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Problem-based learning in K-12 engineering lessons: Supporting and scaffolding student learning (RTP)

Kimberly Farnsworth, Arizona State University

Kimberly Farnsworth is Education Coordinator at the Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) a National Science Foundation Engineering Research Center (ERC). She is currently a doctoral student in Instructional Systems Technology at Indiana University and has a M.Ed. from Arizona State University. Kimberly has over 25 years of experience in the fields of education and technology. Her research focus is on authentic learning environments in the sciences.

Dr. Jean S Larson, Arizona State University

Jean Larson, Ph.D., is the Educational Director for the NSF-funded Engineering Research Center for Biomediated and Bio-inspired Geotechnics (CBBG), and Assistant Research Professor in both the School of Sustainable Engineering and the Built Environment and the Division of Educational Leadership and Innovation at Arizona State University. She has a Ph.D. in Educational Technology, postgraduate training in Computer Systems Engineering, and many years of experience teaching and developing curriculum in various learning environments. She has taught technology integration and teacher training to undergraduate and graduate students at Arizona State University, students at the K-12 level locally and abroad, and various workshops and modules in business and industry. Dr. Larson is experienced in the application of instructional design, delivery, evaluation, and specializes in eLearning technologies for training and development. Her research focuses on the efficient and effective transfer of knowledge and learning techniques, innovative and interdisciplinary collaboration, and strengthening the bridge between K-12 learning and higher education in terms of engineering content.

Problem-based Learning in K-12 Engineering Lessons: Supporting and Scaffolding Student Learning

Introduction

This paper describes a case-based, mixed-methods study of how K-12 teachers support and scaffold student learning in a Problem-based Learning (PBL) engineering lesson. The study examined how K-12 engineering teachers planned to support student learning using scaffolding, how they implemented scaffolds during PBL engineering activities, and how they reflected upon their PBL engineering lesson implementation.

PBL in engineering education

Engineering practice and other design-focused fields involve solving complex problems, often in collaborative teams. Generally, these engineering problems do not have a single solution and require multifaceted skillsets from many domains. However, engineering students often find themselves unprepared to manage messy, real-life projects [1]-[4]. PBL allows learners to engage with complex problems which require them to use and develop problem-solving strategies in collaborative groups [5]-[7].

Problem-based Learning is also a student-centered approach to learning [6], [8]. In the PBL environment, the instructor serves as a guide as opposed to the purveyor of knowledge. As learners work together in collaborative groups, the instructor supports and facilitates the learners' knowledge construction through the problem-solving process. This complex learning approach, rooted in solving authentic problems, promotes higher-order thinking skills, cooperative problem-solving, and has as its goal the transition of the learner from novice to expert [9]. The literature tells us that PBL in engineering curricula can help bridge the gap between the engineering classroom and real-world practice [1], [3].

One of the primary benefits of using PBL in engineering education is the focus on real-world design problems [4], [10]. Authentic, messy problems provide learners with experience navigating the complexities and variables often encountered in industry practice. This affords them a learning environment in which they can gain engineering knowledge, but also develop higher-order thinking skills and strategies, learn to work collaboratively, identify problems and potential solutions [11], [12]. Another important element of PBL is to reflect on one's learning experience [6], [8], [13]. Learners are encouraged to reflect on the strategies they used, what went well, what didn't go well, and what they would do differently next time.

There are potential limitations to PBL in engineering activities, however, including the possibility that learners may arrive at incorrect answers, be unsure of how to proceed with problem-solving, or experience frustration [14]. In addition, the complex nature of real-world problems can exact a heavy cognitive load on the learner [6], [14]. If the cognitive load is too heavy, it can interfere with learning by overwhelming the student's ability to process information, strategize potential solutions, and it may decrease motivation [14]. Strong scaffolding of the PBL environment can support and guide learners, enabling them to maintain learner autonomy while also providing effective support [15]-[19].

Scaffolding and supporting

In order to effectively scaffold student learning, the instructor serves as a guide and supports the problem-solving process by controlling "those elements of the task that are initially beyond the learner's capacity" [19, p. 90]. This scaffolding of student learning allows them to manage the heavy cognitive load required in complex problem-solving, such as engineering [13], [16], [18], [20]. This is accomplished by helping learners to structure their learning, highlighting critical features or components of the problem, supporting their planning and performance, guiding their understanding, and problematizing content [21].

Saye and Brush [18] suggest that two types of scaffolding are often incorporated into learning: *soft* scaffolding and *hard* scaffolding. Soft scaffolding is operationalized as continuous, dynamic teacher support providing just-in-time guidance and feedback. Hard scaffolding is operationalized as elements of the learning environment that are pre-planned and anticipate "typical student difficulties with a task" [18, p. 81].

In addition to Saye and Brush's model of scaffolding [18], Wood, Bruner, and Ross [19] in their scaffolding framework include the following functions: (1) recruitment, (2) reduction in degrees of freedom, (3) direction maintenance, (4) marking critical features, (5) frustration control, and (6) demonstration. Van de Pol, Volman, and Beishuizen [22] build on Wood et al.'s framework [19] distinguishing between scaffolding *means* (strategies) and scaffolding *intentions* (functions). Scaffolding *means* include (1) *feedback*, (2) *hints*, (3) *instructing*, (4) *explaining*, (5) *modeling*, and (6) *questioning*. While scaffolding *intentions* include (1) *direction maintenance*, (2) *cognitive structuring*, (3) *reduction of degrees of freedom*, (4) *recruitment*, and (5) *contingency management*.

These scaffolding *means* and *intentions* are operationalized by van de Pol et al. [22] in the following way. The scaffolding means of *feedback* is defined as providing information to the learner about their performance. *Hints* relate to providing important suggestions or clues to the learner to guide problem-solving. *Instructing* is telling a learner what to do or explaining how a given task should be done. *Explaining* is clarifying or providing more detail to the learner. *Modeling* can be a demonstration or completing a task or behavior for students to imitate. *Questioning* involves asking the learner questions that require an active answer.

The scaffolding *intention* of *direction maintenance* is to keep the learner focused or directed on the task at hand. *Cognitive structuring* is to support the learner's organizing and justifying their thinking. *Reduction of degrees of freedom* relates to simplifying a task by doing what the learner cannot do themselves, yet. *Recruitment* is to get the learner interested in a task, helping them to follow the requirements of the task. *Contingency management* or *frustration control* involves using rewards and punishments to facilitate learner performance while also preventing or minimizing frustration. Van de Pol et al.'s scaffolding framework [22] and Saye and Brush's *hard* and *soft* scaffolding [18] are used in this study as the means of analysis and interpretation of the data collected by the researchers. These frameworks enabled the analysis of instructor-learner interactions, specifically examining how instructors supported student learning through the various scaffolding strategies and goals. A detailed description of how these scaffolding frameworks were used will be described below.

Research questions

This study examined how K-12 engineering teachers planned to scaffold and support student learning, how teachers implemented scaffolding in a PBL engineering activity, and how teachers reflected upon the PBL lesson implementation. These were explored using data collected in teacher interviews, classroom observations, and lesson implementation teacher reflections. The following research questions were explored:

- How do K-12 teachers plan to scaffold student learning in a PBL engineering activity?
- How do K-12 teachers implement scaffolding of student learning in a PBL engineering activity?
- How do K-12 teachers reflect on the implementation of scaffolding in a PBL engineering activity?

Methods

A case-based, mixed-methods study was conducted of K-12 instructor support and scaffolding of student learning in engineering PBL environments. Researchers examined how the teachers planned to scaffold and support students, how they implemented scaffolding in the PBL engineering activity, and how they reflected upon their PBL engineering lesson implementation. Data were collected through semi-structured interviews, classroom observations, and teacher written reflections. Observations were coded using Saye and Brush's model of *soft* and *hard* scaffolding [18], as well as coding for van de Pol et al.'s scaffolding *means* and *intentions* [22].

Supporters of mixed methods research suggest that by triangulating data using both qualitative and quantitative methods, one advantage is a more holistic view of the data than either approach would provide alone [23]-[25]. For example, by using mixed methods researchers may be better able to examine relationships between variables. This study utilized both semi-structured interviews and quantitative data analyses of observed scaffolding strategies and goals to understand how and why teachers used various scaffolding types. These mixed methods also allowed researchers to examine how teachers planned to scaffold student learning as opposed to how they implemented scaffolding.

Participants and setting

Participants included two K-12 instructors in public school classrooms in a large Southwestern metro area. The ages of their students ranged from elementary (grades K-6) to high school (grades 9-12). The participants were a purposeful sample of two STEM educators who were a part of a Research Experience for Teachers (RET) program sponsored by the National Science Foundation (NSF) at a multi-university Engineering Research Center (ERC). The RET program selects up to twenty K-12 teachers from minority-serving schools who teach STEM courses. Those selected engaged in research with civil engineering faculty at a large Research I university in the Southwest United States. This summer program ran for five weeks including the lab research component, as well as a requirement to develop an engineering lesson plan and

implement it in the classroom the following semester. RETs received professional development training in PBL and were invited to incorporate PBL in their engineering-focused lesson plans. Additionally, a PBL-focused lesson plan template was provided to them and several of the RETs chose to build PBL-integrated lesson plans, including the two participants in this study.

The two RETs who participated in this study included one elementary teacher, Sean, and one high school teacher, Manuel. Sean teaches fourth-grade science in an urban underserved public elementary school. Manuel teaches high school engineering courses in an urban high school which serves underrepresented minorities.

Lesson plans

Participants developed engineering-focused PBL lesson plans during their summer research experience. Sean, a fourth-grade science teacher, developed his PBL engineering lesson on plant growth through an Enzyme Induced Carbonate Precipitation (EICP) soil crust. For his lesson, students created mini terrariums using cardboard egg cartons and created capillary action to water the plants they grew. The students were provided with soil and chose their plants from a selection of seeds offered by the teacher: rye grass, radish, clover, pea, barley, or corn. On Day 1, students planted their seeds and watered them from the top. All subsequent watering occurred from the bottom up. The top layer of soil was sprayed with an EICP solution creating a crust. Students recorded and observed their plants' growth through the EICP crust. For this study, researchers observed Day 1 of the lesson and the pre-lesson interview also focused on Day 1.

High school teacher, Manuel, developed a PBL engineering unit focused on the analysis of enzyme-treated 3D-printed concrete. Students were asked to take on the role of biogeotechnical engineers and determine if the compression of 3D-printed structures can be increased using biomediated concrete. Similar to Sean's lesson, Enzyme Induced Carbonate Precipitation (EICP) was used as a bio-mediated solution. Students created 3D-printed columns and treated some with the EICP solution, while not treating others. The students then compared load versus displacement and porosity of treated and untreated columns. Researchers observed Day 10 of the unit and the pre-lesson interview also focused on Day 10.

Data collection and materials

Prior to lesson implementation, the researchers conducted semi-structured interviews to gather data focused on how the teachers were planning to scaffold student learning in their PBL lessons. An interview protocol was developed by the researchers to allow for the surfacing of themes in teachers' plans for scaffolding student learning in the PBL activities to be implemented. The researchers developed four initial jumping-off questions related to the study's research questions, allowing participants to share their thoughts and perceptions. As the interviews were semi-structured, the researchers asked follow-up questions to gain further insight into teacher responses. In addition, the researchers observed one day of PBL engineering activities which were a part of the lesson plans. Observations were coded based on a scaffolding coding scheme of scaffolding *means* and *intentions* per van de Pol et al. [22], as well as Saye and Brush's *hard* and *soft* scaffolding frameworks [22], as described above.

In the final phase, each teacher submitted a written reflection of their lesson plan implementation, specifically reflecting upon how they scaffolded student learning and what they would or would not change in their PBL engineering lesson plans. These data were analysed using a grounded approach to surface emerging themes [26].

All of these data collection methods allowed for triangulation and provided both quantitative and qualitative data to inform this study's research questions.

Data analysis

Semi-structured interviews of both teachers, Sean (elementary school) and Manuel (high school), were coded for scaffolding *means* and *intentions* using van de Pol et al.'s (2010) scaffolding framework [22] and Saye and Brush's *soft* and *hard* scaffolding [18]. Each mention of a scaffolding *means* or scaffolding *intention* was coded for the six *means* (*questioning*, *feedback*, *hints*, *instructing*, *explaining*, *and modeling*) or the five *intentions* (*direction maintenance*, *cognitive structuring*, *reduction of degrees of freedom*, *recruitment*, *and contingency management*). It is important to note that in some cases more than one *means* or *intention* could have been coded for a single mention of scaffolding. These codes were assigned using a grounded approach and allowed for emergent themes to surface from the interview data [26]. In addition, researchers recorded the participants' answers to be used to further elucidate the data.

Classroom observations of both teachers were also coded using the same scaffolding frameworks described above [18], [22]. Each observed instance of scaffolding was coded for its scaffolding *means* and *intention*, as well as whether it was an instance of *soft* or *hard* scaffolding. The researchers met and reviewed the coded observations to come to a full consensus, ensuring interrater reliability.

Descriptive statistics and Pierson-point coefficient correlations were conducted to analyze frequencies of scaffolding instances (*hard, soft, scaffolding means, and scaffolding intentions*), as well as relationships between scaffolding *means* and *intentions*.

Finally, post-implementation written teacher reflections were analyzed for emergent themes related to how they planned for, implemented, and reflected upon scaffolding of student learning throughout the PBL engineering lesson.

Results

Results of the data analyses informed the three research questions guiding this study. This section is divided by data source and results are reported accordingly.

Semi-structured interviews

Elementary teacher, Sean, was interviewed prior to implementing his PBL engineering lesson and the interview data were coded for scaffolding *means*, *intentions*, and for *hard* and *soft* scaffolding. When asked what supports students might need, Sean described how he planned to scaffold in various ways to simplify tasks for them (*reduction of degrees of freedom*) and to manage potential frustrations or confusion (*contingency management*). For example, Sean stated that "students might struggle with the soil because it's not organic" which would be a new kind of soil students hadn't encountered before. In order to manage any possible frustrations, Sean planned for students to use a handout he had created (*hard* scaffold) and prepared notes in their composition notebooks (*hard* scaffold).

Additionally, Sean expressed his intentions to allow for learner independence through the problem-solving process (*cognitive structuring*). He shared that he had been trying to give students more independence and hoped "that I can grow and foster that independence." Likewise, he worried about students feeling pressured to select certain seeds but wanted to allow them to choose their own seeds as opposed to preassigning specific seed types to students. Although he mentioned his desire to foster independent problem-solving, or *cognitive structuring*, he did not mention specific scaffolding strategies he would use to accomplish this. Most of the scaffolds he described were *hard* scaffolding that were prepared in advance.

Coding of the interview identified the following mentions of scaffolding *intentions*: three mentions of *contingency management*, two mentions of *cognitive structuring*, and four mentions of *reduction of degrees of freedom*. Researchers coded the following mentions of scaffolding *means*: one mention of *questioning*, one mention of *explaining*, and three mentions of *instructing*. Interview data also revealed three mentions of *hard* scaffolds that Sean planned to use in his lesson.

High school teacher, Manuel, was interviewed by researchers prior to implementing his PBL engineering lesson. Interview data were coded for scaffolding *means*, *intentions*, and for *hard* and *soft* scaffolding. When asked what supports students might need, Manuel shared that he expected students would need help to get started, that he would need to "give them a push" (*recruitment*), although he did not describe how he would "push" the students. Manuel explained that he planned to scaffold student problem-solving by "roaming around the room asking probing questions" (*questioning*). His hope was to use *questioning* to help student organize their problem-solving (*cognitive structuring*).

Manuel described how the physical setup of each station that students would work in was in itself a form of scaffolding. For example, he stated that the students "should be able to tell from the cues what they are doing". When asked to elaborate on what those "cues" would be, Manuel said that the equipment and setup of each station would tell the students what they should do (*hard* scaffolding). He also shared that students may need to be guided through the steps of their tasks (*instructing*) and that he planned to "describe the whole process the day before" as well as model the tasks to be completed. Finally, Manuel planned to facilitate a whole-class discussion in order to reflect upon the day's activities (*cognitive structuring*).

Coding of the interview identified the following mentions of scaffolding *intentions*: one mentions of *contingency management*, five mentions of *cognitive structuring*, five mentions of *reduction of degrees of freedom*, and one mention of *direction maintenance*. Researchers coded for the following mentions of scaffolding *means*: one mention of *questioning*, two mentions of *recruitment*, two mentions of *instructing*, and one mention of *modeling*. Interview data also revealed two mentions of *hard* scaffolds and two mentions of *soft* scaffolds that Manuel planned to use in his lesson.

Classroom observations

As previously described, two teachers (one elementary, one high school) were observed during one class session of instruction. In both cases, the class session was one of several days of activities which were a part of larger PBL engineering units.

A total of 54 distinct instances of scaffolding were observed and coded. Sean accounted for 28 scaffolding instances while Manuel accounted for 26 instances. As described earlier, each instance of scaffolding was coded by the observed *means* and *intentions*. It is important to note, however, that each instance of scaffolding was often associated with more than one scaffolding *means* and/or *intention*. In light of this, dichotomized variables were created for each scaffolding *means* and *intention* indicating that an instance was (1) or was not (0) an example of a given *means* or *intention*. Frequency distributions are presented below of the dichotomized variables.

Scaffolding means

Observation data revealed that the most frequently used scaffolding *means* were *questioning* (43%) and *instructing* (33%), followed by *explaining* (31%) and *feedback* (24%). *Hints* (19%) and *modeling* (7%) were observed least frequently. Frequency and percentage data for all scaffolding *means* are presented in Table 1 below.

Scaffolding means	Observed scaffolding means	%
Questioning	23	43%
Instructing	18	33%
Explaining	17	31%
Feedback	13	24%
Hints	10	19%
Modeling	4	7%

Table 1

Frequency distribution of scaffolding means.

Note. A total of 54 distinct scaffolding examples were observed. The total number of observed means exceeds 54 (and the corresponding percentages exceed 100%) because individual scaffolding examples were associated with multiple means in some cases.

Scaffolding intentions

The scaffolding *intention* of *cognitive structuring* was observed in half (50%) of scaffolding instances. *Contingency management* (41%), *direction maintenance* (35%), and *reduction of degrees of freedom* (35%) were also commonly observed *intentions*. The intention of and *recruitment* (7%) was the least frequently observed among the participating teachers. Frequencies and percentages for all scaffolding *intentions* are presented in Table 2 below.

Scaffolding intentions	Observed scaffolding intentions	%
Cognitive structuring	27	50%
Contingency management	22	41%
Direction maintenance	19	35%
Reduction of degrees of freedom	19	35%
Recruitment	4	7%

Table 2Frequency distribution of scaffolding intentions.

Note. A total of 54 distinct scaffolding examples were observed. The total number of observed intentions exceeds 54 (and the corresponding percentages exceed 100%) because individual scaffolding examples were associated with multiple intentions in some cases.

Hard vs. soft scaffolding

The majority of observed scaffolding instances were classified as *soft* scaffolding (91%), while less than 10 percent of instances were coded as *hard* scaffolding (9%). Forty-nine instances of *soft* scaffolding were observed, while only five examples of *hard* scaffolds were recorded during all classroom observations.

Relationships between scaffolding means and intentions

Pearson product-moment correlation coefficients were calculated to determine the extent of associations between the six scaffolding *means* and the five scaffolding *intentions*. Due the dichotomous nature of the variables, correlation coefficients are equivalent to phi coefficients. The results are presented in Table 3 below.

Table 3

Statistically significant relationships between scaffolding means and scaffolding intentions.

Direction maintenance	Cognitive structuring	Reduction of degrees of freedom	Recruitment	Contingency management
.385**		478**		
		415**		.415**
	.286*			
		.384**		
	Direction maintenance .385**	Direction Cognitive maintenance structuring .385** .286*	Direction Cognitive Reduction maintenance structuring of degrees .385**478** .286* .384**	Direction maintenanceCognitive structuringReduction of degrees of freedom 478** 415**Recruitment.385**478** 415**.286*.384**

Note. p < .05, p < .01. N = 54 for all analyses.

Of the statistically significant observed relationships between scaffolding *means* and scaffolding *intentions*, four were positive, demonstrating that the instance of a given *intention* was associated with the instance of a given *means*. Positive correlations were observed between *feedback* and *contingency management* (r = .415, N = 54, p<0.01), *questioning* and *direction maintenance*

(r = .385, N = 54, p<0.01), *instructing* and *reduction of degrees of freedom* (r = .384, N=54, p<0.01), and *hints* and *cognitive structuring* (r = .286, N = 54, p<0.05).

Negative relationships also emerged between scaffolding *means* and scaffolding *intentions*, indicating that as instances of a given *means* increased, instances of a given *intention* decreased. For example, as instances of *questioning* increased, observations of *reduction of degrees of freedom* declined. There was a significant negative correlation r = -.478, N=54, p<0.01. Similarly, as instances of *feedback* increased, observations of *reduction of degrees of freedom* declined (r = -.415, N=54, p<0.01).

Post-lesson reflections

Both Sean and Manuel submitted written reflections of their lesson plan implementation. They were asked to reflect upon the overall lesson effectiveness, student outcomes, and how they scaffolded student learning. Manuel reported that his lesson went "without a hiccup" and that "it went very well." His primary concern related to the materials used in the experiment and how they affected the overall experimental results. Interestingly, Manuel did not identify any future changes he would make to how student learning was scaffolded, suggesting that he was satisfied with how scaffolding was implemented in his lesson.

Sean addressed the use of scaffolding in his lesson more directly and identified what worked in his view and what he would change. For instance, he determined that in order to scaffold student attention to the learning task (*direction maintenance*), he needed to adjust the plant growth rates. Additionally, Sean mentioned that the students needed higher levels of scaffolding in the concepts of absorbency and capillary action. His suggested change for future implementation was to provide a mini lesson (*instructing*) to the students. Sean further detailed the students' limited knowledge of investigative, experimental and "bench skill abilities." In order to overcome this, he modelled the experimentation and investigation processes to students in preparation for the PBL engineering activity.

Discussion

Matching scaffolding goals to practice

Both Sean and Manuel spoke, during pre-lesson interviews, about their desire to foster independent and higher-order thinking in their students. Manuel suggested that he planned to use "probing questions" to promote problem-solving for learners, while Sean said that he also wanted to foster independent problem-solving (*cognitive structuring*). However, the observation data showed that there was no correlation between the scaffolding strategy or *means* of *questioning* and the scaffolding *intention* of *cognitive structuring*. In fact, the only scaffolding *means* that was somewhat related to supporting student cognition (*cognitive structuring*) was providing *hints*.

This is interesting, specifically in Manuel's case, because he stated in his pre-lesson interview that he planned to use *questioning* for the express purpose of promoting higher-order problem-solving (*cognitive structuring*). In Sean's case, he did mention his intention for fostering independent thinking and problem-solving, but he did not identify any specific scaffolding strategy or *means* to accomplish that.

On the other hand, *questioning* was strongly negatively correlated to simplifying the task for learners (*reduction of degrees of freedom*). In other words, as both teachers increasingly used *questioning* as a scaffolding strategy, they were not simplifying the learning task nor doing what students couldn't do for themselves. The data also showed that *questioning* was positively correlated to directing students to the task at hand (*direction maintenance*). Winters, Farnsworth, Berry, Ellard, Glazewski, and Brush [27] similarly found that middle school teachers in a PBL engineering activity used *questioning* for redirecting students.

Both teachers also indicated in pre-lesson interviews that they had developed hard scaffolds to guide student problem-solving during the PBL lesson. Sean described a handout that students were to include in their notebooks and use during the experiments conducted during his lesson. He specifically identified the scaffolding *intention* as providing "directions of what to do" (*instructing*) in order to simplify the task for his students (*reduction of degrees of freedom*). The observation data indicated that Sean did focus on reducing his students' degrees of freedom during the problem-solving process, using both *instructing* and *modeling* as scaffolding strategies. However, as mentioned previously, his use of *questioning* did not reflect the scaffolding goal of simplifying the learning task. This focus on doing what students couldn't do for themselves, however, did not fully align with his pre-lesson plans to foster student independence. It is important to note that his students' age range was nine to ten years old. Eshach, Dor-Ziderman and Arbel [28] suggest that younger students do need higher levels of scaffolding in complex learning environments due to the heavy cognitive load that this type of learning places on them. Sean himself stated that, "Even if it's highly scaffolded, that doesn't mean it's not PBL. If they're doing the problem-solving, that's still PBL."

Likewise, Manuel also provided hard scaffolds to his high school students both prior to the day of the PBL lesson and during the lesson. He mentioned in the pre-lesson interview that he modelled several of the problem-solving steps for students the day before the PBL lesson and had them write notes. This is an example of how he intended to use the scaffolding *means* of *instructing* to reduce the students' degree of freedom by simplifying the task. Despite this, classroom observation data revealed that Manuel's use of *instructing* did not correlate with the scaffolding *intention* of *reduction of degrees of freedom*. The scaffolding *intention* that did have a significant negative correlation with *instructing* was *cognitive structuring*. In other words, as Manuel used instruction to scaffold learners' problem-solving, he was less likely to be supporting student cognitive processing.

These results highlight a mismatch between how Manuel and Sean planned to support student learning and how they implemented scaffolds in their lessons. Additionally, their post-lesson reflections suggest that they may not be aware of this mismatch or were not concerned about it.

Teacher and learner characteristics' impact on PBL implementation

Winters et al. [27] also looked at scaffolding goals and strategies and how teachers planned for scaffolds in a PBL engineering activity. In their study, instructors indicated in pre-lesson interviews that they intended to support learners' cognition and transfer of knowledge using probing questions. Observation data revealed that the teachers' scaffolding strategy of *questioning* did in fact have a significant positive correlation with *cognitive structuring*. This is a different outcome from what researchers in the current study found. Although both Manuel and Sean intended to use probing questions to foster learner cognition, they did not do so while implementing their lessons.

The different outcomes may be explained by the differences in the learning environments in both studies, specifically the level of teacher preparation and training in PBL and student exposure to PBL in engineering. In the current study, both Manuel and Sean received some PBL professional development during their summer RET experience; however, neither had extensive prior PBL experience. In Winters et al. [27], the instructors had been using PBL in their classroom instruction for several years and had received extensive professional development. One of the obstacles to PBL implementation often identified by K-12 teachers is a lack of professional development [29]-[31]. Other barriers include a lack of institutional support and also students' lack of prior exposure to complex learning environments.

In this study, Manuel and Sean taught in public K-12 schools serving underrepresented minorities and low SES communities. Although both schools supported STEM and engineering-focused instruction, they were also subject to state-wide standardized testing and primarily used traditional instructional methods. The learning environment in Winters et al., [27] however, was a charter middle school focused on inquiry- and problem-based learning. Instructional units which were interdisciplinary and supported student-directed learning were encouraged, and the school environment allowed for the time and resources needed to effectively implement and scaffold PBL.

Public K-12 teachers like Manuel and Sean, however, often struggle to integrate complex and authentic learning into their curricula due to the barriers that are inherent in many school environments [29]-[31]. For instance, a common barrier to PBL implementation is that of time [29]; instructors' time is limited but the demands on that time are many and persistent. PBL requires a great deal of time to prepare and implement, and effectively scaffolding student learning during the problem-solving process adds further demands for preparation and training [8]. Without strong institutional support and resources, teachers often don't have the time to effectively scaffold student learning in PBL. Puntambekar and Kolodner [32] highlight the difficulty teachers face when scaffolding multiple students and groups in a classroom during complex problem-solving. They found that students needed multiple types of scaffolding offered at varying levels, what they called *distributed scaffolding*, in order to be successful in STEM PBL environments [32]. In the case of Manuel and Sean, the mismatch between their plans for scaffolding and how they implemented scaffolding in their lessons may be a reflection of a need for distributed scaffolding.

Limitations

Although this study's mixed-methods approach allowed for triangulation of the data, there are potential limitations. One is the small sample size of two participants. It is important to note that any results only apply to the limited context of these two teachers in their specific classrooms. Data gathered, therefore, may not be generalizable to a larger population of K-12 STEM teachers.

In addition, correlational results do not speak to causation. This study did not seek to answer questions of effectiveness of scaffolding or effectiveness of PBL in engineering education. The primary focus of this study was to consider how these teachers planned for student scaffolding, how they implemented scaffolding – looking at *hard* and *soft* scaffolding, scaffolding *means* and *intentions* – and how they reflected upon their scaffolding of learners during a PBL engineering lesson.

The results of this study suggest that further research is warranted examining potential barriers that may exist to teachers' effectively aligning their scaffolding plans with how they implement scaffolding into engineering instruction. Other areas that bear further study include how teacher characteristics, such as level of experience with and amount of PBL professional development, may affect how they scaffold students in problem-solving activities.

Conclusion

This study examined how K-12 engineering teachers planned to support student learning using scaffolding, how they implemented scaffolds during PBL engineering activities, and how they reflected upon their PBL engineering lesson implementation. The two K-12 teachers who participated in this study planned to scaffold student problem-solving using strategies such as asking probing questions, providing handouts, recruiting student attention, modeling, and providing feedback, among other strategies. Both teachers used most of the scaffolding strategies that they planned to use; however, the scaffolding goals for using those strategies did not always match their implementation as revealed in classroom observations.

There may be several explanations for this mismatch between how the teachers planned to scaffold student learning and how they implemented scaffolding in the classroom. As previously described, the participants in this study had received some limited training in PBL, but they did not have extensive professional development nor experience implementing PBL. Additionally, they taught in traditional school environments which often do not provide the resources and time needed for effective PBL implementation.

One approach that may help align the teachers' planned scaffolding with classroom implementation is distributed scaffolding, which allows for many types of scaffolding at various levels to be implemented in PBL lessons. Further research on how teachers plan for and implement scaffolding and support for student learning is recommended.

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