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Development of PBL Students as Self-Directed Learners

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How PBL Graduates Experience
Self-Directed Learning: A Phenomenographic Study

Abstract
This research paper describes the study of the impact of a project-based learning (PBL) curriculum on the learners' development of self-directed learning abilities. The motivation for this study is that self-directed learning (SDL) ability is positioned as one of the essential outcomes of engineering education. This can be seen in the following quote from the International Engineering Alliance[1] "The fundamental purpose of *engineering education* is to build a knowledge base and attributes to enable the graduate to continue learning and to proceed to formative development that will develop the competencies required for independent practice."

There are many terms that are used to describe the processes that are desired in and used by individuals when they acquire new knowledge. Metacognition, lifelong learning, self-regulated learning, and self-directed learning are among those terms most commonly used. The commonalities and differences of these concepts are presented in the paper in order to then describe the development of the self-directed learning abilities in undergraduate students.

This research is grounded in the prior works of others who have studied the changes of engineering students' SDL abilities across the four to five years of an undergraduate education. Compelling evidence is presented showing that students in a traditional, lecture-based, engineering education experience no significant growth as self-directed learners. Prior studies by multiple researchers indicate students experiencing PBL curricula have experienced significant growth. These studies all used the Self-Directed Learning Readiness Scale (SDLRS), a commercially available tool that has been administered to 120,000 adults and as been used in over 90 PhD studies.

The researchers developed a qualitative study in an attempt to characterize how the PBL graduates experienced self-directed learning. 27 PBL graduates were interviewed. A phenomenographic methodology was used to determine how the graduates experience SDL in their engineering practice.

The result of the qualitative study is a set of six different "ways of experiencing". In a phenomenography, the "ways of experiencing" are the outcome space. By studying and interpreting the different ways of experiencing, academic decision makers who are considering the implementation of PBL can contemplate how these results can impact their design decisions.

Introduction
Engineering outcomes have been prevalent for the past two decades. Upon graduation from university, new engineers enter the field of practice expected to perform well across technical, design, and professional skill domains. While some of the knowledge necessary to succeed in these domains may have been acquired in their education, much of what they need will be acquired, as it is needed, in their new capacity. Further, the

half-life of technical knowledge in the profession is often stated to be between 2-7 years[2], meaning new learning will be a continual event throughout a 30-40 year career. The recruiter of new engineering students for a PBL engineering curriculum often engages potential students with this commentary:

> "I'd like you to visualize your first day of work after graduation. Let me tell you two things that are not going to happen on that day… two things your new boss isn't going to say. First, she won't say "*Greetings John, welcome to ABC Engineering, we are glad you are here. I would like to introduce you to Dr. Jill. We have hired her to be your professor. When you need to learn something new, Dr. Jill will be here to teach it to you*."
>
> The second thing she is not going to say is *"Here are some textbooks. Each week, your job is to do the problems at the end of each chapter. If you get them correct, we will issue you a paycheck. At the end of each month, we will give you some written exams. Your performance on the written exams will determine the amount of your bonus."*

This story resonates with the students. To this point in their engineering education, nearly all of their learning has been one-directional from an instructor and nearly all of their performance has been through the completion of closed-ended chapter problems and written exams. They know this is what they neither expect nor want as the duties of their profession. Therefore, they struggle with this misalignment of activities during college, with these expectations after college.

Lifelong learning, self-directed learning, self-regulated learning, and being metacognitive are all terms used, often interchangeably, to address the outcome expected of new graduates. The definitions, similarities, and differences are addressed below. However, a summary is that new engineering graduates are expected to be able to acquire new knowledge efficiently and effectively and be able to use it to solve complex, ill-defined problems quite different than those at the end of a chapter in a textbook.

Research Question

"How do PBL students experience self-directed learning?"

Methodology

The perspective of the research is interpretivist/constructionist/situational. A phenomenographic methodology/method was selected. The mixed-methods approach is to perform a quantitative study to confirm the hypothesis from the literature. Then, perform a phenomenographic qualitative study to seek to understand the SDL experiences of PBL students.

The research question: "How do PBL students experience self-directed learning?" is addressed in this study by investigating students' conceptions of the phenomenon of self-directed learning. Svensson[40] defines phenomenography as the study of "peoples' lived experiences and conceptions". This study analyzes how the PBL students experience and conceive the development of their self-directed learning ability.

Phenomenography aligns with the study by specifically describing the collective variations of how PBL students conceive self-directed learning. This collective variation, described as the outcome space, was identified through structured, one-on-one interviews between the students and the researcher, in a non-dualistic engagement, to explore their experiences. This method's appropriateness will be confirmed through its ability to provide value, beyond the study, to others wishing to consider how PBL can benefit the development of SDL abilities of engineering students in other environments[41].

Method

"Analysis is guided by the research questions of the study. During analysis, the researcher seeks an empathetic understanding of what is involved in the phenomenon of study derived from interviewees' descriptions of what it means to them. The researcher tries to maintain a participant perspective assuming the interviewees experiences and ways of reasoning are logical, even if they do not appear as such at first. Phenomenographic analysis is an hermeneutical process."[42]

Dahlgren and Fallsberg's[43] eight-step model for data analysis was chosen for this research project. The steps are 1) familiarization, 2) compilation, 3) condensation, 4) grouping, 5) comparison, 6) naming, 7) contrastive comparison, and 8) create a hierarchy. Based on this work, an outcome space was developed. The outcome space includes both the referential aspects, which are the global meanings of each conception, as well as the structural aspects, which are the features of each referential aspect[42].

<u>Selecting Participants for the Study</u>

Marton and Booth[44] advocate for selecting a wide variety of participants so that the widest possible variations of experiencing can be identified. The number of participants in a typical phenomenographic study is 15-30[45].The group to be studied included the PBL students graduating from a PBL engineering program in the 2014-2015 academic year as well as recent graduates. 27 people participated in the study. Selecting this population allowed for a wide possible variety of conceptions, while still being in a range that is reasonable for the time intensive transcription and data analysis. Table 1 displays the demographic data of the participants. Each of the divisions closely parallels the overall population of the PBL engineering program.

The participants in the study experienced a PBL curriculum where the project was central to all technical, design, and professional learning for both years of their upper-division study. As contrasted with a PBL course, where projects are central to the learning in the course, in the PBL curriculum, the project is central to the entire learning experience. The PBL model under study was adapted from the Aalborg University (Denmark) model.

Table 1. Demographic information on participants

Demographic Category	Number
Male	**23**
Female	**4**

Under 25	*17*
25 and Over	*10*
Mechanical	**13**
Electrical	**8**
Other Engr. Major	**6**
Graduate in practice	*15*
Student near graduation	*12*

Collecting Data

Data was collected by audiotaping the interviews and transcribing them verbatim. The first questions were used to help the interviewee become comfortable and for the interviewer and the interviewee to arrive at a common language. Following the introduction, structured questions, aimed at the phenomenon of self-directed learning, were asked. A pilot interview was employed, as a test case, for learning how the interview process worked, vetting the interview questions, and learning from initial responses to further develop questions used in later interviews (an accepted phenomenographic technique per Limberg[42].)

The initial questions aimed to look both backward and forward:

> "Think of a technical topic where you took on the greatest level of ownership in the learning, describe the self-directed learning processes you used to complete the study."

and

> "In a few months you will be in the engineering workforce. Describe how you will use self-directed learning processes to acquire the next technical competence you will be required to attain."

Following the protocol of phenomenographic interviews, follow-up questions were then asked to empathetically seek out, as deeply as possible, the perspectives and experiences from the students, without imparting the views or perspectives of the questioner[46]. It is, however, necessary to recognize that the topic is jointly explored between the researcher and the interviewee[45]. It is just that the researcher must "bracket" his or her views to prevent imparting beliefs onto the interviewee[47].

Validity

Verification of a phenomenographical study is addressed through the generalizability of the work and the role of the researcher(s). Validity can further be addressed through the use of quotes from the participants in the analysis as opposed to only the interpretations of the researcher. In this study, quotes were extensively used to put the words of the participants' front and center for the reader to interpret their thoughts.

The intent of the study was to provide knowledge for others to consider as they contemplate the implementation of PBL or the development of self-directed learning skills in students. The outcomes of the study have been purposefully generalized for use by others. The assessment of this generalizability will be determined by the extent to which others ultimately use the work.

The role of the researcher is openly discussed as being intimately intertwined in the lives of the participants and the implementation of the PBL program under study. This intimate role is recognized for the value it might add and for any adverse effects it might have. Several steps were taken to minimize adverse influence of these relationships on the outcome of the work. The steps include the following: performing a pilot interview that was observed by colleagues, having other researchers perform some of the interviews, blinding the identity of participant's transcripts to the researcher during analysis to minimize the influence of previous shared experiences on the interpretation of results, and being explicit with the interviewees in regards to desire for openness.

The outcome space comes from identifying the different ways that the participants experience SDL. Each participant, at some point during the interview, communicated his or her views on self-directed learning. The responses seemed to take on a definitive tone. For example: "…being responsible and taking over without being told what to do" or "…you develop a set of skills to where you learn an efficient process that helps you acquire new knowledge at a faster rate than you normally would." As all responses were being aggregated, key words and phrases began to emerge. The key words included: Independence, ownership, responsibility, value, outcome, management, efficiency, initiative, learning, motivation, effectiveness, future use, evaluation, process, control, behavior change, researching, retention, continuous improvement.

A quote was extracted from each transcript in an effort to capture each individual's way of experiencing self-directed learning. After multiple readings, the 19 key phrases above began to combine through interpretation of common meaning into fewer categories. For example, initiative and motivation as seen in these two excerpts "…*you have the skills and ability to recognize when you need to know more than you currently do or you have a desire to and you take the initiative to find ways to learn it…*" and *"...that I pick something I'm motivated to learn about, instead of someone just telling me to do something…*" were combined into one category where the intents of the students seemed similar. Further, the new categories began to develop distinct boundaries from one another. An example boundary would be how some students were focused on who was doing the learning (independence or responsibility) while other were focused on the outcome of the learning (future value or effectiveness) others were focused on the process of learning (managing the act), and still others were focused on the impetus for the learning (motivation or initiative). Six primary themes emerged.

Related Theories and Frameworks

There are many terms that are used when describing the processes that are desired in, and used by, individuals when they acquire new knowledge. Metacognition, self-regulated learning (SRL), and self-directed learning (SDL) are among those terms most commonly used. Of further interest is the motivation that empowers the learner to initiate and continue as a self-directed learner.

Metacognition

Flavell and Brown are often credited with bringing the concept of metacognition to the forefront[3] through their writings of the late 1970s and early 1980's. As a term and an entity, mostly due to its complexity, metacognition itself is "fuzzy" and both hard to understand and to describe[4]. Flavell's first written definition of metacognition in 1976 was " 'Metacognition' refers to one's knowledge concerning one's own cognitive processes and products or anything related to them, e.g. the learning –relevant properties of information or data….Metacognition refers among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data on which they bear, usually in service of some concrete goal or objective."[4,5]. Dissecting this quote, metacognition involves the following: knowledge, monitoring, regulation, and organization all in regards to learning goals. Another conception of metacognition is that it has two parts, a metacognitive knowledge and metacognitive processes[6]. Where metacognitive knowledge is an understanding of how learning happens in both a general sense and a personal, individual sense[7], metacognitive processes are actions taken such as self-monitoring, judgment, and regulation[8].

Self-Regulated Learning

Zimmerman and Schunk are credited as being at the center of bringing self-regulated learning into the forefront of discussion[9-11]. In turn, Zimmerman and Schunk credit their work to the inspiration of Albert Bandura[12] as well as Paul Pintrich[13]. Research began to emerge on how people develop self-regulated academic learning in the 1980's[14]. As with metacognition, there are many perspectives to consider when defining self-regulated learning (SRL).

In 1986, Zimmerman first defined SRL: "Students are self-regulated to the degree they are metacognitively, motivationally, and behaviorally participants in their own learning"[15]. A key to SRL is that the "learner displays personal initiative, perseverance, and adaptive skill" when pursuing her learning[14]. Further features of SRL include students' "self-oriented feedback loops" and the students' choices of learning processes, strategies, and responses[14]. Key components in SRL are planning, goal setting, strategy selection, environmental monitoring, help seeking, and maintaining a sense of self-efficacy[12].

Whereas metacognition covers all aspects of the person, tasks, and strategies from both the knowledge of and process using domains, self-regulated learning is more focused on using metacognitive aspects to excel, to become better at self-regulating one's own learning. Self-regulated learners use metacognitive skills and knowledge to[16]:

- Set better learning goals
- Plan to achieve goals through strategy selection
- Establish productive learning environments
- Implement strategies
- Monitor goal progress
- Adjust strategies
- Seek assistance when needed
- Expend effort

- Persist
- Evaluate
- Set new goals

Self-Directed Learning

In a presentation at Harvard in 1952, the revered psychologist, Carl Rogers, stated this view on learning: "I have come to feel that the only learning which significantly influences behavior is self-discovered, self-appropriated learning. Such self-discovered learning…cannot be directly communicated to another"[17]. Further, "The discipline necessary to reach the student's goal is a self-discipline and is recognized and accepted by the learner as being her own responsibility"[18].

In the relevant research on self-directed learning (SDL) in engineering education, Candy's work[19] is often cited[11,20,21]. Candy describes SDL as consisting of both product and process, each of which, he again subdivides. "Self-direction… refers to four distinct (but related) phenomena: 'self-direction' as a personal attribute (*personal autonomy*); 'self-direction' as the willingness and capacity to conduct one's own education (*self-management*); 'self-direction' as a mode of organizing instruction in formal settings (*learner control*); 'self-direction' as the individual, noninstitutional pursuit of learning opportunities in the 'natural social setting' (*autodiaxy*)"[19]. Personal autonomy and self-management would be the products of having attained some level of being a self-directed learner; whereas, learner control and autodiaxy would be processes of using self-directedness in learning in formal and informal settings. If an outcome of engineering education is to have students ready to face the workplace as self-directed learners, it would seem desirable to have them acquire the attributes of personal autonomy and self-management so that they can learn autodidactically in their engineering workplace.

Self-directed learning and PBL

"The SDL emphasis is a distinguishing feature of PBL. In PBL, students become responsible for their own learning, which necessitates reflective, critical thinking about what is being learned[22]. In PBL, students are asked to put their knowledge to use and to be reflective and self-directed learners."[23]

Barrows and Kelson[24] identify five goals behind the design of PBL instruction. Self-directed learning is explicitly stated. The goals are the following:

1) construct knowledge;
2) acquire problem-solving skills;
3) become self-directed learners;
4) develop effective collaborative skills; and
5) enhance intrinsic motivation to learn.

The act of engaging in SDL is an essential component of the student learning in PBL. Whether this is implicit for the students or made explicit by their facilitators, the students are involved in the practice of SDL when performing PBL. There are several elements of self-directed learning that are directly supported in project-based learning environments;

they are the following: awareness of what they do/do not know, making learning goals, planning their learning, selecting strategies, monitoring goal attainment, and evaluating learning[25].

Self-determination theory

PBL gives students more opportunities to have control over their own learning. This ownership creates increased motivation to learn[26].

Metacognition, self-regulated learning, and self-directed learning, as described above, represent the set of knowledge and actions taken by self-directed learners. Inherent in these concepts is a continuum of sophistication. At the low end of the continuum, the knowledge and actions are tacit and result in lower levels of learning. As the knowledge and actions become more explicit and intentional, the level of learning increases. An element needing further discussion is the role of motivation in causing the learner to start any phase of a learning cycle and impact the levels to which the knowledge is accessed, and the actions are executed. Self-regulated learning acknowledges that motivation is necessary to start any phase in the learning cycle. Schunk and Zimmerman[16] identified personal attributes that impact motivation such as one's own personal competence and causal attribution. Self-determination theory provides a different framework for interpreting the impact of motivation on self-directed learning.

Deci and Ryan developed self-determination theory (SDT) in the 1980's[27]. SDT is an organismic theory from a Piagetian point of view, meaning that humans are naturally inclined to "elaborate their cognitive schema and representations of themselves and their world in a systematic and organized manner"[28]. SDT is a "theory of motivation concerned with supporting our natural or intrinsic tendencies to behave in effective and healthy ways"[29]. Within SDT are six mini theories addressing the variety of topics from *intrinsic motivation* to relationships motivation[29]. The two mini-theories most applicable to self-directed learning are cognitive evaluation theory, which addresses *intrinsic motivation*, and organismic integration theory, which addresses *extrinsic motivation.*

These two mini-theories are based on three basic psychological needs: *competence*, *autonomy*, and *relatedness*. *Competence* refers to the belief that our learning actions are resulting in a gain of competence. Examples of learning actions that do not result in feelings of competence are actions that are perceived as either too easy (not worthy of time spent) or too hard (not achievable). Thus, optimal learning challenges can lead toward meeting the needs of competence, as can positive feedback and freedom from demeaning evaluations[27]. *Autonomy* in this context is where the learner perceives choice and opportunity for self-direction as being present in the learning environment. *Relatedness* is the feeling of belonging and connectedness in the learning environments. Self-determination theory holds that when these three basic needs are satisfied, self-motivation and well-being are enhanced. Whereas when they are inhibited, motivation and well-being are diminished. *Intrinsic motivation* occurs when the learner finds the topics interesting, challenging, and engaging. The levels to which these three basic psychological needs are met impact the levels of *intrinsic motivation*. When learners are more intrinsically motivated, they perform better, persist, and achieve higher levels of self-esteem, well-being, and interest[27]. However, *intrinsic motivation* to learn only happens when the only desired outcome is the learning itself. In other words, it happens when no external factors such as grades, degrees, career progression, etc. are present. These considerations make the motivations extrinsic.

This positions self-determination theory as a further connector between PBL and SDL. PBL is highly dependent on the social interactions between group members. Thus, PBL learning environments provide many more opportunities for the psychological need of *relatedness* to be met. Further, PBL theory is dependent on participant-directed learning. When participants direct their learning, they are acting much more *autonomously* than when in lecture-directed learning. Higher levels of *relatedness* and *autonomy* mean more motivation, volition, and engagement. More motivation, volition, and engagement mean higher levels of performance, creativity, and persistence[27], which mean higher levels of self-directed learning[30].

De Graaff and Kolmos[31] report it is "very common experience that students are more motivated and work much harder [in] the PBL model than [in] the traditional teaching model". Self-determination theory applied to the principles of PBL theory would predict this increased motivation and effort expenditure.

Self-determination theory would predict that students in PBL environments would have more opportunities to develop the motivation, volition, and engagement to achieve higher levels of self-directedness.

<u>Previous works</u>
From the literature, there is evidence that self-directed learning has become a highly valued outcome of engineering education[11,20,32-34].There is a pattern of quantitative research indicating that a traditional engineering education results in little, if any, development of self-directed learning abilities[20,35-37]. Further, there is a pattern of research that indicates project-based learning can result in SDL development[20,21,32,34] Guglielmino's self-directed learning readiness scale (SDLRS) has been validated and widely used to measure self-directed learning readiness[20,21,34-36]. SDLRS results The SDLRS can be used to predict success in PBL[36].

Explicit self-directed learning skill acquisition and scaffolding should be included in the curriculum[38,39]. Student ownership in choice during instruction is key to the motivational aspect of SDL[10,32,37]. The basic psychological needs of competence, autonomy, and connectedness as identified by Deci and Ryan's self-determination theory can commonly be connected to the outcomes of this current research. Considering the importance, little work has been done to understand *how* engineering students develop as self-directed learners[37]. Nearly all works reported in the literature on self-directed learning are quantitative in nature, whereas qualitative approaches have promise[32].

Results - Phenomenographic Model
The primary themes represent how the participant identifies what self-directed learning means to them. The themes are *independence, managing the act of learning, owning the*

responsibility of learning, focusing on the value or future use of the learning, efficiency/effectiveness of the learning, and *taking initiative or being motivated*. Figure 1 shows the primary themes in a tree-map graph where the relative size of the box demonstrates the frequency of the primary theme.

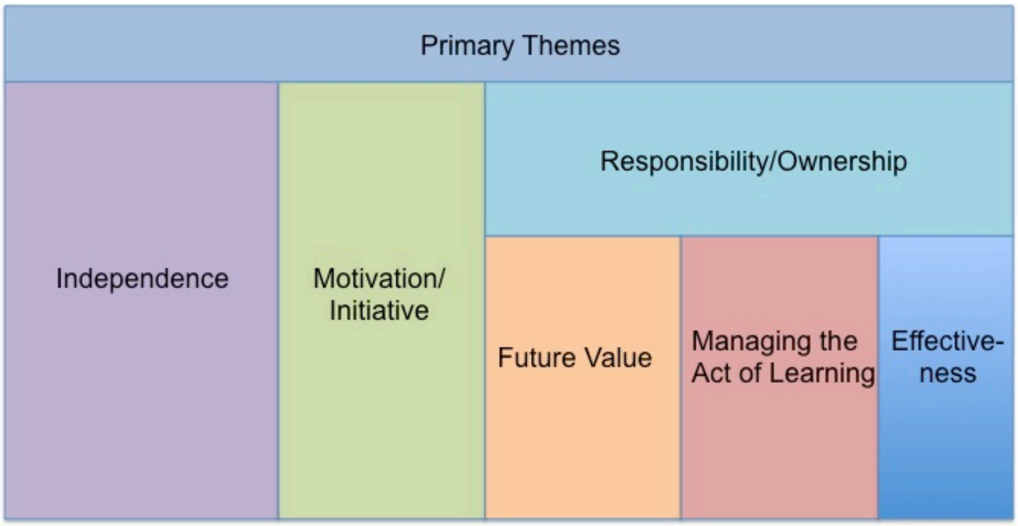

Figure 1. Differing perspectives of self-directed learning

Following, under the headings described in figure 1, are the ways in which the PBL graduates describe self-directed learning. These descriptions, in the words of the PBL participants, indicate the differing ways they experience self-directed learning.

<u>*Independence*</u>

Independence, as experienced by the participants, is the view of self-directed learning as being done completely by the individual without any help from or even any interaction with others. They view themselves as being on an island alone.

> "*…being able to work through things on my own and be independent, um, not having to bug other people and constantly go running to someone for what's going to happen, what needs to happen, say, in a job or in a project, and being efficient and working, being self-directed, being efficient and knowing the best way to get to things."* [person L]
>
> "*…going out to find information independently um, and learn the information to be able to use it in the future ...so everything that I've done has been I guess by myself and then that requires self-direction in order to learn the material*." [person I]
>
> "*It's just your own methods of figuring out how you're going to learn the techniques that you to need to do to solve that problem. It's basically not somebody telling you how to do it; it's figuring out how to do it yourself in a broad sense*." [person G]

Motivation / Initiative

The learners consider self-directedness of self-directed learning to be the act of beginning. They focus on the desire to learn as being more important than the acts of learning. They view the aspiration to start and continue the learning as being self-directed.

> "*That I pick something I'm motivated to learn about, instead of someone just telling me to do something. So it gives me a passion behind it, which I think in turn makes me remember it and care about it more*." [person J]
>
> "*…it's either something that you're interested in or you see as an opportunity area that you take steps, you take steps to I guess get better at that certain skill set.*" [person H]
>
> "*…means having the motivation um, to be able to obtain the resources that you need to be able to achieve a certain goal*." [person T]

Responsibility / Ownership

In this "way of experiencing",f the participants view the learning as being directed by themselves. They take accountability for the actions of learning. They view themselves as the "CEO" of their learning.

> "*…being responsible and taking over without being told what to do*." [person Q]
>
> "*I take responsibility for my learning; I don't leave it up to an instructor per se. If they present a topic or use a word or a concept, it isn't gone into detail in, in a course or during the lecture, learning conversation, I make a note, or make a mental note and I go research that and dig into, you know, what it is, you know*." [person W]
>
> *"I am solely responsible for the information that I want to learn or that I am able to learn."* [person AA]

Future Value

Here the learners were much less focused on the ownership, leadership, or management of the learning and more focused on the value of the learning. They view the learning as the final outcome rather than as the process.

> "*…you're learning something to make it, um, make it stick better or make it mean more instead of just reading to memorize or learning to get through a class, but to actually be able to recall it as useful information and be able to use it in some kind of application or other context later o*n." [person B]
>
> "*…you have kind of the ambition or drive to um, be kind of in a continuous state of improvement, um, I don't think that it necessarily means you're learning useless things everyday that you're never going to use, but kind of like, I look at it as continuously bettering yourself in your trade or the parts of your life where it kind of benefits you*." [person X]

Managing the Act of Learning
In this category, the learning rather than happening from some sort of top-down model with the learner at the top, is experienced with the learner in the middle managing all of the various actions and interactions. The learners view themselves as the "project managers" of their learning and recognize the involvement of others as being contributors to their learning.

> "*…researching a different subject or different topic that you're interested in and then going in depth and doing your own style of learning… finding your own pattern of how you learn effectively and then continuing to use it and if there's any extra like key things that you learn along the way, you know, you kind of learn how other people learn more effectively and maybe that worked for you so you pick up some ideas from them*." [person M]
>
> "*…the ability to, the ability to pick up, to develop new skills, or to, uh, consciously change your behavior by being the person that leads it, so rather, so for example, I think um, lectures could still be, could still be an aspect of self-directed learning, but rather than the professor determining the curriculum for the whole, no, whatever skill set you're trying to learn, it's, you're deciding what that skill set is. So lectures could for example, be a component of self-directed learning, but for me, I think the key is that, um, the learner is the main driver."* [person D]

Effectiveness
These learners, when experiencing self-directed learning, are concerned with the expediency and effectiveness of the learning. They view self-directed learning as being the level to which the processes are like lean manufacturing.

> "*It means the capability of achieving those resources through a systematic and efficient, time efficient way*." [person T]
>
> "*You develop a set of skills to where you learn an efficient process that helps you acquire new knowledge at a faster rate than you normally would*." [person P]

Secondary themes
The six primary themes were sometimes also mentioned as a secondary theme. For example in the following quote, the participant describes self-directed learning as *managing the act of learning,* while also mentioning *effectiveness*:

> "*…researching a different subject or different topic that you're interested in and then going in depth and doing your own style of learning… finding your own pattern of how you learn effectively and then continuing to use it and if there's any extra like key things that you learn along the way, you know, you kind of learn how other people learn more effectively and maybe that worked for you so you pick up some ideas from them*." [person M]

To quantify, *effectiveness* was secondarily mentioned by six (of the 28) participants, *future value* was mentioned by four, *managing the act of learning* by two, and *motivation/initiative* by one.

Analysis of Phenomenographic Model
To identify similarities and differences between the categories, the theoretical perspectives are invoked. Lifelong learning, metacognition, self-regulated learning, self-directed learning, and self-determination theory, as well as Stolk's framework for self-directed learning[11], serve as a background to delineate the "ways of experiencing". Differences are highlighted as a particular category or categories that stand apart by not being a part of the language used in the descriptions. For example, self-regulated learning highlights *responsibility/ownership*, *managing the learning act*, the *future value* of the knowledge, *motivation/initiative*, and *effectiveness/efficiency*, but does not highlight the *independence* aspect, thus setting independence apart as being different. Likewise, similarities are identified through categories being common. For example, metacognition focuses on the categories of managing the act, future value, and effectiveness/efficiency. Following in Table 2, the 6 categories from the "ways of experiencing" are listed as they apply to the five theories. This table highlights the similarities and differences between the ways of experiencing categories.

Table 2. Categorization of ways of experiencing with respect to theory

	Lifelong Learning	Meta-cognition	Self-Regulated Learning	Self-Directed Learning	Self-Determination Theory
Independence	X			X	
Responsibility/ Ownership			X	X	
Managing the Learning Act	X	X	X	X	
Future Value		X	X		
Motivation / Initiative			X	X	X
Effectiveness / Efficiency		X	X	X	

As is portrayed in the following quote that was used to describe lifelong learning above, lifelong learning focuses on the categories of *independence* and *future value*. From the Washington Accord, "lifelong learning (is the) preparation for and depth of continuing learning: recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change." Person X demonstrated these beliefs:

> "*…you have kind of the ambition or drive to um, be kind of in a continuous state of improvement… I look at it as continuously bettering yourself in your trade or the parts of your life where it kind of benefits you*." [person X]

Metacognition is focusing on *monitoring the act of learning* and using the results of that monitoring (*effectiveness/efficiency*) to regulate the actions taken during the learning (*managing the act of learning*). Metacognition is done in the "service a concrete goal or objective (*future value*)"[32].

> "…*what process really worked for learning bearing calculations that I can apply and help me to learn the material faster, better and more thoroughly with the final element analysis?*" [person Z]
>
> "…when you execute your plan, make changes as you go, if needed. So you kind of have that feedback process throughout everything. And then once, let's say you learned it then that's when you kind of go for the final, did I actually learn it, it's kind of another feedback step, but it's more defined. There should be feedback in everything…" [person F]

While self-regulated learning includes in its title the word self, it is not characterized as independent in the way that the interview participants claimed independence. They leaned more towards isolation.

> *"...go out and learn basically on your own with very little involvement from, from an instructor or an outside source."* [person N]

To the contrary, SRL is not about isolation. Zimmerman[15] focuses on the self as participatory rather than independent: "Students are self-regulated to the degree they are metacognitively, motivationally, and behaviorally participants in their own learning". Further descriptions of SRL identify all other categories. This separates independence from the others.

Similarly, the theories of self-directed learning isolate one of these categories through omission. The category is *future value* of the learning. The future value may be implicit in SDL, however the other categories are explicitly identified. The theory of SDL focuses more on the processes of learning and attributes of the learner than on the outcome of the learning, as was stated above "A self-directed learner possesses the personal autonomy and self-management attributes necessary to employ her metacognitive knowledge and metacognitive actions in a self-regulated learning process while learning in either learner-control or autodiaxy environments."

Self-determination theory is explicitly focused on personal motivation. SDT addresses "the motivations that cause the learner to start any phase of a learning cycle and impact the levels to which the knowledge is accessed and the actions are executed. Self-determination theory provides a framework for interpreting the impact of motivation on self-directed learning".[27] This explicit focus on motivation by self-determination theory sets motivation/initiative apart from the other categories.

> "*I feel like I learn a lot better when it's more carefree than when something's pressure. Cause when you have pressure when it involves learning you stop caring about what, what you're actually learning. You find patterns instead. You find patterns, this, whenever this is, then this is going to be the result. And that's what happened with pressured learning. You no longer care about the thing, about what you're learning.*" [Person E]

Stolk[11] characterized self-directed learning in each of the 16 cells of the four by four matrix. The four columns represent phases of self-direction (intention, planning/forethought, monitoring/control, and reflection/reaction) whereas the four rows are the areas of self-direction (cognition, motivation, behavior, and context). To further compare the six categories of self-directed learning identified in this phenomenography, they can be placed in Stolk's framework:

-*Independence,* as described by the interview participants, is not well represented in the Stolk framework. It is implicit in many descriptors such as self-actualizing, self-recording, or self-observation, but not explicit in the way described by the interview participants:

> "*…going out to find information independently um, and learn the information to be able to use it in the future …so everything that I've done has been I guess by myself and then that requires self-direction in order to learn the material*." [person U]

-*Responsibility/ownership,* as described by the participants, was most aligned with the behavior area of self-direction:

> "*…taking that ownership and then um, forming your own plan for the direction that you want within your learning." [person 25] And: "I'm the one responsible for setting some sort of schedule to be able to learn it. Um, it means I have a vested interest in what I'm going to be learning, means I have to set some sort of timetable for myself."* [person G]

The descriptors, used by Stolk, that align with this category are choice to engage, planning, and acquisition of resources.

-*Managing the act of learning* aligns with cognition through need recognition, choice of topic, selection of strategies, and judgments of learning:

> "*…being able to know what you're, what you need to know. Uh so kind of defining it and then also know where to go and then kind of, how to, how to judge whether what you originally planned for was accomplished*." [person f]

- *Future value*, as described by the participants focused on use of the learning beyond the learning:

> "*…make it stick better or make it mean more instead of just reading to memorize or learning to get through a class, but to actually be able to recall it as useful information and be able to use it in some kind of application or other context later on."* [person X]
>
> Or:
>
> "*…more importantly than just learn it, you need to retain it and uh, you do that by repetition, practices. And then at the end of the day you can go up to anyone and explain exactly what you just learned in a way that you're comfortable doing it and saying it in an almost speaking voice*." [person H]

The Stolk attributes, which most closely align, are in the monitoring/control phase and cognition area where monitoring of cognition and metacognitive awareness are placed. The concept of making use of specific retention activities to "make it stick better" is not explicit in the Stolk framework.

-*Motivation/initiative* is a "way of experiencing" for the participants of this study. Motivation is an area of self-direction (row) in Stolk's framework and intention is a phase (column). The descriptions by students align with descriptors in the both the column and the row: need recognition, desire for growth, choice to engage, goal orientation, awareness of interests:

> "*…you have the skills and ability to recognize when you need to know more than you currently do or you have a desire to and you take the initiative to find ways to learn it…*"[person E]
>
> "*…means having the motivation um, to be able to obtain the resources that you need to be able to achieve a certain goal*." [person L]
>
> "*That I pick something I'm motivated to learn about, instead of someone just telling me to do something. So it gives me a passion behind it, which I think in turn makes me remember it and care about it more*." [person J]

-*Efficiency/effectiveness* is represented in Stolk's framework in the reflection/reaction phase through descriptors like self-evaluation of performance and outcomes, self-evaluation of efforts and actions, evaluation of task demands.

> "*It means the capability of achieving those resources through a systematic and efficient, time efficient way*." [person L]
>
> "*You develop a set of skills to where you learn an efficient process that helps you acquire new knowledge at a faster rate than you normally would."* [person P]
>
> "*…finding your own pattern of how you learn effectively and then continuing to use it and if there's any extra like key things that you learn along the way, you know, you kind of learn how other people learn more effectively and maybe that worked for you so you pick up some ideas from them*." [person B]

This phase of the phenomenography is intended to compare and contrast the different ways the participants experience self-directed learning. Through aligning the categories of SDL experienced with the theories and with the prior work done by other researchers, the similarities and differences of these categories have been highlighted.

Conclusion

In this study, we aimed to establish the importance of self-directed learning as an important outcome in engineering education and to identify it with the important theories of metacognition, self-regulated learning, PBL, and self-determination theory. From the literature, there is extensive quantitative evidence that PBL graduates developed self-directed learning abilities whereas traditional engineering graduates do not. This brought to bear a desire to understand how the PBL graduates develop these abilities. To understand this will take research from multiple perspectives. The purpose of this research study was to highlight one such perspective; the perspective of understanding how the PBL graduates *experience* self-directed learning. Through a qualitative, phenomenographical study, results were obtained highlighting six different ways the PBL graduates experience SDL. The model was described using the quotes from the study's participants. Using the previously presented theories and a framework from the literature, along with quotes from the participants, the model was analyzed.

The value of this work is in its potential use by curriculum decision makers who are considering implementing PBL curricula as well as the curriculum developers and implementers. The results can be contemplated as factors to be considered and addressed in the design of new structure and learning activities.

A critique of this work is that the participants of this study were graduates of one PBL engineering program while the results are being generalized to all PBL curricula. Another critique would be the intimate relationship that the researchers had with the program under study and the research participants. Further, a missing element in the study is the characterization of how non-PBL students experience self-directed learning. Each of these criticisms point to potential future work. The researchers could perform a similar protocol at another PBL institution and on students graduating from traditional engineering programs. These studies would broaden the perspective of PBL graduate development and would make the visible the differences in how PBL vs. non-PBL graduates could be characterized. It would also mitigate any adverse effects caused by the intimate relationships.

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