Measuring Changes in Professional Skills in a Systems Exploration, Engineering, and Design Laboratory (SEED Lab)

Dr. Vibhuti Dave, Colorado School of Mines

Dr. Vibhuti Dave has been teaching for 10+ years. She joined Colorado School of Mines in 2011 and is currently serving as Dean of Undergraduate Studies. She is also a teaching professor in the departments of Computer Science and Electrical Engineering. She served as Assistant Department Head for Electrical Engineering from 2013 to 2018. She has experience leading assessment efforts for degree programs and is currently co-directing CS and industry partnership program called C-MAPP.

Prior to Mines, Dr. Vibhuti Dave taught at Penn State Erie, The Behrend College as an Assistant Professor in the Electrical, Computer, and Software Engineering program. She received her undergraduate engineering degree in the field of Electronics and Communication from Nirma Institute of Technology, India in 2000. She received her M.S. in Electrical Engineering and Ph.D. (2007) in Computer Engineering from the Illinois Institute of Technology, Chicago, IL.

Dr. Dave's research interests lie in the field of engineering education, high-speed computer arithmetic, and computer architecture. Her research has been focused on the design high-speed multi-operand adders. In addition, she is also interested in performing research in VLSI implementation of signal processing algorithms, and low power integrated circuit design.

Her teaching interests include Digital Logic Design, Computer Architecture, Computer Arithmetic, VLSI Design.

Dr. Stephanie Claussen, San Francisco State University

Stephanie Claussen is an Assistant Professor in the School of Engineering at San Francisco State University. She previously spent eight years as a Teaching Professor in the Engineering, Design, and Society Division and the Electrical Engineering Department at the Colorado School of Mines. She obtained her B.S. in Electrical Engineering from the Massachusetts Institute of Technology in 2005 and her M.S. and Ph.D. from Stanford University in 2008 and 2012, respectively. Her current engineering education research interests include engineering students' understanding of ethics and social responsibility, sociotechnical education, and assessment of engineering pedagogies.

Dr. Tyrone Vincent, Colorado School of Mines

Tyrone L. Vincent received the B.S. degree in electrical engineering from the University of Arizona, Tucson, in 1992, and the M.S. and Ph.D. degrees in electrical engineering from the University of Michigan, Ann Arbor, in 1994 and 1997, respectively. He is currently a Professor in the Department of Electrical Engineering and Computer Science, at the Colorado School of Mines, Golden. His research interests include system identification, estimation, and fault detection with applications in materials processing, and energy systems.

Dr. Megan Sanders, Colorado School of Mines

Megan Sanders is the Senior Assessment Associate at the Trefny Innovative Instruction Center at the Colorado School of Mines. Before joining Mines, Megan worked at the Eberly Center for Teaching Excellence and Instructional Innovation at Carnegie Mellon University, where her role focused on supporting instructors in conducting research about student outcomes in their courses. Megan's disciplinary background is in educational psychology. She earned her PhD from the Ohio State University, and her research focused on the idea of relevance in higher education—how we define it, how students perceive it, and how to measure it—an interest that continues to inform her work.

Measuring Changes in Students' Engineering Practice Skills in a Project-Based Laboratory

Introduction

Undergraduate engineering curricula across the United States are largely designed to prepare students to enter industry upon graduation, yet studies over the past decade have suggested a gap between what is emphasized in this curriculum and the competencies that are most useful in industry [1-4]. These studies indicate that important competencies are often underdeveloped in the engineering curriculum, including the so-called professional skills that relate more closely to the sociotechnical side of engineering and the ability to work in complex, dynamic and uncertain environments.

In the engineering education literature, the skills utilized by engineers in the field have been termed engineering practice [3, 5, 6]. While problem solving is often considered the core of engineering practice, there are many skills beyond technical knowledge that are needed to deliver solutions to problems in the real world [3, 5, 6]. In order to narrow the scope of this paper, we focus on the following engineering practice (EP) skills:

- EP1: The ability to work on a team with disparate knowledge bases
- EP2: Problem solving through error elimination and prototyping
- EP3: Planning and interpreting experiments
- EP4: Identifying knowledge gaps and obtaining information from disparate sources
- EP5: Planning for technical failure

EP1 captures the team aspect of engineering, which includes both the need for coordinating teamwork and the need for effective communication across a team for a successful design outcome. The inclusion of disparate knowledge is highlighted in the literature. For example, Trevelyan found that the most crucial skill reflected in high performing engineers is coordinating multiple competencies to accomplish a goal [3]. EP2 highlights an aspect of problem solving that goes beyond the application of domain knowledge to include creativity, analysis, and evaluation. This skill is defined in [6] as "being able to generate, evaluate and implement candidate solutions, as well as to understand that problem solving is intrinsically an iterative and integrative process." EP3 is closely related to EP2, but highlights the generation of more fundamental knowledge, rather than the challenges that arise from integration and synthesis. EP4 is one aspect of what is often called lifelong learning [6]. The final skill, EP5, is related to planning and coordination, but highlights the need for engineers to consider risk and mitigation strategies when developing new technology [2, 5].

In this paper, we describe the assessment of a lab-based course designed to help students develop these five engineering practice skills. The Systems Exploration, Engineering, and Design (SEED) Laboratory is a project-based junior-level laboratory in the Electrical Engineering Department at the Colorado School of Mines ("Mines"), a science- and engineering-focused public university in Golden, Colorado. SEED Lab is a project-based course where the central project requires the integration of multiple subsystems, each of which in turn requires knowledge from distinct areas of electrical engineering (EE). The distribution of knowledge is developed by having each member of the team go through different preliminary projects, each related to a different subdiscipline within EE. This creates distributed expertise within the team which students then must manage as they work through the project. SEED Lab also requires teams to perform hardware demonstrations several times during the semester, with the performance of their design judged relative to other designs. This is meant to encourage a process of iteration, reflection, and redesign throughout the semester. Finally, the lab is designed for students to practice information gathering and synthesis. There are no formal technical lectures within the lab. Students are provided handouts with a description of the overall goal of the assignment, some key information and links to further resources. As they develop their projects, students are expected to locate necessary technical information and develop simulations or experiments as needed to implement or improve their design.

This paper is organized as follows: first, we describe the research-supported course design decisions made in the development of the SEED Lab. Then, we describe the development and application of an assessment tool to track how the SEED Lab affects the development of students' skills in engineering practice. Our results suggest that students currently exhibit more growth in some skills than others. Students show the most growth in being able to recognize working on a team with disparate knowledge bases as an important component of engineering practice. Finally, we discuss the implications of our findings both for future iterations of SEED Lab and for the development of similar engineering courses.

Background: The Research-Informed Design of SEED Lab

SEED Lab was developed in 2015 to develop industry-readiness in our students and support their learning of professional skills. The course is not designed to teach additional technical content, but rather to give students opportunities to integrate the content learned across other courses into a single project. Because of this, students are required to have two engineering science prerequisite courses completed before taking the course, an introductory controls systems course and a microcontrollers course. In our curriculum, SEED Lab replaced another required multidisciplinary discrete experiments-based laboratory course which had less intensive technical learning objectives and lacked an explicit emphasis on intradisciplinary systems integration. SEED Lab is a prerequisite course for EE students to take the two-semester capstone design course that is required of all electrical, mechanical and civil engineering students in their senior year.

Four aspects of SEED Lab were intentionally designed to support the development of students' professional skills, based on findings from the empirical literature: the open-ended and project-based nature of the course; the high degree of teamwork required in the class; multiple opportunities for iterative design to practice and receive feedback; and assessment using performance-based grading. Each of these qualities of the course will be described further below alongside the prior literature which informed these choices.

Open-ended Project-based Learning

SEED Lab was designed to use project-based learning (PBL) in order to simulate industry work. PBL has frequently been identified in the literature as a pedagogical method that mirrors professional behavior [7, 8]. It has been suggested that, in order for project-based learning to appropriately reflect the work expected of engineers in the workplace, the projects need to become more complex and independent as students progress through their program [9]. To achieve this requirement, SEED Lab projects are authentic tasks with no single, "correct" solution. Rather, students must make tradeoffs in selecting which performance parameters they optimize in their design. Such authentic tasks have been suggested as a way to increase student motivation and aid in developing their ability to integrate and apply content knowledge [10]. The tasks assigned in SEED Lab are chosen so that they meet the problem criteria suggested in the literature, including being complex [11], open-ended, and rife with ambiguity [9].

In SEED Lab, a single problem is assigned as the goal for the semester project for all the groups to work on. This problem is referred to within the context of the course as the "challenge problem" [12]. For example, a challenge problem used in a previous semester reads as follows:

> A challenging yet promising arena for robots is for search and rescue in dangerous areas. This provides the inspiration for this year's challenge project: as a team, you will build and program a mobile robot that is able to explore an area that is known only as the robot starts to explore. In this challenge, six beacons of your design will be placed on the ground to denote the exploration area. The robot must be able to traverse a path around the outside of these beacons, but cannot stray too far away, or cut inside the beacons. That is, the robot must complete a circuit that contains the area defined by straight lines drawn between beacons, but cannot go more than 1.5 feet away from this area at any time.

To construct their solutions, students are given an Arduino embedded controller and Raspberry Pi compact computer, along with a variety of structural parts, motors, wheels, motor drivers, Bluetooth modules and an LCD display.

At the beginning of the course, students self-select to be experts in one of four areas. These areas closely align with the four subsystems that the overall challenge problem integrates. Students are given preliminary assignments related to their selected subsystem. For the project description above, the subsystems were computer vision, control, system integration, and localization. (The students select which subsystem they want to work on, though all students who take the class have completed the same two prerequisite courses.) After completion of these initial assignments, the project groups are formed, composed of students representing each subsystem. The groups are first tasked with completing a mini-project that has the same subsystems as the full project but much simpler requirements (e.g. control the velocity of a single wheel with the desired velocity set by holding structured markers in front of a camera). During this time, students are introduced to literature on effective group practices. After completion of the mini-project, the groups begin work on the main challenge problem. Groups must demonstrate their progress towards a final design three times during the remainder of the semester; this process is described more in the *Iterative Development Process* subsection, below.

Teamwork

A team-based approach was chosen for the course in order to allow students to practice professional skills related to the social aspect of engineering [13, 14]. These skills include decision making, problem solving, leadership, a multidisciplinary perspective, negotiation, conflict resolution, and goal setting. When project groups are formed, they include at least one member from each subsystem area of expertise, which models the interdisciplinary teams often utilized in industry. After the groups are formed, the team reviews the behaviors of effective groups using the material in [15] and develops a group contract that establishes group norms [16]. Peer feedback on group behaviors is provided through the online platform, Comprehensive Assessment of Team Member Effectiveness (CATME) [17].

Iterative Development Process

As students develop their solutions, the course provides multiple opportunities for them to practice engineering skills and receive feedback on their progress. There are four formal demonstration periods during the semester. The first demonstration is of a simplified integrated system that is feasible to compete in two weeks. This gives students their first practice working together as a group. The remaining three demonstrations are related to the course challenge problem. After each demonstration, peer feedback on observed teamwork behaviors is provided via CATME. Students fill out a reflection log with prompts for them to list what false starts they encountered, what debugging techniques they used to overcome problems, how well they integrated subsystems, and what aspects of working on a team they found helpful or a barrier to completing the project. Instructors review the reflection logs and provide feedback on methods to improve future performance.

The structure of repeated demos across the semester is beneficial for several reasons. First, it allows students distributed practice. Research suggests that spacing practice across time leads to better retention of knowledge and skills compared to massed practice [18]. Additionally, the repeated demonstrations create regular opportunities for students to receive authentic feedback about their progress. Among a range of factors, feedback has one of the greatest positive impacts on student learning [19]. The feedback students receive is also powerful in that it directly informs their subsequent learning and design, a characteristic that makes feedback particularly effective [20]. Between demonstrations, the groups reflect on the performance from the prior demo, organize their work towards the next demonstration, and execute their planned tasks.

Performance-based Grading

As part of the demonstrations, the performance of systems or subsystems is measured against specific metrics (e.g. speed, accuracy, robustness, etc.). As the demonstrations progress, these metrics become more and more closely related to the objectives of the challenge problem, with the final demonstration being an assessment of the whole system. Goal-directed practice with clearly defined metrics like this has been shown to be much more beneficial to student learning compared to less goal-directed practice [21].

A large part of the grade assigned for each demonstration is based on how well the team's system performed within each metric. For the performance-based grading system used in SEED, students are provided with criteria and targets ahead of time. Teams receive a grade based on how closely their system performance matches the best performing team in each specific design criteria.

Study Methods

To assess the impact of SEED Lab on students' skills relevant to engineering practice, a case study activity was developed as an open-ended prompt to elicit students' concepts of the design and development process. The case study activity presents a hypothetical capstone design project and asks students to describe their general approach to completing the project, rather than for a specific solution. The case study activity was chosen as a way to elicit students' understanding of the design process because the task was open-ended, so as to not to shape or limit students' answers, and similar in nature, if not scope and length, to an authentic design problem. A similar case study prompt scored from a rubric was developed by Schmeckpeper et al. and validated by Zhang et al. [22, 23]. However, this prior demonstration of this method focused on assessing a different set of skills which included ethics and knowledge of the societal context, and excluded teamwork, prototyping, experimentation, and planning for failure.

The case study activity was piloted at the end of the Fall 2017 semester. Following the pilot implementation, the prompt was refined to focus more explicitly on describing a general approach, rather than a design of a very specific solution. These changes were made to better align the case study prompt with the aspects of students' skills related to engineering practice. Starting in the Spring 2018 semester, the faculty assigned the activity at the beginning of the semester to measure students' incoming ideas about the design process. This case study activity was repeated at the end of the semester to assess students' perceptions of the design process after participating in SEED Lab. The case study scenario was the same for both the beginning- and end-of-semester assignments. Students were asked to complete the case study activities for homework and were given participation credit for completing the assignments.

Shown in Table 1, the rubric was developed to focus on the five aspects of engineering practice, named in the rubric as *research, prototyping, experimentation, collaboration, and planning for technical failure*. Each of these aspects is scored at four broad levels: doesn't recognize the need for this dimension (0 points), recognizes the need for this dimension but does not articulate any strategies for accomplishing (1 point), recognizes the need and articulates simple strategies (2 points), and recognizes the need and articulates more advanced strategies (3 points). An initial version was used to score several sample student responses to iterate, refine, and calibrate the rubric.

Though thoughtfully designed, the case study assignment serves as a proxy for students' engineering practice during the design process. It does not directly measure changes in how they approach the process, but instead measures changes in how they *describe* and *conceptualize* their approach. This is a limitation of our research methods.

Scoring Procedure

Responses from students enrolled in the Spring 2018 and Spring 2019 offerings of SEED Lab were scored. In Spring 2018, 18 students completed both the pre and the post case studies and 31 students completed both in Spring 2019, for a total sample size of 49. Each of these students completed both the pre and the post case study, for a total of 98 case study responses.

TABLE 1
SCORING RUBRIC

Skill	Level 0 (Does not recognize)	Level 1 (Recognizes)	Level 2 (Recognizes and articulates simple strategies)	Level 3 (Recognizes and articulates advanced strategies)
Research	Does not recognize the need to do research.	Recognizes the need to do research.	Articulates simple strategies for research. For example, describes specific areas of focus for one topic area or source.	Articulates advanced strategies for research. For example, plans for research in various areas or for multiple facets of the project and/or uses research to inform future work.
Prototyping	Does not recognize the need to build a prototype.	Recognizes that a prototype needs to be built.	Articulates simple strategies for prototyping. For example, describes building and testing multiple prototypes with the goal of improving the next prototype.	Articulates advanced strategies for prototyping. For example, describes how they will determine which prototype best meets the criteria and/or how they will decide how to iterate the design for the next prototype.
Experimentation	Does not recognize the need to collect data from physical or simulated models.	Recognizes that physical or simulated models will be used to collect data.	Articulates simple strategies for experimentation. For example, integrates data collection from physical or simulated models into the design process.	Articulates advanced strategies for experimentation. For example, identifies features of the design that would require experimentation and describes the design of experiments.
Collaboration	Does not recognize the need for team work.	Recognizes the need for teamwork.	Articulates simple strategies for teamwork. For example, indicates that the team will need to work through conflicts and/or divide up the work.	Articulates advanced strategies for teamwork. For example, describes how tasks will be assigned, how conflicts within the team will be resolved, and/or how team members will integrate subsystems.
Planning for Technical Failure	Does not account for failures or setbacks in the project.	Recognizes that failure can occur.	Articulated simple strategies for dealing with technical failure. For example, anticipates needing extra time to deal with failures and re-planning.	Articulates advanced strategies for dealing with technical for failure. For example, plans the project in a hierarchical fashion to facilitate debugging and/or has a plan for when integration of subsystems does not work.

To eliminate the possibility of bias in scoring due to either familiarity with the student or knowledge of whether a particular example was from the pre or the post, a student employee not affiliated with the course or the research project assigned each of the 98 pre and post responses a random number, developed a key linking these random IDs to the individual student and the time point, and then reordered the responses in numerical order. These blinded and randomized responses were scored. To help establish consistency among the scorers, the four faculty members of the research team scored the first ten student responses from Spring 2018 together, discussing points of disagreement until a consensus was reached. Then, two pairs repeated this process, with each pair double-scoring the remaining responses from Spring 2018 and discussing points of disagreement. Percentage agreement between the pairs of raters was 68% on prototyping scores and 61% on scores for planning for technical failure, and above 70% for the remaining three dimensions. As a result, the description of the prototyping and planning for technical failure dimensions on the rubric were refined. Because all responses were coded by two raters and points of disagreement were discussed and resolved, these initial differences in agreement are unlikely to have skewed the final scores.

For the Spring 2019 data, three undergraduate research assistants were trained to use the rubric to score responses. Each research assistant was responsible for scoring ⅔ of the responses, such that each response was double-scored by each possible pair of research assistants. After scoring, the research assistants and faculty members met to discuss and resolve points of disagreement in the scores. Initial percentage agreement for the research assistants was somewhat lower than agreement for the faculty coders, ranging from 56% agreement for scores on planning for technical failure to 70% agreement for scores on research. This suggests that the dimension of planning for technical failure was still less clearly defined than some of the others. However, each response was double-coded and points of disagreement in scores were discussed and resolved, reducing the impact of the initial disagreement on final scores.

Results

The pre-case study averages for the five dimensions highlight differences in students' incoming skill level (see Table 2). In particular, students' scores on experimentation and planning for technical failure were lower at the beginning of the course compared to the other three dimensions. There were also notable differences in the amount of change in students' scores on these five dimensions through the course. In paired-samples t-tests, two of the dimensions showed statistically significant changes: research and collaboration. Interestingly, students received lower scores for research at the end of the class ($M=1.61$, $SD=1.00$) than at the beginning ($M=2.04$, $SD=.96$, $t(48)=2.48$, $p=.02$). On the other hand, students' scores for collaboration showed the opposite trend: scores were significantly higher at the end of the class ($M=1.57$, $SD=1.48$) compared to at the beginning of the class ($M=1.29$, $SD=1.17$, $t(48)=-2.09$, $p=.04$). Students' scores on the other three dimensions of the rubric were not significantly different between the beginning and the end of the course. Although disappointing, this finding is nonetheless useful. It suggests that there is additional room within the SEED Lab course to push students' thinking around prototyping, experimentation, and planning for technical failure.

TABLE 2
MEANS AND STANDARD DEVIATIONS FOR THE FIVE RUBRIC DIMENSIONS

	Research		Prototyping		Experimentation		Collaboration		Planning for Failure	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre	2.04	.96	1.22	.96	.78	.96	1.29	1.17	.84	.83
Post	1.61	1.0	1.08	.86	.90	1.03	1.57	1.04	.71	.89

Discussion

One of the key factors that governs student success in SEED Lab is the practice of working on a team with disparate knowledge bases, which was also identified as an important component of engineering practice. Results show that students show the most growth in this dimension (termed collaboration in Table 2) of engineering practice. This is especially encouraging since learning how to collaborate to achieve desired outcomes is one of the objectives of SEED Lab. It also does not come as a surprise since the complexity of the project demands cohesive collaboration between members who are “experts” in a sub-discipline. Evidently, students realized how critical teamwork is and therefore, it is something at the forefront of their minds as a pathway to success.

For the team to succeed, more is required beyond the completion of individual pieces. When the teammates come together to integrate their subsystems, it gives them a means of practicing and learning collaboration. The phase of integration brings to the fore the issue of hard demarcated boundaries, and gives the students a chance to practice a more flexible approach to being a member of the team. Rather than playing a specific role, they realize they need to change their perception on what their duties are toward the team. Their performance on the intermediate and final demos with respect to other teams can emphasize the importance of group dynamics for the students and help them recognize what it takes to be a high-functioning team.

In contrast to collaboration, the data show that there is no statistically significant difference in students’ scores on the prototyping, experimentation, and planning for technical failure dimensions of the rubric between the first and second submissions to the case study activity. Because SEED Lab was developed with a structure of multiple demos in order to encourage these practices, this was somewhat surprising. There are several possible reasons for this. Students may already be familiar with and/or recognize the importance of these dimensions from prior courses. However, the average scores for these rubric dimensions are relatively low across time, indicating that students may have an awareness of the dimension but may lack the ability to describe simple strategies to achieve it. These low initial scores – maintained over time—seem to indicate that any abilities that the students enter the class with are relatively low in these areas. Alternatively, students may understand the benefit of prototyping, experimentation and planning for technical failure within the SEED Lab activities, but the case study failed to capture this understanding, perhaps because of the specific prompt. Finally, the SEED Lab structure may not be useful in developing students’ competence in these dimensions.

Under the theory that it is the course structure that is not sufficient, it is interesting to compare the difference in student autonomy with regards to the collaboration and prototyping aspects of the course. While students are provided some introductory material on effective groups and are required to submit meeting agendas throughout the course, they are empowered to choose how the group will operate and are responsible for overcoming challenges related to team organization and execution. On the other hand, the quantity, timing, and goals for the demonstration periods are set by the instructors, reducing the amount of student decision-making concerning prototyping, and perhaps reducing students’ recognition of the process. Indeed, while the repeated demonstration periods allow students to first develop subsystems, integrate those subsystems, and iterate on their design, students may not recognize this as part of a prototyping process, but more as modular course design.

Finally, the results show a statistically significant decrease in students’ research scores. While the goal was not for any scores to decrease from the pre- to the post-, this trend could possibly be explained by the timing of the pre- and post-assessments during the semester. The pre-assessment was administered near the beginning of the semester, when students were likely more engaged in preliminary research for their projects within the course. The post-assessment was administered at the end of the semester, when the students were nearing the completion of the design process and polishing their final deliverables. It is possible that research is less salient at the end of the design process, and thus students were less likely to think about it as they responded to the post-test case study.

Alternatively, it is possible that the emphasis that students placed on research skills in their pre-course responses was displaced by other concerns that emerged as they proceeded through the design process (and that were perhaps occupying their attention at the time that they worked on the post-course case study), such as the realization that collaboration was a necessary and important part of their team's work.

A third potential explanation is that, by the end of the design process, the students realized that it is not possible to plan for everything, and as a result, they placed less value in research, especially that which might happen at the beginning of the design process. Our rubric did not differentiate between descriptions of research that took place at the start of the project and that which occurred throughout the design process.

Limitations

The primary limitation of the current study is not having a control group of students. Using a pre/post measure can help to establish change through students' experience in the course. However, without a control group of students who completed the case study activities but did not participate in SEED Lab, it is not possible to fully ascribe any change in students' thinking solely to participation in the class. There was also not a way to account for prior experience in other design courses that students may have taken or were taking concurrently with SEED Lab, including the capstone design course. (This course is designed to be taken by students in their junior year and is a prerequisite course for the capstone design, which is usually taken in their senior year. However, some students request waivers to this requirement due to scheduling challenges.) The students who had already taken capstone design or who were concurrently enrolled may have come into the class with additional skills and prior experience and may have not shown much change in their scores from pre- to post-, potentially attenuating the observed effect. Students who were concurrently enrolled in the capstone design course and SEED Lab could have improved scores on the post- case study because of their experience in the capstone design course, not SEED Lab. These are challenges with classroom-based research, and are directions that will be explored in the future.

Future Directions

These baseline results provide a way to monitor changes to the course in the future. The lack of change in students' scores for prototyping, experimentation and planning for technical failure make these aspects of particular interest for further development. Possible course-based interventions include giving students more autonomy in deciding on the prototyping and experimentation activities, including additional assignments that require students to articulate how they have used prototyping, experimentation and planning for failure in their design process, and changing the course structure to place more value on these elements, for example by limiting the times that students have access to hardware. It is also of interest to determine how students' perceptions of failure affect their concept of development and design. SEED Lab instructors have noted from anecdotal experience that students are very reticent to acknowledge setbacks or problems, perhaps indicating that students believe that failures are uncommon in actual practice. By supporting students in learning how to fail or to see failure as a useful tool, it may also improve their ability to make use of prototyping, experimentation and planning for failure as part of the design process. Taken together, these results suggest that SEED Lab offers a promising approach for helping students develop skills related to engineering practice.

Acknowledgements

The authors gratefully acknowledge the contributions of Amanda Blickensderfer, John-Paul Meyer, Colin Siles, Tyler Stuhldreier, and Naya Winkelstein in coding the student responses. This work was funded in part by a grant from Epilog Laser.

References

[1] R. Martin, B. Maytham, J. Case and D. Fraser, "Engineering graduates' perceptions of how well they were prepared for work in industry," European Journal of Engineering Education, vol. 30, pp. 167-180, 2005.
[2] J. Walther and D. F. Radcliffe, "The competence dilemma in engineering education: Moving beyond simple graduate attribute mapping," Australasian Journal of Engineering Education, vol. 13, no. 1, pp. 41-53, 2007.
[3] J. Trevelyan, "Reconstructing engineering from practice," Engineering Studies, vol. 2, pp. 175-195, 2010.
[4] H. Passow, "Which ABET Competencies Do Engineering Graduates Find Most Important in their Work?," Journal of Engineering Education, vol. 101, 2012.
[5] H. Passow and C. Passow, "What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review," Journal of Engineering Education, vol. 106, pp. 475-526, 2017.
[6] S. Sheppard, A. Colby, K. Macatangay and W. Sullivan, "What is Engineering Practice?," International Journal of Engineering Education, vol. 22, 2006.
[7] J. Mills and D. Treagust, "Engineering Education, Is Problem-Based or Project-Based Learning the Answer," Australasian Journal of Engineering Education, 2003.
[8] L. Shuman, M. Besterfield-Sacre and J. MCGOURTY, "The ABET 'professional skills'—Can they be taught? Can they be assessed?," Journal of Engineering Education, vol. 94, 2005.
[9] E. P. Douglas, M. Koro-Ljungberg, N. J. McNeill, Z. T. Malcolm and D. J. Therriault, "Moving beyond formulas and fixations: solving open-ended engineering problems," European Journal of Engineering Education, vol. 37, no. 6, pp. 627-651, 2012.
[10] T. Litzinger, L. Lattuca, R. Hadgraft and W. Newstetter, "Engineering Education and the Development of Expertise," Journal of Engineering Education, vol. 100, pp. 123-150, 2011.
[11] D. Huntzinger, M. Hutchins, J. Gierke and J. Sutherland, "Enabling Sustainable Thinking in Undergraduate Engineering Education," International Journal of Engineering Education, vol. 23, 2007.
[12] V. Dave, T. L. Vincent, M. Sanders, and S. Claussen, "Student Engagement and Industry Readiness in a Systems Exploration, Engineering, and Design Laboratory (SEED Lab)," Proceedings of the 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah.
[13] R. Lingard, "Teaching and Assessing Teamwork Skills in Engineering and Computer Science," Journal of Systemics, Cybernetics and Informatics, vol. 8, 2010.

[14] A. Mohan, D. Merle, C. Jackson, J. Lannin and S. S. Nair, "Professional Skills in the Engineering Curriculum," IEEE Transactions on Education, vol. 53, pp. 562-571, 2010.
[15] E. Sarkisian, "Working in groups: a note to faculty and a quick guide for students," [Online]. Available: http://ddi.cs.uni-potsdam.de/Lehre/WissArbeitenHinweise/WorkingInGroups/wigintro.html.
[16] R. Hughes and S. Jones, "Developing and assessing college student teamwork skills," New Directions for Institutional Research, vol. 2011, pp. 53-64, 2011.
[17] M. L. Loughry, M. W. Ohland and D. J. Woehr, "Assessing Teamwork Skills for Assurance of Learning Using CATME Team Tools," Journal of Marketing Education, vol. 36, no. 1, pp. 5-19, 2013.
[18] D. Rohrer and K. Taylor, "The effects of overlearning and distrubted practise on the retention of mathematics knowledge," Applied Cognitive Psychology, vol. 20, pp. 1209-1224, 2006.
[19] J. Hattie and H. Timperley, "The Power of Feedback," Review of Educational Research, vol. 77, pp. 81-112, 2007.
[20] D. J. Nicol and D. Macfarlane-Dick, "Formative assessment and self-regulated learning: a model and seven principles of good feedback practice," Studies in Higher Education, vol. 31, no. 2, pp. 199-218, 2006.
[21] K. Ericsson, R. Krampe and C. Tesch-Roemer, "The Role of Deliberate Practice in the Acquisition of Expert Performance," Psychological Review, vol. 100, pp. 363-406, 1993.
[22] Edwin R Schmeckpeper, Mike Kelley, and Steve Beyerlein. Using the EPSA rubric to evaluate student work on ethics case studies in a professional issues course. In Proceedings of the 2014 Zone 1 Conference of the American Society for Engineering Education, pages 1–6. IEEE, 2014.
[23] Mo Zhang, Ashley Ater Kranov, Steven W Beyerlein, Jay P McCormack, Patrick D Pedrow, and Edwin Schmeckpeper. Investigating a scenario-based performance assessment of engineering professional skills]. In 2015 IEEE Integrated STEM Education Conference, pages 230–235. IEEE, 2015.)