may be considered in terms of the balance between content and process oriented learning goals. For the purposes of this paper, content-focused learning goals refer to those goals that are concerned primarily with assisting the students to acquire new content knowledge or to review recently learned content knowledge with the intent of incorporating such knowledge into the students' expanding knowledge of the field. Process-focused learning goals refer to a set of goals that are concerned with assisting the students to (a) set goals and select strategies to investigate an open-ended problem (b) identify resources (information, lab, and human) relevant to the problem, (c) design and implement a project plan, and manage a project team, and (d) reflect on the learning process and self-assess progress. Each course has some of each of these types of goals but the balance varies among the four courses. *Applied Thermodynamics* (Instructor 1) is most heavily focused on content with *Electrical Circuits* (Instructor 2) next most heavily content-focused but with more process-focus entering in student homework teams followed by *Heat Transfer* (Instructor 3) which brings in more focus on process through its problem-based type format but retains a significant content focus and *Failure Analysis and Prevention* (Instructor 4) which is most heavily focused on process with its project-based type format with content much less emphasized.

Another way to consider the differences among the courses is in terms of the amount of independence that the students have or ownership of their own learning. This can be thought of along a continuum from teacher-directed (teacher makes all decisions, controls evaluation, content, and class time) to student-directed (students share in decision making, influence content and class time). The more student- directed format allow for more autonomy for the students. Figure 1 shows the instructor's estimation of where their courses lie on these continua.
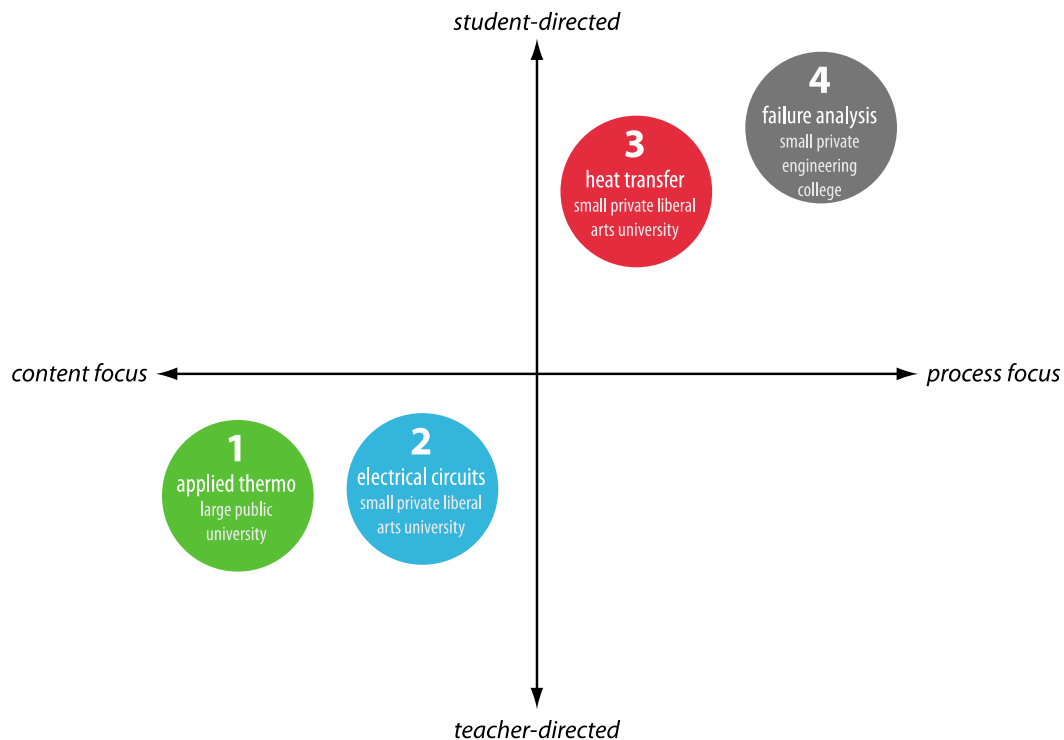

Figure 1 Continua of *content to process focus* (horizontal axis) and *student-directed to teacher-directed* (vertical axis) for the four courses in this study.

Instruments

To begin to measure student's development of characteristics associated with those of lifelong learners, we used the Motivated Strategies for Learning Questionnaire (MSLQ).[28] To assist in characterizing the learning environment from the students' point of view, we used the Learning Climate Questionnaire (LCQ).[29]

Motivated Strategies for Learning Questionnaire (MSLQ)
Student motivational, cognitive, and behavioral outcomes are measured using the MSLQ, 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 each subscale are reported. The MSLQ has high internal consistency, reliability, and predictive validity. [30,31] The MSLQ includes 15 subscales. 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 a 76 item MSLQ survey at the beginning and end of the semester using an electronic survey system.

Learning Climate Questionnaire (LCQ)
In this study, the LCQ was used to assist in characterizing the learning environment in each class. The LCQ is one of the Perceived Autonomy-Supportive Climate Questionnaires developed by Deci and Ryan based on self-determination theory (SDT).[21] The LCQ is typically used to describe the learning environment in a particular class at the university level as autonomy-supportive or controlling. This self-report instrument measures students' perceptions of the amount of faculty support for their growth as independent learners or instructor autonomy support. In this study, students responded to 15 items on a 7-point Likert scale using an electronic survey system at the end of the semester. Scores range from 1 to 7 with 1 meaning "strongly disagree" and 7 meaning "strongly agree". One total score (from 0 to 7) results as the average of the item scores. A higher score represents a higher perception of autonomy support.

Analysis and Findings

One-Sample t-tests were used to situate the sample of engineering students in each course of this study relative to the data in the MSLQ manual. Dependent groups t-tests were used to compare within group differences from pre-test to post-test on the subscales of the MSLQ. Effect sizes were calculated using Cohen's d with 0.2 being interpreted as a small effect, 0.5 a medium effect, and 1.0 a large effect.[32] One-way analysis of variance was used to compare differences of perceived support for autonomy across the four courses at the end of the course.

Where do our students start? MSLQ for engineering students
The MSLQ manual provides mean scores based on data from a sample of Midwestern college students at a four-year university. The authors note that they have not provided norms for norm-referenced comparisons because the instrument is designed to be used at the course level. They

recommend that for comparative purposes, the establishment of local norms would be most appropriate. However, because no engineering students were included in the sample that produced the means provided in the MSLQ, we felt it was important to obtain a reference point from which to understand where the engineering students in this study started. We compared our engineering students in individual classes to the means in the MSLQ manual. The results of this analysis are shown in Table 2 and inform some of the discussion later in the paper.

Table 2 shows significant differences between the MSLQ reference data and course-specific engineering student groups in this study. Instructor 1's students reported significantly higher mean scores in the learning strategy of time and study environment; and lower mean scores in the learning strategy scales of rehearsal and organization, and in the metocognitive scale of metacognitive self-regulation. Instructor 2's students reported significantly higher mean scores in the learning strategy scales of peer learning and help seeking, and higher mean scores in the motivation scale of extrinsic goal orientation. Instructor 3's students reported significantly higher mean scores in the learning strategy scales of time and study environment, peer learning, and help seeking, and lower mean scores in the motivation scales of control of learning beliefs and self-efficacy for learning and performance and in the learning strategy scales of rehearsal, elaboration, organization, and effort regulation. Instructor 4's students reported significantly higher mean scores in the motivation scales of intrinsic goal orientation and task value and in the learning strategy scales of time and study environment, peer learning and help seeking, and lower mean scores in the motivation scale of extrinsic goal orientation and the learning strategy scales of rehearsal and organization

Table 2 Means on MSLQ subscales for Engineering Students by Course Compared to MSLQ Sample. Statistically significant differences are shown with two-tailed p-values in parentheses.

MSLQ subscale	MSLQ sample mean	Instructor 1 (N =20)	Instructor 2 (N = 16)	Instructor 3 (N = 16)	Instructor 4 (N = 10)
Intrinsic Goal Orientation	5.03				5.65 (p=0.014)
Extrinsic Goal Orientation	5.03		5.58 (p=0.024)		3.35 (p=0.002)
Task Value	5.54				6.08 (p=0.005)
Control of Learning Beliefs	5.74			5.00 (p=0.015)	
Self-efficacy for Learning and Performance	5.47			4.94 (p=0.013)	
Rehearsal	4.53	3.33 (p=0.001)		3.33 (p=0.000)	2.8 (p=0.002)
Elaboration	4.91			4.22 (p=0.016)	
Organization	4.14	3.44 (p=0.027)		3.51 (p=0.029)	3.33 (p=0.021)
Critical Thinking	4.16				
Metacognitive Self-regulation	4.54	3.72 (p=0.01)			
Time and Study Environment	4.87	5.46 (p=0.018)		5.27 (p=0.026)	5.43 (p=0.022)
Effort Regulation	5.25			4.60 (p=0.000)	
Peer Learning	2.89		4.83 (p=0.000)	4.35 (p=0.000)	3.87 (p=0.000)
Help Seeking	3.84		5.17 (p=0.000)	5.17 (p=0.000)	5.43 (p=0.000)

What are the learning environments like? Faculty and Student Perceptions
The faculty descriptions of their courses provided in the previous section highlighted the pedagogical approaches of the instructors and illustrated the significant variation in learning environments. Despite the variation in the learning environments, all were considered to incorporate aspects of active learning, thus allowing students some degree of autonomy as learners. Providing opportunities for students to take ownership over some aspects of their learning may not always result in students actually seizing those opportunities. Supporting students in becoming managers of their own learning processes and behaviors is often a critical instructional condition that needs to be satisfied. Student perceptions of the degree of support for autonomy within each learning environment were captured by the LCQ. The means and standard deviations of the LCQ results for the courses in this study are summarized in Table 3. There are differences in the reported means for several of the courses indicating that students felt varying degrees of autonomy support in

these environments. Instructor 1's perceived level of autonomy support was not different from any of the other isntructors. Instructor 3's perceived level of autonomy support was significantly lower than that of Instructor 2 (p= 0.021) and Instructor 4 (p = 0.005). Instructors 2 and 4 were not perceived as different by their students in their support of student autonomy.

Table 3 LCQ Results for Courses Studied

	Instructor 1	**Instructor 2**	**Instructor 3**	**Instructor 4**
Mean	5.35	6.1	4.87	6.46
Standard Deviation	1.1	0.81	1.38	0.36

How do our students change? Differences in MSLQ after taking courses
Analysis of the MSLQ results at pre- and post-course show some significant temporal differences for student outcomes on several subscales of the MSLQ for different instructors. The statistically significant results are summarized in Table 4. For all other subscales, no statistically significant differences were seen between pre and post. No statistically significant differences were found following Instructor 1's course. After the course with Instructor 2, students reported a statistically significant increase in organization. After Instructor 3's course, students reported statistically higher intrinsic motivation, peer learning, effort regulation, elaboration, and organization. After Instructor 4's course, students reported statistically significant lower task value and higher peer learning.

Table 4 Statistically significant pre- and post MSLQ Results. (No statistically significant differences were seen for Instructor 1.)

MSLQ Subscale	**Instructor**	**Pre (start of term)**		**Post (end of term)**		**p**	**Effect size**
		Mean	**Std. Dev.**	**Mean**	**Std. Dev.**		
Intrinsic Goal Orientation	3	4.99	1.04	5.44	0.92	0.023	0.22
Peer Learning	3	4.35	0.79	4.85	1.39	0.024	0.21
	4	3.87	0.55	4.43	0.67	0.045	0.91
Task Value	4	6.08	0.46	4.65	0.96	0.001	1.90
Effort Regulation	3	4.60	0.42	5.30	0.98	0.004	0.42
Elaboration	3	4.22	1.02	4.17	1.08	0.016	0.13
Organization	2	4.02	1.38	4.64	1.43	0.002	0.21
	3	3.51	1.05	4.17	1.30	0.015	0.26

Discussion and Conclusion

The different ways that students change in different courses suggest that different pedagogies influence development of certain behaviors related to self-regulated learning and by extension to lifelong learning.

Considering these results in light of the continuum of content and process provides some insights. The courses with more emphasis on content goals (Instructors 1 and 2) showed fewer gains in the process-related strategies and behaviors. The courses with more emphasis on process goals (Instructors 3 and 4) showed more gains in areas related to the processes of learning such as peer learning (collaborating with one's peers), effort regulation (controlling one's effort despite competing alternatives or lack of interest), elaboration (strategies such as paraphrasing, summarizing, analogical reasoning, generative note-taking), and in the affective variable of intrinsic goal orientation (participating in the task for value of learning). The decrease of Instructor 4's students for task value (an evaluation of how interesting, important, or useful the task is) might be related to their high initial values and the nature of the course. Given that it is a multidisciplinary elective, students may enter the course excited. However, some students find projects more relevant to their major or using more of their existing knowledge base while others learn that this topic is not as relevant as they initially thought.

Comparing the LCQ, MSLQ, and faculty course data yields some interesting findings. Students in Instructor 3's course were all in the same engineering major and the content was relevant to their progression in their curriculum. The design of this course seems to have achieved outcomes associated with self-regulated learning, as evidenced by the high reported gains in many categories associated with increased independent learning on the MSLQ. However, these students reported lower scores on the LCQ in terms of the perceived instructor support for autonomy. From the faculty course descriptions, the level of autonomy provided to the students in Instructor 3's course is high. Perhaps the students report less support on the LCQ because they feel frustrated at having to "do things on their own" in this required course. This was the first time many of these students experienced a pedagogy such as this and were not accustomed to taking control of their learning and solving problems with a high degree of ambiguity. Thus they may have explained their discomfort with their own uncertainty as a lack of supportiveness on the part of the instructor in the open-ended setting. This might be explained in terms of the constructive "friction" between teaching and learning strategies as described by Vermunt and Verloop[20]. It is also noteworthy that this Instructor's students had the most subscales below the MSLQ mean at pretest, which may indicate a generally lower level of intrinsic motivational orientation or cognitive strategy development, or perhaps a higher dependence on authority.

How much choice is too much? In Instructor 4's class, the students report feeling very supported and valued as contributors to their own learning consistent with the Instructor's description of providing significant amounts of autonomy. Reports of peer learning increased significantly from the start to the end of the semester, a result that is somewhat expected given the emphasis on authentic team projects. These students also started out highest on several MSLQ subscales such as intrinsic motivation and task value, possibly reflecting their anticipated interest, curiosity, and expectations for useful learning in this technical elective course. However, the students do not report the level of gains of Instructor 3's students despite the greater autonomy. In fact, as discussed earlier, they report significant drops in task value throughout the semester. The decrease in task value may result when students in this high autonomy environment are unable to find project

topics of personal interest, or when they discover that the projects they choose do not lead to the type of content learning or skill development that they anticipated. Since the instructor does not set the project topics, project timelines, or project strategies, students are free to make their own choices – even choices that lead to disappointing project results and undesirable learning outcomes.

In Instructor 2's course, students reported high feelings of instructor support for their learning as measured by the LCQ but they only reported gains in the organization learning strategy subscale of the MSLQ (strategies that help to make connections among information to be learned). This student gain may be a result of Instructor 2's course notes, in-class problem solving, and homework teams, which provided scaffolding to help students succeed. Instructor 2's course was for sophomores and the topic has a reputation of being difficult. Thus the instructor did focus on trying to dispel fears and encourage students that they could be successful in learning the material. This certainly is consistent with support for their learning although it might not reflect high degrees of student autonomy.

Future Work

The work presented here is part of a larger study. Further analysis of the quantitative data from a total of eight courses is underway including correlations between the different instruments. In addition, we are analyzing qualitative data from focus groups and student dialogue from audio and videotaped classes to gauge students' perceptions of the degree to which the learning environment supported their autonomy. 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.

Future work will also consider variables such as gender and student development. Preliminary analysis shows that year in school (sophomore, junior, senior) plays a large role in the outcomes of our students on the MSLQ.

References

[1] American Society for Engineering Education Deans Council and Corporate Roundtable, *The Green Report: Engineering Education for a Changing World*, Washington, D.C.: ASEE (1994).

[2] National Research Council's Board on Engineering Education, *Engineering Education: Designing an Adaptive System*, Washington, D.C.: National Academy Press (1995).

[3] Peden, I. C., E. W. Ernst, and J. W. Prados, Systemic Engineering Education Reform: An Action Agenda, Washington, D.C.: National Science Foundation (1995).

[4] *The Engineer of 2020: Visions of Engineering in the New Century*, Washington, D.C: National Academy Press (2004).

[5] Clough, G., *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, Washington, D.C.: National Academy Press (2005).

[6] Criteria for Accrediting Engineering Programs, Accreditation Board for Engineering and Technology, Engineering Accreditation Commission (2005). Available at http://abet.org/forms.shtml

[7] Candy, P. C., *Self-Direction for Lifelong Learning*, San Francisco: Jossey-Bass (1991).

[8] Zimmerman, B. J., Attaining self-regulation: A social cognitive perspective. In M. Boekarts, P. Pintrich, and M. Zeidner (Eds.), *Self-regulation: Theory, research, and applications* (pp. 13-39). Orlando, FL: Academic (2000).

[9] Blumenfeld, P. C., Classroom learning and motivation: Clarifying and expanding goal theory, *Journal of Educational Psychology*, 84, 272-281 (1992).

[10] Dickinson, L., Autonomy and motivation: A literature review. *System*, 23(2), 165-174 (1995).

[11] Deci, E. L. and Ryan, R. M. Self-determination research: Reflections and future directions. In E. L. Deci and R. M. Ryan (Eds.), Handbook of self-determination theory research, (pp 431-441). Rochester, NY: University of Rochester Press (2002).

[12] Wigfield, A., Byrnes, J. B. and Eccles, J. S., Adolescent development. In P. A. Alexander and P. Winne (Eds.), Handbook of Educational Psychology, (2nd ed; pp 87-113). Mahwah, NJ: Lawrence Erlbaum (2006).

[13] Vermunt, J. D. and Vermetten, Y. J., Patterns in student learning: Relationships between learning strategies, conceptions of learning, and learning orientations, *Educational Psychology Review,* 16(4), 359-384 (2004).

[14] Boekaerts, M., Self-regulated learning: A new concept embraced by researchers, policy makers, educators, teachers, and students, *Learning and Instruction*, 7(2), 161-186 (1997).

[15] Pintrich, P. R. A conceptual framework for assessing motivation and self-regulated learning in college students, *Educational Psychology Review*, 16, 385-407 (2004)

[16] Zimmerman, B. J., Self-Regulation involves more than metacognition: A social cognitive perspective, *Educational Psychologist*, 30, 217-221 (1995).

[17] Rogers, C. R., *Freedom to Learn: A View of What Education Might Become*, Columbus, OH: Charles E .Merrill Publishing Company (1969).

[18] Noels, K. A., Clement, R., and Pelletier, L. G., Perceptions of teachers' communicative style and students' intrinsic and extrinsic motivation, *The Modern Language Journal*, 83, 23-34 (1999).

[19] Black, A. E. and Deci, E. L., The Effects of Instructors' Autonomy Support and students' Autonomous Motivation on Learning Organic Chemistry: A Self-Determination Theory Perspective, *Science Education*, 84, 740-756, (2000).

[20] Vermunt, J. D. and Verloop, N., Congruence and friction between learning and teaching, *Learning and Instruction,* 9, 257-280 (1999).

[21] Ryan, R. M., and Deci, E. L. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being, *American Psychologist,* 55, 68-78 (2000).

[22] Deci, E. L. and Ryan, R. M., The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior, *Psychological Inquiry*, 11, 227-268 (2000).

[23] Stefanou, C. R., Perencevich, K. C., DiCintio, M. andTurner, J. C., Supporting Autonomy in the Classroom: Ways Teachers Encourage Student Decision Making and Ownership, *Educational Psychologist,* 39(2), 97-110 (2004).

[24] Blumenfeld, P. C., Kempler, T. M., and Kracjik, J. S., Motivation and cognitive engagement in learning environments. In R. K. Sawyer, (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp 475-488). New York, NY: Cambridge University Press (2006).

[25] VanderStoep, S. W., Pintrich, P. R., and Fagerlin, A., Disciplinary differences in self-regulated learning in college students, *Contemporary Educational Psychology*, 21, 345-362 (1996).

[26] Kaplan, H., Assor, A., and Roth, G., Effects of autonomy support and competence support on academic functioning, Paper presented at the *8th Workshop on Achievement and Task Motivation*, Moscow, Russia (2002).

[27] Computer Science and Engineering, University of Washington, available at http://classroompresenter.cs.washington.edu/ Last Accessed on March 2, 2011.

[28] Pintrich, P. R., Smith, D. A. F., Garcia, T., and McKeachie, W. J., A manual for the use of the Motivated Strategies for Learning Questionnaire (MSLQ) (Ann Arbor, MI: National Center for Research to Improve Post-Secondary Teaching, (1991).

[29] available at http://www.psych.rochester.edu/SDT/measures/paslearning.php Last Accessed on March 2, 2011.

[30] Duncan, T. G., and McKeachie, W. J., The Making of the Motivated Strategies for Learning Questionnaire. *Educational Psychologist*, 40, 117-128 (2005).

[31] Pintrich, P. R., Smith, D. A. F., Garcia, T., and McKeachie, W. J., Reliability and predictive validity of the motivated strategies for learning questionnaire (MSLQ). *Educational and Psychological Measurement*, 53, 801-803 (1993).

[32] Cohen, J., *Statistical power analysis for the behavioral sciences* (2nd ed.), New York: Academic Press (1988).