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Engineering Students' Definitions of and Responses to Self-Directed Learning*

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In this paper we present the results of a study on engineering students' characterizations and critiques of self-directed learning experiences in their classrooms. Using a social-cognitive conceptual framework for examining self-directed learning processes, we analyze qualitative survey responses from a gender-balanced group of engineering students at a small, private engineering college. The data indicate that students believe self-directed learning focuses primarily on cognitive tasks associated with planning and monitoring the self-directed activity. Motivational considerations are frequently cited as significant positive aspects, while behavioral aspects such as goal setting and resource acquisition are the most commonly noted negative aspects. The survey results suggest that reflection tends to be undervalued both by students and by instructors, that motivation is key for creating positive self-directed learning experiences, and that there is a need for instructors to develop an improved ability to deal with the challenges that arise when students are asked to engage in self-directed learning processes.

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

1. INTRODUCTION

COLLEGE INSTRUCTORS have struggled with a lack of self-directed learning (SDL) development in their students for many decades. Self-direction is by no means a new topic in teaching and learning, but it is one of growing significance in engineering educational discourse. In 1969, Carl Rogers articulated the need for flexible, independent learners:

> Teaching and the imparting of knowledge make sense in an unchanging environment. This is why it has been an unquestioned function for centuries. But if there is one truth about modern man, it is that he lives in an environment which is *continually* changing . . .We are, in my view, faced with an entirely new situation in education where the goal of education, if we are to survive, is the *facilitation of change and learning.* The only man who is educated is the man who has learned how to learn; the man who has learned how to adapt and change; the man who has realized that no knowledge is secure, that only the process of *seeking* knowledge gives a basis for security [1].

Maslow targeted traditional engineering education approaches in 1971, arguing that 'we must teach and train engineers not in the old and standard sense,' but in a manner that enables them to confront novelty, to improvise, and to gain comfort with change [2]. The need for agile, self-directed learners has only increased since Rogers and Maslow expressed their concerns about the state of our educational systems, and the National Academies recently echoed the decades-old appeal for graduates who are adaptable and committed to continuous growth. In a 1995 call to action, the National Academies' Board on Engineering Education asked educators to 'instill in students a desire for continuous and lifelong learning to promote professional achievement and personal enrichment' [3]. The National Academies assert that students must develop dynamism, agility, resilience, flexibility, and the skills and attitudes that foster continuous learning in order to succeed in our accelerating global environment [4]. They include lifelong learning as a key attribute of the 'technically proficient engineers who are broadly educated see themselves as global citizens, can be leaders in business and public service, and who are ethically grounded' [5].

The American Society for Engineering Education (ASEE) and the National Science Foundation (NSF) also emphasize lifelong learning in their calls for engineering educational reform [6, 7]. In addition, ABET now *requires* engineering educators to demonstrate the development of students' lifelong learning skills through their curricula [8]. Clearly, the engineering educational community considers students' capacity for lifelong learning as a critical outcome for educational systems.

Achieving the long-term outcome of lifelong learning requires that learners gain competence in self-direction. The UNESCO Institute for Education noted that lifelong education, as a means for promoting lifelong learning, is 'dependent for its successful implementation on people's increasing ability and motivation to engage in self-directed learning activities' [9]. Candy describes the relationship between lifelong and self-directed learning as reciprocal: self-directed learning is a means by which individuals pursue learning throughout their

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life, and lifelong learning aims at equipping people with the skills required for self-direction [10].

2. WHAT IS SELF-DIRECTED LEARNING?

One of the greatest challenges associated with SDL lies in its definition. Most engineering educators agree that skills in SDL are important for success in today's global engineering environment, and that SDL skill building in students will encourage the developmental patterns required for lifelong learning. Yet few engineering educators have a clear notion of what it means for students to be self-directing. Often, engineering educators consider SDL as a single skill that individuals either have or lack. For example, instructors may believe that students are unskilled in SDL if they cannot effectively manage their time and effort. Other instructors may question SDL ability if students cannot set their own learning goals, if they show low levels of motivation, or if they are unable to self-assess their own performance. The reality is SDL involves all of these processes, and much more. SDL is complicated, and the details of how we may best engage students in SDL (and eventually lifelong learning) still pose a substantial challenge. Engineering instructors are aware that approaches used in conventional curricula are deficient, but without a clear conception of SDL skills and processes, designing learning environments that foster student growth in SDL is extraordinarily difficult.

Engineering educators may gain some insight into SDL from educational research in self-determination theory, self-regulated learning, and adult learning. The work in these areas has shown that individuals become self-directing through mastery of a broad range of skills, attitudes, and knowledge that enables construction of processes for managing thoughts, motivations, actions, and interactions with the learning environment [11]. The sections that follow provide a brief review of the relevant literature on SDL. By leveraging the existing literature, engineering educators may gain a more complete understanding of how SDL processes develop, and how capacities for lifelong learning may be realized in engineering classrooms.

2.1 Self-determination theory and the importance of autonomy

A key concept in SDL is that of autonomy. Deci and Ryan define autonomy as 'volition—the organismic desire to self-organize experience and behavior and to have activity be concordant with one's integrated sense of self' [12]. In self-determination theory (SDT), Deci and Ryan assert that humans have innate tendencies toward personal growth and development, i.e., we are all natural born lifelong learners. Self-determination theory argues, however, that certain psychological and social conditions must be satisfied in order for individuals to realize their growth potential. Important among these conditions is a need for autonomy. Self-determination research demonstrates that autonomy is a critical component of self-motivation, and that autonomy is necessary for individual internalization of learning goals. When learners feel a sense of freedom, choice, control, and ownership, they demonstrate higher intrinsic motivation and healthier psychological development [12, 13]. Garcia and Pintrich showed that autonomy fosters self-efficacy, intrinsic goal orientation, and task value [14]; and Black and Deci demonstrated that autonomy-oriented students have higher perceived competence, higher interest and enjoyment, and lower anxiety and grade-focused goals [15].

Instructor support and a healthy classroom climate are absolutely essential for self-directed learner development, and students' natural inclinations toward learning may be easily disrupted by non-supportive conditions [13]. Self-determination studies show that students' positive perceptions of their assigned tasks and instructors' autonomy support can lead to increases in intrinsic motivation, self-regulation, perceived competence, interest, enjoyment, retention, engagement, and academic performance [16–19]. Instructor provision of choice and opportunities for self-direction may simultaneously enhance skill development, achievement, and self-motivation for learning. For successful development, our environment must support our innate growth tendencies.

2.2 Self-regulated learning perspectives

Much of what we know about SDL comes from research in self-regulation, a term that refers to 'self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals' [20]. Self-regulation research includes a diverse set of theoretical viewpoints, including personality, social psychological, developmental, phenomenological, operant, and systemic perspectives [21, 22]. For this investigation, we focus primarily on social psychological conceptualizations for self-regulated learning (SRL) presented in the educational psychology literature.

Zimmerman [20] and Pintrich [23, 24] present models for self-regulated learning that are based on a social-cognitive perspective that assumes learners are active, constructive participants in the learning process. Zimmerman describes self-regulated learners as individuals who are 'metacognitively, motivationally, and behaviorally active participants in their own learning' [25], and he views self-regulation as a cyclical interaction of personal, behavioral, and environmental processes (Fig. 1). In this model, *behavioral* self-regulation involves processes such as self-observation and adjustment of learning strategies; *environmental* self-regulation refers to student adjustments to the context in which learning takes place; and *covert* self-regulation refers to self-monitoring and management of cognitions and emotions [20].

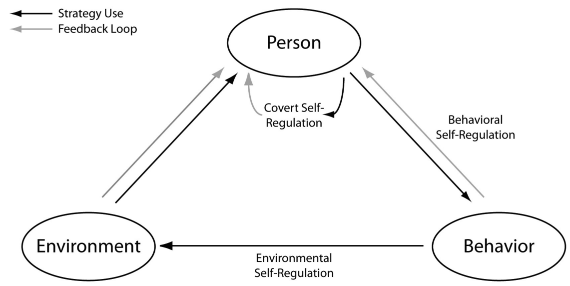

Fig. 1. Zimmerman model for self-regulation that highlights the interplay among person, behavior, and the learning environment [20].

Learners use feedback from prior experiences to adapt their current self-regulated learning efforts.

Pintrich describes self-regulated learners as those who 'set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment' [23]. Both the Zimmerman and Pintrich views of self-regulated learners emphasize the interaction of person and context, and highlight the importance of individuals' balancing motivational, cognitive, behavioral, and contextual factors in the classroom. These factors play a fundamental role in the literature and in our own conceptual framework, and we define them as follows:

- *Cognitive and metacognitive* factors include students' abilities to recognize needs, develop strategies for planning, monitoring, and adapting learning processes, understand and reflect on their cognitive processes (metacognition), and engage in accurate self-evaluation of performance [20, 26].
- *Motivational* factors reflect students' self-efficacy, perceptions of choice and control, task interest, perceived task value, anxiety control, and affective responses to the learning experience [26, 27].
- *Behavioral* components include time and effort planning and management, mechanisms for attention focusing, and appropriate attribution of outcomes to behaviors.
- *Contextual* aspects of self-regulated learning encompass learners' responses to the educational setting. In courses, these may include the management of peer relationships [28] and physical resources [20], and responses to the instructor styles and requirements [15, 18, 29].

As with the autonomy-motivation linkages illustrated in self-determination research, work in self-regulated learning has shown clear interrelationships among motivational, cognitive, behavioral, and contextual factors [30]. For example, students' motivations are known to correlate to their use of cognitive and metacognitive strategies [26, 31]. Pekrun et al. demonstrated that academic emotions, which are shaped by the classroom environment, relate in significant and reciprocal ways to a variety of self-regulated learning-relevant factors such as task interest, learning strategies, motivation, and perceived ability in self-regulation [32]. Individuals' epistemic beliefs also affect their self-regulated learning capacities by shaping their choice in goal selection and use of cognitive and behavioral strategies [33].

Pintrich and Zimmerman each present conceptual frameworks for self-regulated learning that aid our understanding of self-regulatory processes. Zimmerman's framework (Table 1) includes three sequential phases of self-regulation: (1) forethought, (2) performance/volitional control, and (3) self-reflection. Zimmerman describes self-regulatory sub-processes for each of his three phases; and he emphasizes that the phases are cyclical, with forethought occurring prior to performance and control efforts, and self-reflections occurring after these efforts [20].

The Pintrich model (Table 2) describes four phases of self-regulated learning: (1) forethought, planning, activation, (2) monitoring, (3) control, and (4) reaction and reflection. Within each of these phases, Pintrich illustrates four possible areas for self-regulation: cognition, motivation, behavior, and context. Pintrich diverges from Zimmerman in one key respect: although these four phases generally represent a time-ordered sequence in self-regulated learning, the earlier phases do not always need to precede the latter phases. Depending on the learning experience,

Table 1. Zimmerman conceptual framework for self-regulation. [20]

Cyclical self-regulatory phases		
Forethought	**Performance/volitional control**	**Self-reflection**
Task analysis: • Goal setting • Strategic planning	Self-control: • Self-instruction • Imagery • Attention focusing • Task strategies	Self-judgment: • Self-evaluation • Causal attribution
Self-motivation beliefs: • Self-efficacy • Outcome expectations • Intrinsic interest/value • Goal orientation	Self-observation: • Self-recording • Self-experimentation	Self-reaction: • Self-satisfaction/affect • Adaptive-defense

Table 2. Pintrich conceptual framework for studying self-regulation. [24]

	Phases of self-direction			
Areas for self-direction	**Phase 1: Planning, forethought**	**Phase 2: Monitoring**	**Phase 3: Control**	**Phase 4: Reaction and Reflection**
Cognition	Target goal setting. Prior content knowledge activation. Metacognitive knowledge activation.	Metacognitive awareness and monitoring of cognition.	Selection and adaptation of cognitive strategies for learning, thinking.	Cognitive judgments. Attributions.
Motivation/Affect	Goal orientation adoption. Efficacy judgments. Perceptions of task difficulty. Task value activation. Interest activation.	Awareness and monitoring of motivation and affect.	Selection and adaptation of strategies for managing, motivation, and affect.	Affective reactions. Attributions.
Behavior	Time and effort planning. Planning for self-observation of behavior.	Awareness and monitoring of effort, time use, need for help. Self-observation of behavior.	Increase/decrease effort. Persist, give up. Help-seeking behavior.	Choice behavior.
Context	Perceptions of task. Perceptions of context.	Monitoring changing task and context conditions.	Change or renegotiate task. Change or leave context.	Evaluation of task. Evaluation of context.

students may simultaneously engage in more than one phase at one time, and they may attempt to gauge or regulate one or more areas of functioning as they progress through a self-regulated learning task [24].

2.3 Adult learning perspectives

Although self-regulated learning researchers often refer to aspects of personal agency and individuals' growth intentions [34–36], most social-cognitive models for academic self-regulated learning presume that individuals are situated within a learning context such as a school or classroom. As such, these models assume a set of starting conditions to the learning experience: a learning need or goal is identified, learning topics or domains are selected, the social environment is established, and tasks are defined. In the early phases of self-regulated learning, learners generate perceptions about the assigned task, the learning context, and their own abilities [23, 33]. These 'classroom context' assumptions work well when considering self-regulatory processes within traditional courses and curricula, but they may not adequately describe processes required at the onset of more exploratory learning such as independent study, research, or design. Open-ended learning experiences are becoming more common in engineering curricula; and students increasingly encounter situations in which they must recognize their own needs, specify their own goals, and intentionally situate themselves in an environment conducive to learning. That is, self-directed learners must take initiative in the pursuit of learning opportunities.

Researchers in the field of adult learning draw a clear distinction between the *processes* of self-directed learning and the *personal orientations* and *attributes* of self-directed learners. Process descriptions in adult learning mirror those from self-regulated learning and include cognitive, behavioral, and environmental factors [37]. For example, Knowles defines self-directed learning as:

> . . . a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes [38].

In addition to recognizing process knowledge and skills, Knowles' definition also highlights the value of personal orientations toward learning, e.g., taking initiative and diagnosing learning needs. Candy expands on these learning process-personal attribute differences by describing four distinct dimensions of the term 'self-direction': as personal attribute, as the willingness and capacity to conduct one's own education, as a mode of organizing instruction in formal settings, and as the individual pursuit of learning opportunities in the 'natural societal setting' [10]. In addition to possessing process-relevant skills, Candy profiles self-directed learners as individuals who are curious, motivated, self-starting, self-aware, reflective, persistent, responsible, flexible, interpersonally competent, venturesome, creative, and open to new opportunities. Willingness and intention to learn are viewed by adult education researchers as core to the SDL experience, and some go so far as to describe SDL as a consciously chosen 'way of life' [39].

Conceptualizations of SDL that focus entirely on process management skills overlook some of these important personal aspects of the learners themselves. Brookfield argues that it is 'possible to be a superb technician of self-directed learning in terms of one's command of goal setting, instructional design, or evaluative procedures, and yet to exercise no critical questioning of the validity or worth of one's intellectual pursuit . . .' [40]. Adult learning researchers point out that the opposite is also true, i.e., individuals may exercise personal autonomy and a desire to learn in the broad sense, but lack the process skills to realize their growth potential [10].

3. ENGINEERING STUDENTS' CONCEPTIONS OF SDL

The primary goal of this study is to use student viewpoints to highlight issues that should be considered by instructors who wish to design SDL experiences. Through the lens of a SDL conceptual framework, we examine student definitions of SDL, and student descriptions of effective and challenging aspects of SDL. The framework is used as a tool to identify key factors that contribute to students' learning experiences, and as a mechanism for highlighting issues that bear consideration in the design, implementation, or evaluation of curricula. The study was conducted at a small engineering college that provides a particularly interesting environment in which to explore these questions, both because the curriculum places a heavy emphasis on self-directed experiences, and because the college has a nominally gender-balanced population.

A secondary goal of this study is presentation of a SDL framework that merges ideas from the self-regulation and adult learning literature (Table 3). The framework is based primarily on the self-regulation phases and processes outlined in the

Table 3. Framework for self-directed learning based on Zimmerman [20] and Pintrich [24] models for self-regulated learning

	Phases of self-direction			
Areas for self-direction	**Intention**	**Planning, forethought**	**Monitoring, control**	**Reflection, reaction**
Cognition	Need recognition. Opportunity assessment. Choice of topic.	Task analysis. Goal-setting. Prior content knowledge activation. Metacognitive knowledge activation. Selection of strategies, resources, evaluations.	Metacognitive awareness. Monitoring of cognition. Self-recording. Self-observation. Judgments of learning. Adaptation of cognitions and strategies.	Knowledge of understanding and learning outcomes. Self-evaluations of performance and outcomes.
Motivation	Self-actualizing tendency. Desire for growth. Positive self view. Perceptions of choice, ownership, control. Intrinsic goal framing.	Goal orientations and internalization. Outcome expectations. Self-efficacy. Self-regulatory efficacy Perceptions of task difficulty, value. Task interest.	Awareness of self-efficacy, interests, anxieties. Positive self-talk. Anxiety control. Self-rewards. Adjustment of process based on motivations.	Efforts to enhance motivation. Attribution of achievement to motivations. Affective responses. Ownership, connection to outcomes.
Behavior	Choice to engage. Identification of a suitable learning environment. Allocation of learning time.	Time, effort planning to attain goals. Deadlines setting. Self-assessment planning.	Time and effort management and adjustment. Acquisition and use of resources. Adaptive help-seeking. Persisting, effort focusing.	Self-evaluation of efforts and actions. Attribution of outcomes to behaviors and actions.
Context	Choice of physical and social context. Flexibility to learn in different settings. Striving for cohesion between personal interests and social context.	Perceptions of context. Perceptions of assigned tasks, grading practices. Establishing social/ teaming interactions.	Monitoring and modification of context. Elimination of distractions. Negotiation of tasks and requirements. Managing social interactions.	Evaluation of task demands. Evaluations of contextual factors. Change of environment.

Pintrich self-regulated learning conceptualization, with the addition of an 'Intention' phase taken from the adult learning literature, which describes the initial student processes that have a large impact in open learning environments. This integrated framework facilitates analysis of the student responses in a manner consistent with concepts presented in self-regulated learning theory, adult learning theory, and self-determination theory.

4. METHODS

4.1 Subjects

Participants were undergraduate students from three engineering majors (engineering, mechanical engineering, and electrical and computer engineering) at a small, private, undergraduate engineering school. The sample of students included all classes, from first-year students to graduating seniors. The institution's engineering curricula emphasize project-based learning and other forms of open-ended exploration and self-study.

4.2 Measures

A survey instrument was administered to the entire student body in spring 2006. The survey included several parts: demographic information, quantitative survey items based on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree), and short answer survey items regarding students' self-directed learning experiences in their college courses. This article focuses on the short answer survey items.

Of the approximately 295 students at the college, 197 completed at least a portion of the survey, representing a 67% response rate. The gender (47% female, 53% male), age, and major distributions of the respondents closely matched those of the student body. In the quantitative portion of the survey, virtually all respondents reported that they had taken part in at least one SDL experience during their time at the college; most reported four or more such experiences. Of the 197 students who participated in the study, 159 students provided responses to the open-ended, short answer survey items used in the present study. Respondents to the short answer survey items included 77 females (48%) and 82 males (52%).

The open-ended, short answer portion of the survey included five items that prompted students to define self-directed learning and reflect on the effective and challenging aspects of SDL. The three survey items analyzed for this study are as follows:

1. Provide a definition of self-directed learning,
2. List the features of self-directed learning that you think make it effective, *and*
3. List the features of self-directed learning that you think make it challenging.

4.3 Analytic strategies

Student responses to short answer survey items 1-3 were coded according to their identification or inference of particular self-directed learning phases and areas shown in the Table 3 framework, e.g., Intention-Cognition, Planning-Motivation, Reflection-Cognition, etc. Many of the individual responses related to multiple phase-area codes. Several responses were sufficiently vague to make coding unfeasible, and a few responses noted concepts that did not correspond to the phase-area codes.

5. RESULTS

Student responses to the short answer survey items 1–3 provided respective totals of 320, 359, and 326 relations to the phase-area codes within the framework described in Table 3. The distribution of these relations is summarized in Fig. 2. Here each subplot indicates the number of student responses to each survey item for each phase-area coding. For example, examining the cognition-intention subplot, we see that a large number of survey item 1 responses (definition of SDL) address this phase-area combination, while very few responses to survey item 3 (challenging aspects of SDL) appear in this phase-area. In other words, student definitions of SDL often contain references to recognizing one's own learning needs, to choice of topic and to flexibility, but very few students identify these considerations when asked what makes SDL challenging.

Student definitions and comments tend to cluster in particular areas and in particular phases. Responses are heavily weighted toward the Cognition area, indicating that engineering students consider thought or reasoning processes to be an important component of SDL, and an attribute of SDL that may provide for both effective and challenging experiences. Examination of the subplots within the Cognition row shows that student responses are focused on the 'action' phases of planning-forethought (e.g., goal setting and selection of resources) and monitoring-control (adaption of learning plan, self-evaluation of processes), and to a lesser extent on the intention phase (e.g., learning needs assessment). Subplots within the Motivation row of Fig. 2 show that student motivations are strongly emphasized at the *start* of SDL experiences. Few student definitions of SDL include motivations beyond these initial phases, and comments regarding motivations sharply decline once the monitoring and control phase begins. The subplots within the Behavior row indicate that students are aware of aspects of SDL such as time and effort management, but that their behavioral considerations are limited to the action phases of SDL. Many more student remarks about behaviors reflect the challenging aspects than the effective aspects of SDL, and comments on behavioral challenges appear most frequently with regard to the monitoring and control phase. Subplots within the Context row

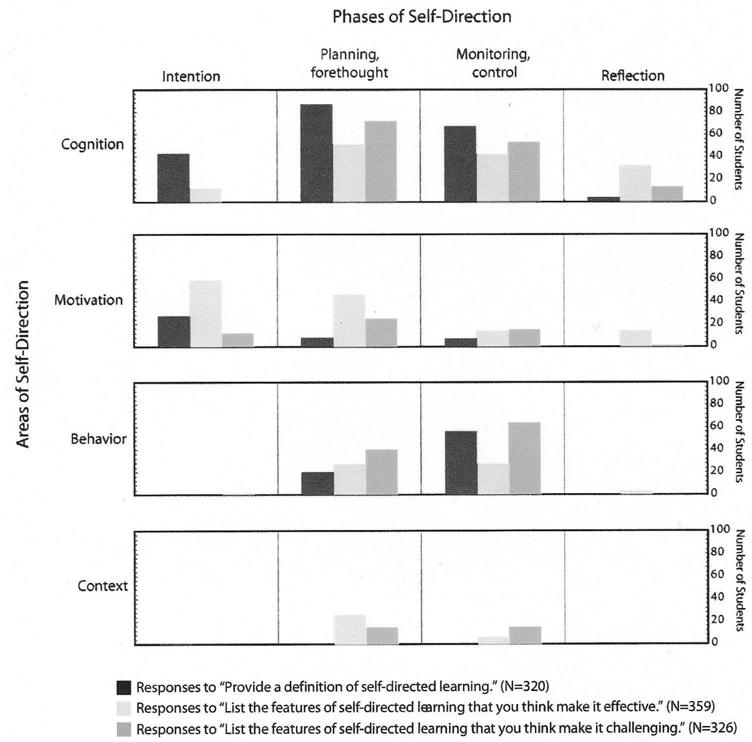

Fig. 2. Results from coding of three short answer survey items according to the self-directed learning framework. N = 159. Each subplot indicates the number of student responses coded for a particular phase and area of self-direction. For example, many student responses to all three questions dealt with cognitive aspects of the planning phase, while cognitive aspects of the reflection phase appeared primarily in answers to the second survey item (effective features of SDL).

of Fig. 2 indicate that few students identify environmental factors as challenging or effective components of SDL, and few students include aspects of the classroom climate in their definitions of SDL.

The Reflection phase subplots (right column of Fig. 2) reveal that a relatively small number of students identify reflection as a component of SDL. Nearly all of the comments about reflection lie in the cognition area, and most of these are related to students' positive views of their learning achievement.

In the sections that follow, we summarize and discuss the kinds of comments that students made for each survey item as they map to the framework. We then discuss some of the implications of this study for the design of SDL experiences. By presenting SDL from the student perspective, and in the words of student participants, we hope to gain insights that enable us to be better designers of SDL-supportive curricula.

6. DISCUSSION

6.1 Student definitions of SDL

Coding of the SDL definitions (survey item 1) reveals that students are concerned primarily with the cognitive aspects of learning that occur during the planning and monitoring/control phases (Fig. 2). Many students are quick to recognize the importance of learning need recognition, goal setting, and selection of resources and strategies. Students often defined SDL as a learning situation that has an end goal, methodology, and topic chosen by the participant. Comments on self-directed goal setting and strategic planning are not as widespread in responses from the first- and second-year students, however, and younger learners sometimes describe SDL as 'learning in which you are provided with an end objective' or assume that 'self-directed learning is an education with individual goals intended to meet a professor's goals.' These comments could reflect students' well-developed processes for intrinsic goal framing or internalization of extrinsic motivations [41], or it could reflect a low sense of individual autonomy.

Students also cite the importance of monitoring and controlling cognitions throughout the learning process, and 'being flexible enough to understand when something on the proposed timeline isn't worth undertaking.' Metacognitive awareness appears in some definitions. For example, one student described SDL as 'understanding how you most effectively learn the material you're working on, and using that to your advantage.' As metacognitive strategy use is a key determinant of both motivation and performance in self-regulated learning [26], it is encouraging to see that undergraduates are engaging in these processes.

Many students connected cognitions and motivations in their consideration of content or knowledge acquisition. Since the subjects in this investigation include students from all four years of the undergraduate programs, and with varied number and intensity of self-directed learning experiences, the views on self-directed content acquisition were diverse. Some students define SDL as starting when they are 'presented with a topic or document or textbook' by the instructor, or when they 'get an open topic/questions and you have to come up with an approach/answer by combining many types of knowledge resources.' Other students highlight the importance of intrinsic motivation in content acquisition. These students connect learning to their own passions and interests, and they describe SDL as 'learning in which the motivation to learn a given piece of material is derived from your own motivations and not scripted by the professor,' 'learning for learning's sake,' or 'the opportunity to explore something that they find personally exciting or significant.' One first-year student made his concern for motivation clear by defining SDL as 'learning that is not per a curriculum of THINGS YOU NEED TO KNOW, but rather is based upon you . . . deciding what is important for you to learn.' These student comments are consistent with self-determination theory, which highlights identified value, personal agency, and choice as key aspects of intrinsic motivation [12].

Behavioral aspects are also identified in students' definitions of SDL, particularly in the planning and the monitoring/control phases of learning. Most comments regarding behaviors relate to setting a time or effort schedule, e.g., 'making your own timeline,' or to adaptive/selective help seeking, i.e., when you 'only go to a professor with questions.' Some respondents noted the importance of solving problems or 'going through academic material on one's own time.'

Many students commented on instructor support in structuring the learning process and identifying resources, but their expectations regarding the levels of support varied. Some believe that SDL involves 'professors who act more as consultants than teachers' and who are 'basically just a guide' for 'defining the 'ballpark' of learning' or 'double-checking connections made or concepts learned,' while others specify the need for a 'general structure . . .directed by the professor' and resolve that 'if a student determines they need a piece of information, and they ask their professor to provide it, the professor should answer or suggest a reasonable alternate resource.' Instructor support is obviously important to students, but their perceptions of the ideal level of support vary dramatically. This is consistent with Vygotsky's zone of proximal development concept, which highlights the importance of appropriate levels of instructor scaffolding in student learning [42].

Interestingly, definitions that referenced self-reflection were practically nonexistent. One student included 'evaluating knowledge of specified material' as a necessary aspect of learning, and a few students made mention of deliverables or grades, but no one commented on self-evaluations of performance, understanding of outcomes, or attributions of learning outcomes to different cognitive, behavioral, motivational, or contextual factors. This failure to mention the critical reflection phase may result from different factors. Since students completed the survey within the undergraduate college environment, they may have considered only those course experiences that were described by their instructors as 'self-directed.' As such, students may have interpreted the survey question as 'Provide a definition of self-directed learning *in your courses*.' With this interpretation, it would be reasonable for students to assume that they may control aspects of the learning planning and monitoring, but that *evaluations are the responsibility of instructors*. Alternatively, students may have neglected to include reflection in their definitions because reflection is seldom emphasized in undergraduate engineering courses. Engineering students are frequently pushed to their limits during the end-of-semester crunch time; and 'successful' completion of completing projects, reports, designs, and examinations often relegates thoughtful self-reflection to an academic afterthought. The reflection phase provides a key opportunity for improvement of our curricula.

Only a few students included comments regarding the contextual or environmental attributes of the learning environment in their definitions. For example, some noted 'cooperation with teammates' and negotiation of evaluations as components of SDL. Since most theoretical models explicitly link classroom attributes to self-regulated learning processes and performance, it is somewhat surprising to see such little mention of these factors in the student SDL definitions. Similar to the self-reflection aspects of SDL, it could be that students in typical course settings simply do not have much control over the classroom environment, or that they perceive little control over the social interactions, assigned tasks, grading schemes, and instructor style.

6.2 Effective features of SDL

As observed in the SDL definitions, cognitive considerations once again rose to the top as the most cited effective features of SDL. Many students believe that SDL offers the opportunity for more effective learning. As one student noted:

> I think you tend to dive deeper into a topic and retain what you learn significantly better. Material that I learn in a traditional lecture format generally doesn't last more than a semester after I learn it, whereas material that I learned the first time in a self-directed way will be easier to reengage with and harder to completely fade away.

Students appreciate 'defining the scope of the learning' and 'the freedom to redirect learning,' and they note the importance of instructor support in initial direction setting and throughout the experience. Many students identify metacognitive gains in self-directed learning, such as the 'ability to learn HOW to learn,' and development of skills in self-observation and self-evaluation. They explain that SDL 'makes you think about how to get where you're going' and 'forces you to really understand what you are reading or working with, instead of just spitting back equations or information that have not yet been internalized.' In the words of one student,

> The best feature of self-directed learning is that it holds a mirror up to the student and shows him or her exactly what he or she can already do on his or her own, and what he or she should learn how to do before . . . the end of their schooling.

Students also identified motivation as a key aspect of SDL. Based on student comments, SDL can be fun. It 'allows room for passion' and 'engages one's creativity, which makes it very interesting and rewarding to do.' Students' intrinsic motivations play an important role in determining engagement, particularly in the early phases of the learning experience. As one student put it, SDL is effective because of the 'freedom to choose a subject you're passionate about.' Choice in the learning topics and goals provides a sense of personal control that serves as a boon to intrinsic motivation, and a 'sense of ownership and customization makes it exciting!' Freedom to explore an area of personal interest is also frequently cited motivational theme. These autonomy-motivation connections made by students are entirely consistent with self-determination research findings [19].

Effective aspects of SDL in the behavioral realm include 'learning at a pace that is comfortable,' the 'ability to modify and tweak around the schedule,' and 'relying on your own time management.' Students recognize that SDL teaches them to manage their time and efforts wisely, and they appreciate the opportunities to develop these self-regulatory abilities. Students also believe that 'there is 'bonus learning' that happens, not in terms of the content in the chosen area, but learning about organization, logistics, communication, yourself . . . all of those soft skills that are really valuable.'

In their discussion of effective features of SDL, students often explicitly connected cognitive and metacognitive factors with motivational or behavioral development. They report that self-directed learning 'helps one learn the material better as well as more enjoyably,' and allows students to see why they need to learn what they're learning.' One senior noted, 'it takes longer to learn a certain amount of information, but students learn it more deeply.' Another commented that SDL 'creates personal investment in knowledge gained, causing more productivity, higher retention, and deeper exploration.' Students' connection building between intrinsic motivation and cognitions/behaviors, and their acknowledgement of the dramatic beneficial effects of contextualization, personalization and choice to their learning, are well supported by social-cognitive educational theory [12, 26, 41, 43].

While students did not strongly identify self-reflection in their SDL definitions, the *effective features* survey item prompted a significant number of students to describe the reflection phase, especially with regard to their development of transferable skills and attitudes. In the words of one junior, SDL 'teaches a student how to think, NOT what to think—forces a student to take responsibility for her education to be successful, thus providing the student with life skills (versus physics knowledge, or ability to differentiate).' Students also reflected on the benefits to their self-confidence, independence, and self-efficacy, e.g., 'if nothing else, self-directed learning has taught me how to approach problems that seem impossible.' Many students expressed a sense of pride and satisfaction due to SDL, e.g., 'there is always a much more profound and lasting sense of accomplishing something when you aren't just doing a problem set.' The fact that students recognize reflection as an important and effective aspect of their experience, but do not call it out in the definition of SDL, is particularly interesting.

Some students mentioned effective features of the classroom context in their descriptions of SDL experiences. The choice of 'surroundings that they find most conducive to learning,' and the social interaction with peers were viewed as effective aspects of SDL. One student reported that, 'working in groups can also greatly improve learning, specifically when the skill levels are similar, so intelligent discussion occurs.'

Somewhat surprisingly, several students reflected on the benefits of frustration and failure in their discussion of *effective* features of SDL. One student noted, 'self-directed learning gives students the chance to fail. In that failure, more learning occurs than in any lecture,' and another commented that, 'students must wrestle with complex issues on their own. While this may initially be frustrating and confusing, once a student has made the necessary connections, his or her understanding of the material is much stronger.' These student comments identify a silver lining in the open-ended nature of SDL, in contrast to the larger number of comments in the next section describing student anguish resulting from independence and uncertainty.

6.3 Challenging features of SDL

The challenging aspects of SDL identified by undergraduate engineering students lie almost exclusively in two phases of learning: planning/forethought and monitoring/control. Student responses primarily indicated cognitive and behavioral challenges in SDL, although many students cited negative effects from motivational or contextual factors.

The reported cognitive challenges reflect students' difficulties with setting appropriate goals, selecting learning strategies, and identifying and acquiring resources. One senior responded that 'self-directed learning is challenging because students' efforts are often poorly guided or focused, and frequently stray beyond the bounds of their goals.' Students express concern that they 'could potentially choose a topic out of their reach' or one that 'doesn't challenge enough,' and they worry about 'not knowing enough to form a problem statement.' 'In the excitement, it's easy to get blown off course and spend a lot of time on something that's only tangentially related to your goal,' another student commented.

Students are also challenged by uncertainties associated with their learning or performance. Without feedback from experts, students feel unsure about their approaches or their ability to learn 'the right thing.' 'If you don't have an answer key,' a student notes, 'it can be difficult and frustrating to learn from mistakes without guidance.' Students express fears about learning things 'the wrong way,' 'learning the 'wrong stuff', 'not learning the 'right stuff', feeling totally on their own, 'losing focus on the goal,' or 'doing too much work because you aren't sure what you 'need' to know.' Students sometimes are left wondering if they are learning everything they are 'supposed to learn,' or if their learning is 'easily communicable to the professor . . . and whether it will be seen as academic or hokey.' Regarding goal setting and effort planning, one student compared SDL to problems sets:

> ' . . . there's always this sense that I'm constantly falling behind. Problem sets are nice because at the end of the day I can say, 'The Professor wanted me to understand these problems. I did them, I understand. Check.' Often times, independent learning lacks this sense of achievement and satisfaction.'

Many students listed the need for instructor support of cognitive processes. In the words of one junior, 'there comes a time when a student has banged his/her head against the wall long enough and it's time for the professor to step in and guide the learning at that point.' A lack of an instructor 'escape valve when things get difficult can make the experience frustrating,' and 'if you get lost, you're toast.'

Students note that cognitive processes often clash with behavioral processes. As one student put it, 'Without familiarity with the idea space, there is no way to schedule your time to be sure to hit the main points (or even to identify what the main points are).' Another student cautioned, 'some fundamental knowledge of the discipline must precede the experience. If one is thrown into the deep end, there still needs to be a lifeguard on duty.'

Students report significant problems with behavioral aspects of SDL, particularly time and effort management. Students find the planning phase particularly challenging, as they have difficulty estimating the required time for tasks. They frequently choose projects of inappropriately large scope ('it's very easy to bite off more than you can chew'), and they do not always know when to pause or stop their efforts ('sometimes projects just spiral toward death, and that sucks'). Students also struggle with self-discipline. They comment that ' . . .having few deliverables makes it easy to leave work until the last minute,' and that self-directed activities 'compete with more rigidly structured classes and obligations' and sometimes 'sink to the bottom of the priority list.' Negative comments regarding behaviors were often illustrative of students' honest affective responses. For example, one student stated, 'I'm lazy. At heart, I want to read the internet and hang out with my friends. I have little self-control when it comes to enforcing my own deadlines.' A senior responded, 'we're given just enough rope to hang ourselves— particularly in terms of allocating a sufficient amount of time to learn the material.' Several students pointed to challenges in transitioning from traditional learning to SDL, and students expressed frustration with unstructured activities in which 'the [learning] process is expected, but not taught.' As described by a sophomore, 'It is difficult to adjust from being spoon-fed the material in high school or some college courses to bearing most of the responsibility.' The transformation from controlled to self-directed learning is indeed a difficult one.

As much as intrinsic motivation can provide a boon to SDL, the lack of intrinsic motivation may serve as a significant impediment. Personal interest is essential, and 'everything falls apart' without it. Remaining passionately motivated is critical for some students, and when learning fails to provide these opportunities, they are left with 'no internal drive to force [themselves] forward.' One student illustrated his lack of motivation by describing an SDL experience as: 'someone just gave me something and told me to figure it out for myself, but I don't really care.' Self-efficacy, an important determinant of motivation, is highlighted in students' recognizing that SDL 'requires a strong sense of assertiveness and much willpower' and that 'self confidence issues make it a worse experience.' 'If a student is too timid and too afraid of failure, then they will not fail, and they won't learn as well.' For many students, commitment, desire, focus, curiosity, and positive self-regard are requirements for SDL success.

Students' recollections of challenging contextual factors primarily focused on difficult teaming interactions. 'Discouraging team dynamics,' or teams comprising individuals with different interests, styles, goals, or backgrounds, were all cited as challenging features of some environments. For at least one individual, SDL was described as a 'lonely' experience. Other contextual factors that appeared in students' lists of SDL challenges include avoidance of various distractions, instructor-assigned grades and task requirements, and management of the student-instructor relationship.

As implied in the discussion of the negative cognitive and metacognitive aspects of SDL, some students find reflection and reaction particularly difficult, but very few provided specific comments regarding self-reflective processes. One student mentioned that, 'real learning is difficult to realize without reflection and abstraction, which I find do NOT come naturally.'

7. IMPLICATIONS FOR CURRICULUM DESIGN

This study suggests a few key messages for instructors who wish to design courses that promote self-directed learning. The authors have identified the increase of student control, the use of self-reflection assignments, and the development of autonomy-supportive 'scaffolding' as three strategies to help instructors introduce SDL experiences into their classrooms. These strategies, as well as brief descriptions of the authors' experiences in implementing the strategies in their own courses, are described in the following sections.

7.1 Consider ways to give students control

The student responses described above illustrate the extent to which motivation is a critical ingredient for creating positive SDL experiences. Particularly in the intention and planning phases, intrinsic motivation strongly emerges as an effective aspect of SDL. For instructors, the implication is clear: providing students with the opportunity to link learning to personal interests and goals, as well as the chance to make choices and be in control, leads to greater student investment and more positive student attitudes about SDL. As instructors, we need to develop an understanding of the various ways in which we can enable different types of student autonomy, and how we may support autonomy throughout all phases of self-directed learning. The areas for student control in the curriculum should be consistent and clear in the minds of both instructors and students.

To promote high levels of intrinsic motivation and personal engagement in their own classrooms, the authors made use of project-based learning approaches that are autonomy-supportive and rich in exploratory opportunities. For example, the authors designed one introductory course as a series of projects that provided broad learning goals and loose constraints. This flexibility allowed students to identify the particular problem to be investigated and select project strategies (e.g., which experiments to run, what type of data to collect, how to analyze the data, how to synthesize experimental data with underlying theory and practical context, etc.). Throughout the semester the degree of instructor control decreased while the level of student discretion and responsibility gradually increased. By the end of the semester, the level of autonomy was extremely high. In addition to selecting their project topic, defining learning goals or research questions, and designing their project plan and experimental processes, students also acquired their own materials, identified supporting information resources, managed their in-class time, and defined their deliverable for the final project. Preliminary results from an ongoing investigation of motivation in the course indicate that the open-ended environment provides for high intrinsic motivation, low extrinsic motivation, and high valuation of the learning tasks.

7.2 Include self-reflection assignments in all courses

The results from this investigation indicate that self-reflection tends to be undervalued by students, and the authors believe that this may reflect an undervaluing of student self-reflection by instructors. Based on the low number of responses regarding the reflection phase, it seems clear that students in the preceding study regarded reaction to their learning as the purview of faculty. The fact that students do not identify reflection in their definition of SDL is particularly troubling, for it suggests that they may view reflection not as part of the learning process, but rather as a positive side effect that occasionally happens after-the-fact. It is, of course, heartening that students frequently refer to reflection as a positive feature of SDL experiences. However, most positive comments about reflection focus on learning process selections and performance (cognitive), and on time management behaviors. Students rarely refer to their development of attitudes or motivations, or to their ability to interact with or shape their learning context, and they do not revisit their initial goals when the learning experience has ended. As instructors, it is important that we remember that learning happens not just in 'doing' (planning, acting, monitoring, and controlling) but also in reflecting.

To encourage thoughtful student reflection in their own classrooms, the authors implemented written self-reflection assignments at the mid- and end-points of the semester. The reflection assignments provide an overview of the various areas of self-regulation (cognitive, motivational, behavioral, and contextual), and ask students to think about their own skills and consider how the course activities contributed to their development in one or more of the areas. In addition to the reflective essays, the authors implemented self-assessment assignments in some courses to further encourage reflection on learning. Shortly after completion of a project report, student teams assess their own submission in several competency areas, e.g., communication, qualitative analysis, and quantitative analysis. To facilitate these self-evaluations, the instructors provided detailed grading/self-assessment rubrics identical to those used by the instructors to evaluate student work.

7.3 Provide appropriate scaffolding for SDL skill building

Finally, there is clearly a need for instructors to develop better knowledge of the various aspects of SDL, with particular emphasis on ways of dealing with the challenges that arise in open-ended classroom settings. While some students applaud the confidence-building experience of overcoming unforeseen challenges, a greater number report frustration at the possibility of failing to 'learn the right stuff' or master unfamiliar information sources or research methods. Students entering college do not have all the necessary skills to master SDL without scaffolding and support from instructors; nor can they automatically understand how to balance and integrate their own goals, the instructor's goals, and disciplinary expectations when faced with an open-ended assignment. As instructors, we must design experiences to help students develop skills like time management, goal setting, and self-evaluation, so that students can become more autonomous as they progress.

The authors use a variety of techniques to balance student control with instructor support and guidance. For example, in one introductory-level course designed around three large projects, the first project serves as a self-directed learning 'training ground.' Students receive a comprehensive description of the first project's expectations, and they prepare a detailed plan of work for critique by the instructors. Students can choose their own project from a collection of 'mix and match' options selected by the instructors in advance, and student teams submit several progress reports prior to the project's deadline. In the second project, many of these supporting structures are lessened: students now have more latitude in selecting a project within broader constraints, receive minimal feedback on their plan of work, and have only one progress report. The third project is completely determined by the students, who now have complete control over their time, choice in topics, and freedom in setting goals and selecting learning strategies. Students in project three are welcome to ask for feedback from the instructors, but they do not have to do so. Assessment criteria for all three projects are clearly explained at the start of the course, and students become thoroughly familiar with experimental processes and report-writing conventions by the time the third project arrives. This structure attempts to introduce flexibility to the students when they are prepared to take advantage of it.

8. CONCLUSIONS

In this work, we have presented a framework for self-directed learning, and we have used that framework to analyze student definitions of and responses to SDL. We find that students define SDL as focusing primarily on cognitive tasks associated with planning and monitoring the activity, and that most students have no difficulty identifying several positive and negative aspects of SDL. Motivational considerations are frequently cited as significant positive aspects, while behavioral aspects (e.g., time management) are the most commonly noted negative aspects. These results reinforce the utility of our proposed SDL framework, which enabled us to organize student feedback and highlight future research goals such as increasing the visibility and perceived importance of student reflection; studying student attitudes throughout a SDL activity; and improving our understanding of the role of team dynamics in self-directed activities. Above all, we hope that this work provides engineering educators with an appreciation of the importance, likely benefits, and potential pitfalls of SDL approaches, along with new knowledge that enables them to be better designers of autonomy-supportive materials, environments, and curricula.

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