AC 2011-1727: SELF-DIRECTED LEARNING CONTENTION: FACULTY AND STUDENT VIEWS

Casey Canfield, Franklin W. Olin College of Engineering

A recent systems engineering graduate from Franklin W. Olin College of Engineering, Class of 2010.

Brittany Strachota, Franklin W. Olin College of Engineering

Brittany Strachota is a member of the Class of 2013, studying engineering at Franklin W. Olin College of Engineering.

Yevgeniya V. Zastavker, Franklin W. Olin College of Engineering

Yevgeniya V. Zastavker is an Associate Professor of Physics at Franklin W. Olin College of Engineering. Her research interests lie at the intersection of project-based learning and gender studies with specific emphasis on the curricula and pedagogies implemented in the first-year engineering programs.

Self-Directed Learning Contention: Student and Faculty Views

Abstract

Self-directed learning (SDL) is a pedagogical technique that is commonly practiced within the framework of project-based learning (PjBL) SDL has been found to be useful in the development of skills necessary for engineering careers, including open-ended problem-solving, life-long learning, and critical thinking. Implemented in a variety of ways, SDL is primarily characterized by developing student autonomy. According to Stefanou *et al.*'s framework, student autonomy can be promoted at three different levels: organizational, procedural, and cognitive. These three levels include varying degree of student choice: organizational autonomy takes into account the environment (e.g., due dates), procedural autonomy incorporates form (e.g., deliverable form), and cognitive autonomy involves content (e.g., designing projects). This range of possible SDL experiences allows for a wide interpretation of the role and value of SDL and student autonomy by both students and faculty. Using methods of grounded theory, three research questions were addressed: (a) How do the pedagogical practices in the first-year mathematics, physics, and engineering classes fit into Stefanou *et al.*'s autonomy framework? (b) How does the level of student autonomy impact student's participation, interest, and perception of performance in these classrooms? and (c) How do student and faculty perspectives on student autonomy affect the classroom environment? Our results indicate that students and faculty have mixed feelings regarding SDL, which drive frustration and discomfort with open-ended learning in the classroom. In general, students often do not feel well-supported in SDL environments and exhibit a lowered sense of competency and expectancy. On the other hand, faculty present blindness towards structural supports necessary for effective SDL classroom environment and specifically their own roles in scaffolding students' SDL experiences.

Introduction

Traditional engineering curricula are no longer adequate for training modern-day engineers. Today's engineers are expected to be creative, bold, technically well-versed team players to meet tomorrow's challenges in an increasingly complex and risk-averse global environment.[1] In response to these needs, engineering programs have begun a shift toward new curricula and pedagogies that have been demonstrated to be effective in building both technical and non-technical skills crucial to solving authentic problems in real-world environments. One such new curricular and pedagogical practice is Project-Based Learning (PjBL). In addition to developing both technical and non-technical skills,[2-3] PjBL has been shown to develop meta-cognitive abilities, as well as promote the acquisition and long-term retention of knowledge.[4-7] Based on the frameworks of Blumenfeld *et al*. (1991), Heitmann (1996), Morgan (1983), and Perrenet (2000), we define PjBL as a pedagogical method that may be a central theme or component of a curriculum.[2,7-9] A PjBL experience places emphasis on the application of knowledge over learning of theory through one or more overarching projects. These projects, which span more than one class period, often address real-world problems and tend to be interdisciplinary and group-work oriented. To encourage student engagement in and ownership of the learning process, faculty act as guides by supporting relevant content acquisition and providing scaffolding for learning, while students exercise autonomy by directing these open-ended projects themselves. Over the course of the projects, students create one or more significant physical deliverables to reflect their work. [2-9]

Central to an authentic PjBL experience are the constructs of student autonomy and self-directed learning (SDL). These PjBL aspects are meant to encourage students' initiative as well as responsibility for and ownership of their own learning. Hence, SDL allows students to serve as agents of their own learning. Students are given a high level of choice in learning activities to encourage connections to their personal goals as well as intrinsic and attainment values.[10] In cases where student choice is not possible, SDL is afforded by faculty providing clear rationale for the activity.[11] Recent literature discusses SDL effectiveness in the development of skills necessary for the engineering profession including open-ended problem solving, life-long learning, and critical thinking by encouraging a meaning-based approach to learning rather than a memorization-based one. What is more, SDL has been shown to enhance motivation, engagement, and expectancy for success in classrooms at all levels of students' educational trajectory.[10, 12-15]

Although cited for a number of benefits, recent literature emphasizes a need for proper support in SDL-driven environments. Specifically, SDL requires properly structured classroom autonomy support to encourage student participation, stimulate interest, and enhance student self-efficacy. Instructors play a significant role in SDL; Black and Deci (2000) found that autonomous self-regulation, perceived competence, and interest increase when students receive appropriate autonomy support from their instructor.[16] Autonomy support may take the form of listening to students, answering questions, and asking about student needs.[12-16] Although in SDL-supported environments instructors offer students opportunities to make choices, provision of choice alone does not automatically render an experience autonomous or serve to enhance student motivation. Based on the theoretical framework of Katz and Assor (2007), choice becomes motivating only when students' basic psychological needs for autonomy, competence and relatedness are met.[11] Students may be both intrinsically (having a strong desire to learn) and extrinsically motivated (e.g., through a desire for a high grade).[11,16] For the choices to encourage the development of intrinsic motivation, appropriate scaffolding must be provided to satisfy students' psychological needs, as well as address students' personal goals and values.[10-11] Effective scaffolding also guides students in making choices of appropriate complexity to encourage higher expectancies and value satisfaction.[10] By doing so, faculty address students' concerns about performance and minimize the level of anxiety related to extrinsic motivations.[16]

In a discussion of student autonomy, it is important to clarify the varying levels of autonomy and associated choice. According to Stefanou *et al.*'s framework, student autonomy can be promoted at three different levels: organizational, procedural, and cognitive. These three levels include varying degrees of student autonomy, ownership, and choice. Specifically, organizational autonomy allows for student ownership of the environment (e.g., due dates), procedural autonomy permits students' ownership of the form (e.g., choice of the final deliverable), and cognitive autonomy provides ownership of overall learning process (e.g., choice of the project design).[15] This range of possible SDL experiences allows for a wide interpretation of the role, value, and perception of the effectiveness of SDL by both students and faculty. To this end, our paper examines the views of students and faculty regarding the implementation of SDL strategies.

Specifically, this study explores the perspectives of students and faculty at a small, private engineering school that implements a first-year curriculum modeled around a PjBL environment with a range of SDL experiences and autonomy structures. The following questions guide our analysis:

- How do the pedagogical practices in the first-year mathematics, physics, and engineering classes at this school fit into Stefanou *et al.*'s autonomy framework?
- How does the level of student autonomy impact students' participation, interest, and perception of performance in these classrooms?
- How do student and faculty perspectives on student autonomy affect the classroom environment?

We argue that by providing clarity to students about the meaning and value of SDL experiences and addressing the issue of faculty blindness towards structural supports necessary for effective SDL classroom environment and specifically their own roles in scaffolding students' SDL experiences, the educators may be able to improve students' sense of competency and expectancy. This is of particular importance during the early formative experiences of the first-year engineering students.

Methods

Part of a larger, mixed-methods investigation at three engineering institutions, this paper focuses on one school, identified here as Eastern Technical University (ETU). This analysis is restricted to ETU's first-year mechanical engineering curriculum, which typically involves students taking Mechanics (ETU Physics), Calculus (ETU Math), Introduction to Manufacturing (ETU Engineering), and/or Introduction to CAD (ETU Design). Each course includes three components: lecture, recitation, and laboratory. ETU's curriculum generally identifies lectures as the main venue through which content knowledge is imparted, while the recitation sessions are primarily used as an opportunity to engage with the material through Q&A experiences and participation in group-work exercises. The laboratories serve as vehicles for specific skill development and attempt to create opportunities for students to apply abstract principles learned in the other portions of the class.

PjBL is mostly employed in ETU's Engineering and Design courses, while the Physics course exhibits some components of PjBL and Mathematics utilizes very little to no PjBL strategies. A semi-structured, open-ended, in-depth interview protocol was employed with twelve students and nine faculty. "Purposive" sampling was employed and the students interviewed were "matched" to those selected in other sites in terms of gender, major, and performance.[17] Three of the interviewed students and two faculty were female. Using grounded theory, the data were coded and narrative summaries were written based upon emergent themes.[18] Validity and reliability were ensured through a group process of codebook development and peer debriefing. Inter-coder reliability was at least 80% among three coders.[19] Further analysis included exploration and comparison of patterns within and among the identified themes through formal memos.

Results and Discussion

Student Perspectives

Students have mixed feelings regarding the definition, role, and purpose of SDL. Despite faculty intentions, few students describe autonomy and open-ended learning experiences as positive. Our data indicates that students hold serious misconceptions regarding the concept of SDL. For example, in several classes, particularly labs, students are instructed to learn at their own pace with the use of step-by-step directions. This activity is described by students as an open-ended experience despite the formulaic nature of the activity. When asked to describe an open-ended learning experience, one student describes using a manual distributed by the professor to build a car:

> *"Well [the professor] helps you out and stuff but there's some guidance but like not really. He gives us a kit, which was a manual and it had all the steps you do for the project, for the little car thing. So yeah [it's open-ended]"* (Interview 1, male student, 11/20/07).

While this activity may be described as type of a hands-on learning experience, it is not an open-ended one. Despite a few elements of organizational autonomy, the inclusion of a manual with "all the steps" is a lost opportunity for both procedural and cognitive autonomy development. In addition to stifling students' development as independent learners and failing to promote problem-solving abilities, such an environment may, in fact, be misleading. Specifically, students' expectations of rigid faculty-supported scaffolding (in this case, high level of hand-holding) conceived of by students as an "open-ended" experience leads to significant misconceptions about the meaning and value of both procedural and cognitive autonomy.

On the other hand, some students seem to believe that hands-on and self-directed activities do not provide a meaningful learning experience. For example, here is how a student involved in an extra-curricular activity to build and deploy a high-altitude balloon reflects on his experience:

> *"It's not like you're being lectured at, while doing a project, it's more of learning certain things through the projects that you do. Like, recently we had done […] a high altitude balloon launch, and I had learned a lot from that as far as concepts of lift generated by a balloon, and different factors that affect the flight of the balloon. Like, on board we had a camera that took pictures of the surroundings, and I learned some things about circuitry […] because we had a circuit attached to the camera so that it would take a picture every five seconds. So, as far as things like lift, and the concepts like radio frequency because we had a GPS aboard to show the flight path of the balloon. I thought that was very interesting to sort of learn by hands-on approach […]. I learn better in the classroom, just because it's more concrete, and you have concepts behind the project that you're doing, like actual lecturing learning rather than just having the people working with you explain just certain things to you […] you don't learn nearly as much as you do in the classroom setting"* (Interview 3, male student, 4/18/08).

While the student reports learning about a wide variety of subjects from both a practical and theoretical perspectives in this real-world learning experience, he still believes that he learns more from lecturing. The student is clearly able to make connections to theoretical concepts (e.g., lift and radio frequency). However, since this experience is not "concrete" and is not structured as a lecture, it does not, in this student's view, hold the value of a "true" learning experience. This statement may indicate that first-year engineering students expect a high amount of structure in their learning, lectures being one way of receiving a "true" and "concrete" learning experience. As a result, this need for structure may inhibit students' ability to develop a sense of competency in and value for alternative learning environments and diminishes development of life-long learning competency. This misunderstanding and underestimating by students of the value of SDL and autonomy in the learning process underscores the role of faculty in providing effective mentorship and support. In this particular example, the student is clearly learning through his project.[15] However, he is neither able to recognize the overall educational value of this experience, nor identify specific learning outcomes.

Students' inability to recognize the significance of SDL experiences may be understood through the lens of Katz and Assor's framework.[11] Specifically, a classroom environment must meet students' psychological needs for autonomy, competency and relatedness. While hands-on PjBL encourages autonomy, faculty must make a specific effort to ensure that students also develop a sense of competency and relatedness that may be more easily met by a traditional lecture-based teaching mode. To realize the full value of SDL and PjBL, students must have appropriate faculty guidance in and outside of the classroom.

Interestingly, students do recognize the value of self-directed learning when reflecting on independent activities associated with existing structured classroom environments. For example, several students observe the value of figuring out problems on their own without help or written directions. As one student explains, SDL encourages creativity and critical thinking:

> *"I spent one day where I was in the lab for a good four hours just trying to figure out this part […] and I didn't have a TA or a teacher there so I had to, you know, try and figure it out on my own […] I like that, having that independence to try and figure out how, you know, trial and error versus someone just telling you step by step, what to do. […] I just feel like there's a sense of creativity and freedom in doing it, and you really do have to think about what you're doing, which I like, versus just parroting what they tell you to do in class"* (Interview 2, female student, 4/18/08).

This student recognizes the value of SDL in encouraging motivation, interest, and performance. In just this short exercise, where the student primarily experiences organizational and procedural autonomy, she expresses the sense of increased attainment value and potentially higher expectancy.[10,15] While high levels of structure is expected from the lecture portion of the curriculum, the labs allow students to engage in some SDL activities. To emphasize the range of student perspectives, it is important to note that this student reports that she had learned more through an SDL approach while the previous student indicates he had learned less despite a higher level autonomy Clearly, students have varying comfort levels with the unstructured nature of SDL experiences and may misjudge their resulting competency and expectancy (e.g., self-efficacy).[10]

In general, appropriate scaffolding and levels of complexity need to be established in classroom environments to ensure that students are not overwhelmed by SDL experiences and such experiences improve students' expectancy.[10] It is easy for students to have negative experiences that drive them away from engineering if appropriate support structure is not in place. Here is how one student involved in a team robotics project with little faculty support describes her experience:

"I was like […] I don't know what to do and I felt devastated because I didn't know how to program, we didn't have a book either so I was basically kind of lost and I would ask people for help and yeah they would show me what to do and I would understand it but when it came to test time, I was just a little unsure of myself. […] I felt very disappointed because I had all this information that I didn't know. So many chunks of information I didn't know thrown at me and I felt like 'wow, what kind of an engineer am I that I can't grasp, I can't even be creative with this'. I felt like […] 'is it worth becoming an engineer for something that I don't even understand'. So I felt discouraged when I finished that class" (Interview 6, female student, 3/28/08).

This type of student experience lowers expectancy, which is negatively correlated with establishment of the positive attainment value and changes the intrinsic values for students. As such, faculty may drive students away from engineering rather than encourage students' potential through SDL. It is up to faculty to create a classroom atmosphere where failure itself is learning rather than a de-motivating experience. In this case, the high complexity of the project becomes a source of frustration and anxiety inappropriate for meeting the student's psychological needs.[11] Despite the fact that this student considers creativity an important characteristic in engineering, she does not feel comfortable in a learning atmosphere where failure is possible.

Overall, students hold a wide range of perspectives regarding SDL qualified by their expectations and previous experiences. While some students indicate a desire for a high level of structure in the curriculum and prefer lectures over projects, others feel that SDL encourages their creativity and academic freedom. Many students feel uncomfortable in SDL environments primarily because of concerns regarding competency and expectancy. It is clear that students do not understand the meaning and value of SDL in their education. Moreover, faculty support and encouragement seem to be critical in the development of students' conception of and attitudes toward SDL.

Faculty Perspectives

Faculty also hold a variety of conceptions about SDL and the associated scaffolding. Several faculty feel that SDL is beneficial for student learning, yet they de-emphasize their own role in supporting students' autonomy. Faculty often perceive that students are not ready for SDL and need additional time to transition away from structured high school learning. In this sense, faculty seem to be blind about their own role in supporting SDL experiences and development of students' autonomy.

Most faculty feel that SDL is beneficial for students in their learning and want to implement it in the classroom. As one professor describes, personal experience has proven that SDL improves knowledge retention and understanding:

"*I'd rather have [learning] be more of discovery. More of a discovery process, where [students] understand. I always found I understood better if I thought I invented it. I was in a boundary values problems class and I invented element analysis, only to find out that someone else had already done it. But …I was amazed, I said* 'Oh, all we have to do is shrink the boundaries and we can use the computer and this will be great'" (Interview 18, engineering faculty, 11/20/07).

This professor comes to value SDL based on his own experience as a student. However, as previously discussed, students often have a limited understanding of SDL experiences. This faculty provides an auto-biographical example of a student-centered experience with little to no mention of faculty involvement. However, as evidenced in one of the above students' comments, this type of hands-off strategy is unlikely to work for all students.

Often unaware of or blind about their own role in SDL, faculty never-the-less observe that students have a wide range of attitudes toward SDL. By doing so, they place the responsibility for taking advantage of SDL environments on the students and placing out of site their own role in scaffolding such environments. One physics professor uses open-ended projects to motivate students' learning of physics. In these projects, students explore the misuse of physics by superhero stories. This professor notes that students are uncomfortable with the flexibility allowed by the project:

> *"I think there [are] mixed feelings [about open-ended learning]. You know, my sense is that some of [the students] are a little worried in the beginning because, you know,* '[How] is my grade going to be determined?'*…I have this much flexibility and they would like maybe less flexibility…while others might say* 'That's great…we can have [the project] fall within the physics of superheroes and I don't want to do Spiderman so I'll just focus on these superheroes and that's fine' " (Interview 13, physics faculty, 9/24/07).

As this faculty observes, students' concern about classroom performance seems to limit their ability to make effective choices about their learning goals or interests, i.e., students' cognitive autonomy is paralyzed by rigid and potentially SDL-inappropriate assessment mechanisms. While this project has a potential for cognitive autonomy experiences , it is unclear whether there is adequate scaffolding in place to either motivate students' learning or allow for effective learning outcomes.[15] According to Katz and Assor's framework, it appears some students have unmet needs related to competency that fuel student discomfort.[11] As a result, this flexibility may encourage extrinsic assessment-based motivation rather than internalization of the learning goals.[10] Care must be taken by faculty to ensure that students recognize the value of such activities in meeting their learning goals by ensuring that the project structure satisfies students' psychological needs.

Another faculty observes that students are uncomfortable in SDL and notes this is likely related to the fact that these are high-achieving students with a high level of expectancy related to success in a lecture-based learning environment.[10] When pushed to learn in a new environment, these students seem to become less confident in their abilities. One professor describes the dichotomy of how different student groups react to PjBL:

> "*But the kids knew how to take tests and they knew how to learn […] and I tried to give them a project where I didn't give them any rules and they freaked out. But I taught [at a different school] for a bunch of kids who almost failed out of high school so they needed to come for an extra year of high school, you know their thirteenth year, to try to get into college. And they ate up projects like that where I didn't give them any rules and they just jumped right in and had no qualms about that*" (Interview 15, math faculty, 10/12/07).

This professor's comment regarding the lack of rules in the project is particularly relevant to the current analysis of autonomy-supportive classroom structures and faculty blindness to such structures. A complete lack of structure may lower expectancy in the high-achieving student group and have the opposite of the intended effect.[10] It is possible that the students at the other school had a higher level of expectancy related to SDL and thus needed less faculty support for the same experience. Similar to the previous quote, this faculty seems to perceive that SDL calls for a hands-off approach on the instructor's part and places full responsibility for learning on students. What is missing in this and other faculty discourses is a discussion of contextualization of such SDL experiences to satisfy students' psychological needs and a scaffolding to support students' autonomy development.

Our analysis indicates that many faculty seem to perceive that students are either ready for an SDL environment or not. Their discourse indicates "autonomy-support blindness" with respect to their own role in student development and support of autonomous experiences. This misconception serves two negative functions. Firstly, it prevents faculty from creating a supportive environment for the students with low levels of expectancy related to SDL. Secondly, this misconception encourages extrinsic motivation rather than internalization of extrinsically motivated learning experiences.[10] In addition, faculty seem to perceive that SDL strategies in the classroom are unsuccessful because students are "not ready" rather than not properly supported. Faculty are eager to implement cognitive autonomy without developing student skills through procedural and organizational autonomy.

Faculty conceptions about what SDL is and their function in guiding students' autonomous learning development is further complicated by the difficulties of effective SDL implementation. As this professor notes, there are a number of limiting factors in the development of effective SDL experiences:

> "*You could design the laboratory experiments so that [students] can pick some of the input variables for the laboratory experiment and then have different lab groups do different experiments and then collaborate on the report, for example… But again, it's having time to prepare the instructions for that is the real problem*" (Interview 18, engineering faculty, 11/20/07).

This faculty details a strategy for implementing procedural autonomy in the classroom.[15] Perhaps as a result of the personal experience described in the first quote, this professor seems to have a better grasp of the appropriate autonomy level to implement for first-year students.

Despite the best faculty intentions, however, there are still obstacles to overcome. Faculty need administrative support to change their curricula for inclusion of full SDL experiences. In addition, education on motivational theory to ensure faculty effectiveness in supporting such experiences may be appropriate.

Finally, appropriate support must be provided for students' transitioning from usually structured high-school learning experiences to an open-ended PjBL environment. Faculty play a key role in facilitating this transition, but it cannot happen overnight:

> "*I took another course where this professor [said to] pick some problems out of a book let's just work on them. […] The kids freaked out and I felt this professor had the greatest opportunity […] He could have taught them to relax, to go with it.* 'Don't worry about the gray area.' *But he would have needed that [in the] first [part of the academic year] to teach them to do that because… these kids that isn't their background*" (Interview 15, math faculty, 10/12/07).

As this faculty explains, students entering college are often accustomed to a very structured learning style and need time to become adjusted to a new learning environment. For example, high-achieving students' lowered expectancy may prevent them from excelling in open-ended environments.[10] Faculty can teach students to work in the "gray area" by developing student skills for SDL in projects with increasing levels of student autonomy. Beginning with organizational and procedural autonomy, students can become accustomed to determining their own learning patterns and identifying how to communicate their ideas. Building to cognitive autonomy in this way allows students to have a richer SDL experience with the resulting higher expectancy and learning outcomes.[15] This also gives students an ability and necessary time to develop cognitive autonomy through generation of personal learning goals and identifying interests to direct their SDL experiences.

Conclusion

Stefanou *et al.* provide a useful framework for identifying levels of autonomy in a classroom. However, the study of motivational theory has had little impact on engineering classrooms despite faculty interest in the subject. Therefore, our description of three levels of student autonomy provided in ETU's classrooms is not reflected in the faculty discourse on the subject. Moreover, neither ETU faculty nor students provide a coherent description of an SDL experience; rather, their discourse presents a patchy understanding of various elements of such an experience. This leads to an overall misunderstanding and misconceptions of the meaning and value of SDL.

Using the Stefanou *et al.*'s framework, the courses in this study may be described as exhibiting varying levels of student autonomy. While on the average faculty members emphasize cognitive autonomy (e.g., identifying learning goals and objectives in Mechanics), students recognize some value in all three levels of autonomy.[15] Students particularly seem to enjoy the process by which to accomplish a task (e.g., a student's experience in an independent laboratory setting), as required in organizational and procedural autonomy, which may or may not be accompanied by cognitive autonomy development (e.g., extra-curricular PjBL experiences).

The SDL experiences in ETU's mathematics, physics, and engineering courses are largely moderated by students' existing self-efficacy concerns about academic performance. These concerns seem to paralyze students' ability to take advantage of autonomous experiences, however small, provided by SDL environment. As a result, open-ended projects in this study may have actually lowered students' expectancy rather than encouraged intrinsic motivation, as intended.[10] The absence of common discourse about SDL may also contribute to limiting students' ability to identify the appropriate levels of scaffolding. While some students feel that they learn best from lecturing, others feel that creativity is a particularly important quality for an engineer and cite SDL as encouraging in this regard. In general, students seem to be unable to fully recognize the value and level of their own learning achieved through SDL strategies.

Faculty perceive that students are not ready for SDL experiences. However, it appears that this may be a result of poorly-designed classroom environments that do little to increase student expectancy in SDL. We have termed the phenomenon of faculty inability to recognize their role in SDL as "autonomy-supportive blindness." None of the faculty reporting lack of students' preparation for SDL experience grounded their observations in a specific set of data or research.

By claiming lack of students' preparation, faculty shift responsibility for their own role in development of student autonomy onto the students themselves.

In order for students to have positive experiences in SDL, faculty must create classroom environments that meet students' psychological needs and take into account students' expectancies and values. In particular, faculty can ensure that students feel competent in their abilities as engineers by requiring them to choose projects within an appropriate range of complexity and suitable for enhancement of learning. Careful consideration of assessment practices to reduce concerns associated with performance is critical when constructing positive SDL environments. An assessment scheme should encourage students to focus on personal skill development rather than measuring performance via project success or failure. Special effort must be exerted in the first year to encourage students to develop their own academic interests and build a foundation for future SDL experiences. By focusing on using the first year for this transition, higher quality SDL experiences later in the curriculum may be ensured; students will be better able and more willing to take advantage of the SDL experience if the first year supports their SDL progress. By increasing student expectancy related to SDL, faculty may provide students with the necessary confidence to take on larger, more complex real-world projects.

This work has implications on the design of first-year engineering curricula regarding the development of student autonomy. By providing common vocabulary about the meaning and value of SDL experiences to both faculty and students as well as developing faculty awareness about structural supports necessary for effective SDL classroom environment, the educators may be able to improve students' sense of competency and expectancy. Future directions of this study may include investigation of the impact of SDL and student autonomy beyond the first year, and its effectiveness in preparing students for future academic and professional careers.

Acknowledgment

This material is based upon work supported by the National Science Foundation under Grant No. 0624738. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We are grateful to Maria Ong of TERC for her invaluable contributions during the stages of study design, data collection, and initial analytical conceptualization. We would also like to thank Elizabeth Blair, Kathleen Farrell, and Rebecca Miller of Harvard Graduate School of Education for their help in the initial stages of instrument development and in data collection. Many Olin students were instrumental in the analytical discussions: Julie Baca, Katarina Miller, Geoffrey Pleiss, Jennifer Simonovich, Emily Towers, Lillian Tseng, and Oren Zadik. Finally, we would like to express our gratitude to the members of our advisory board, Theda Daniels-Race of Louisiana State University, Joni Falk of TERC, Yehudit Judy Dori of Technion (Israel Institute of Technology), Susan Silbey of MIT, and Barbara Whitten of Colorado College.

References

1. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, DC: National Academies Press (2005), <http://books.nap.edu/catalog/11463.html> (accessed 13 January 2011).

2. Perrenet, J.C., Bouhuijs, P.A.J. and Smits, J.G.M.M. “The Suitability of Problem-based Learning for Engineering Education: theory and practice,” *Teaching in Higher Education*, 5(3), 345-358 (2000).
3. Helle, L., Tynjala, P. and Olkinuora, E. “Project-based learning in post-secondary education – theory, practice and rubber sling shots,” *Higher Education*, 51, 287-313 (2006).
4. Strobel, Johannes, and van Barneveld. “When is PBL More Effective? A Meta-synthesis of Meta-analyses Comparing PBL to Conventional Classrooms.” *The Interdisciplinary Journal of Problem-based Learning*, 3(1), 44-58 (2009).
5. Walker, Andrew and Leary Heather. “A Problem Based Learning Meta Analysis: Differences Across Problem Types, Implementation Types, Disciplines, and Assessment Levels.” *The Interdisciplinary Journal of Problem-based Learning*, 3(1), 12-43, (2009).
6. Prince, Michael. “Does Active Learning Work? A Review of the Research”. *Journal of Engineering Education*, 93 (3), 223-231 (2004).
7. Blumenfeld, P.C., Soloway, E.,Marx, R.W, Krajcik, J.S., Guzdial, M. and Palincsar, A. “Motivating project-based learning: sustaining the doing, supporting the learning,” *Educational Psychologist*, 26, 369–398 (1991).
8. Heitmann, Gunter. “Project-oriented Study and Project-organized Curricula: A Brief Review of Intentions and Solutions,” *European Journal of Engineering Education, 21(2), 121-131* (1996).
9. Morgan, A. “Theoretical aspects of project-based learning in higher education,” *British Journal of Educational Technology* 1, 66–78, (1983).
10. Eccles, Jacquelynne S. and Wigfield, Alan. “Motivational Beliefs, Values, and Goals,” Annual *Review of Psychology*, 53, 109-32 (2002).
11. Katz, Idit and Avi Assor. “When choice motivates and when it does not,” *Educational Psychology Review* 19, 429-442 (2007).
12. Mioduser, D., & Betzer, N. “The contribution of project-based learning to high-achievers' acquisition of technological knowledge and skills,” *International Journal of Technology and Design Education*, 18(1), 59-77 (2007).
13. Ciani, Keith D., Middleton, Michael J., Summers, Jessica J. and Kennon M. Sheldon. “Buffering against performance classroom goal structures: The importance of autonomy support and classroom community,” *Contemporary Educational Psychology* 35, 88-99 (2010).
14. Summers, J. J., Bergin, D. A., & Cole, J. S. “Examining the relationships among collaborative learning, autonomy support, and student incivility in undergraduate classrooms,” *Learning and Individual Differences*, 19, 293–298 (2009).
15. Stefanou, C. R., Perencevich, K. C., DiCintio, M., & Turner, J. C. “Supporting autonomy in the classroom: Ways teachers encourage student decision making and ownership,” *Educational Psychologist*, 39, 97–110 (2004).
16. Black, A. E., & Deci, E. L. (2000). “The effects of instructors’ autonomy support and students’ autonomous motivation on learning organic chemistry: A self-determination theory perspective,” *Science Education*, 84, 740–756 (2000).
17. Maxwell, J.A. *Qualitative research design: An interactive approach*. Thousand Oaks: Sage, 2005.
18. Glaser, B.G. and Strauss, A.L. *The Discovery of Grounded Theory: Strategies for Qualitative Research*, Aldine Transactions, 1967.
19. Seron, Carrol. Private communications (2010).