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The Impact of Scaffolding and Student Achievement Levels in a Problem-based Learning Environment

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Abstract. This study examined how scaffolds and student achievement levels influence inquiry and performance in a problem-based learning environment. The scaffolds were embedded within a hypermedia program that placed students at the center of a problem in which they were trying to become the youngest person to fly around the world in a balloon. One-hundred and eleven seventh grade students enrolled in a science and technology course worked in collaborative groups for a duration of 3 weeks to complete a project that included designing a balloon and a travel plan. Student groups used one of three problem-based, hypermedia programs: (1) a no scaffolding condition that did not provide access to scaffolds, (2) a scaffolding optional condition that provided access to scaffolds, but gave students the choice of whether or not to use them, and (3) a scaffolding required condition required students to complete all available scaffolds. Results revealed that students in the scaffolding optional and scaffolding required conditions performed significantly better than students in the no scaffolding condition on one of the two components of the group project. Results also showed that student achievement levels were significantly related to individual posttest scores; higher-achieving students scored better on the posttest than lower-achieving students. In addition, analyses of group notebooks confirmed qualitative differences between students in the various conditions. Specifically, those in the scaffolding required condition produced more highly organized project notebooks containing a higher percentage of entries directly relevant to the problem. These findings suggest that scaffolds may enhance inquiry and performance, especially when students are required to access and use them.

Keywords: problem-based learning (PBL), middle school, scaffolding

Introduction

Problem-based learning (PBL) has been endorsed by many educators to promote understanding, integration, and retention of concepts, facts, and skills (Gallagher et al., 1995; Gallagher, 1997). PBL combines learning theories about problem solving with the case study approach (Gallagher). In this context, students are presented with problems embedded in relevant, resource-rich contexts (Hoffman & Ritchie, 1997) and assume the role of primary researchers. They then work in small groups to analyze the problem, consider possible solutions, develop a plan, and evaluate the outcome (Kaufman & Mann, 1997). Models of problem-based learning range from limited implementations, which engage students in problem solving of a question or case, to broad implementations, where students define and research their own problems in collaboration with a teacher or practicing professional (Barrows, 1986; Pierce & Jones, 1998).

Early reviews of research have provided an overview of the comparative effects of PBL on student learning and motivation. A meta-analysis by Albanese and Mitchell (1993) reported that medical students enrolled PBL programs tended to score lower on standardized measures of basic science knowledge than peers in traditional programs; however, PBL students seemed to have superior long-term recall, since they purportedly held a deeper understanding of the content. The authors also concluded that students in the PBL curriculum expressed more positive attitudes than students in traditional programs. Norman and Schmidt (1992) reviewed the literature regarding the psychological bases of PBL, and drew similar conclusions regarding student attitudes and long-term retention. Similarly, a meta-analysis by Vernon and Blake (1993) found medical students enrolled in PBL programs demonstrated greater clinical functioning and knowledge and tended to have more positive attitudes than students in traditional programs. However, PBL students also performed lower on national board examinations and other measures of knowledge.

In a more recent meta-analysis, researchers examined the impact of PBL on learning outcomes among three distinct levels of assessment: (1) concepts, (2) principles that link concepts, and (3) linking of concepts and principles to conditions of application (Gijbels et al., 2005). Findings demonstrate a significant effect for PBL over more conventional curriculum when learning was being assessed at the second level (Gijbels et al.). In other words, PBL is differentially effective depending on the level of knowledge being assessed, and learner performance in PBL is strongest when asked to demonstrate understanding of principles that link concepts. Furthermore, no negative effects for PBL were reported in this meta-analysis.

Despite a relatively long history of successful use in medical and pre-professional schools, PBL has yet to be widely adopted by K-12 teachers (Ertmer & Simons, 2006). Furthermore, researchers who have examined PBL in these settings report mixed results regarding various outcomes such as problem-solving, achievement, and attitudes. In addition, Pedersen and Liu (2003) note that much of the PBL research has focused on gifted learners, making it difficult to draw conclusions regarding PBL's effectiveness for a broad range of primary and secondary learners.

Nevertheless, research in this area, while limited, reveals some important findings regarding measures of problem-solving. For example, a study of advanced high school students revealed that learners demonstrated an increase in problem finding but a decrease in brainstorming throughout a PBL course (Stepien et al., 1993). The authors also report a change in students' argumentation skills, from presenting arguments based mostly on emotion and conjecture to arguments based on supporting evidence. A study of sixth graders indicated that achievement was enhanced for students in a modeling condition when compared to students in other conditions, suggesting that modeling target strategies may lead to enhanced problem-solving in other situations (Pedersen & Liu, 2003).

Other researchers have examined the impact of PBL on student attitudes and motivation. In the field-test report with over 1,000 students of *Alien Rescue*, a PBL science unit for the middle school grades, Liu et al. (2002) reported overwhelmingly positive comments from both students and teachers. A later study with *Alien Rescue* reported the effects of PBL on students' intrinsic and extrinsic motivational orientation, and compared the PBL context with typical class activities (Pederson, 2003). Results showed significantly higher intrinsic learner motivation for the PBL unit than for the traditional activities. Qualitative interview data suggest students' enhanced motivation may be related to a greater opportunity for collaboration and student control afforded through problem-based learning.

It is also important to examine student learning in problem-based contexts. One study of sixth grade students found overall student performance to be average, but lower than expected by the teacher, who attributed it to time constraints that limited adequate review and reflection (Simons et al., 2004). Another study investigated sixth-grade students in two different classrooms working on the same project (Barron et al., 1998). Students in one class were presented with an initial problem-solving planning activity prior to beginning their projects, while students in the other class began their projects without benefit of the framing problem-solving task. Results indicated that students in the problem-solving condition were better able to apply the targeted math concepts and had higher achievement than those not in the problem-solving condition.

Overall, PBL research is inconclusive regarding measures of student learning, attitudes, and problem-solving skills. Additionally, teachers who implement PBL have reported students encounter various challenges, such completing more open-ended tasks (Brush & Saye, 2000; Land, 2000), transitioning to a more active role (Gallagher, 1997; Mammen, 1996), and exercising problem-solving skills necessary to present a high-quality recommendation or solution (Brush & Saye, 2000; Oliver & Hannafin, 2000).

Addressing the challenges of problem-based learning

One of the most significant barriers to successful PBL implementation stems from the lack of skilled facilitators to support learners (Hmelo-Silver, 2004). This is particularly true in K-12 environments where resource limitations prevent the allocation of group tutors, as is customary among pre-professional programs. Thus, it becomes necessary to examine other methods of supporting learners. In this context, scaffolds may offer beneficial support. Scaffolds can be defined as tools, strategies, or guides that support students in gaining higher levels of understanding that would be beyond their reach without this type of guidance (Jackson et al., 1996; Saye & Brush, 2002). Wood et al. (1976) define effective scaffolding as "...controlling those elements of the task that are initially beyond the learner's capability, thus permitting him to concentrate upon and complete only those elements that are within his range of competence" (p. 9). Doyle (1986) defines scaffolding similarly as an instructional tool that reduces ambiguity for learners, thus maximizing growth opportunities.

Scaffolding framework

Scaffolds appear in multiple forms, but Saye and Brush (2002) note that most scaffolding techniques can be classified as either *soft* or *hard* scaffolds. Soft scaffolds are dynamic and refer to the domain of teacher actions in support of learners' efforts at the moment of when a learner has a specific need (Berk & Winsler, 1995; Roehler & Cantlon, 1997; Saye & Brush, 2002). For example, a teacher in a PBL study employed soft scaffolding when she consistently circulated among groups of students, questioned them on their understanding, and provided feedback on their progress (Simons et al., 2004). In contrast, hard scaffolds are static supports that can be developed in advance based on anticipated or typical learner difficulties associated with a task (Saye & Brush). For example, a teacher might develop a scaffold to help students deliver a strong, evidence-based argument to support learners at a specific stage of the process that is difficult for most learners. While good teachers may already use these types of techniques or strategies to support their students, this discussion is meant to highlight the deliberate planning for, and use of, these approaches to support student learning, especially during processes or with content with which students have been known to struggle.

Two specific types of hard scaffolds include *conceptual* and *strategic* support (Hannafin et al., 1999). Conceptual scaffolds guide the learner toward ideas to consider during the problem-solving process through hints or cues (Hannafin et al.). For example, Linn et al. (1999) embedded conceptual scaffolds within in an online, PBL project in the form of a *hints* button when students were asked to explain why frogs from a certain area are deformed. Strategic scaffolds provide advice from experts to assist students with analyzing and approaching the task (Hannafin et al.). One multimedia PBL program, *Alien Rescue*, contains video excerpts of an expert discussing explicit strategies he uses to manage and organize information (Pedersen & Liu, 2003). In one example, he describes the process used to determine if information is relevant to the problem, which represents a typical student difficulty among elementary and middle school students.

A question that arises when discussing hard scaffolding, specifically when it takes the form of conceptual and strategic approaches, is the extent to which such external hints, cues, and strategies should be classified as "authentic scaffolds" or simply "good directions." For example, Pea (2004) suggests, "the concepts of scaffolding has becomes so broad in its meanings ... that it has become unclear in its significance" (p. 423). However, he also notes how scaffolds should function including constraining efforts, focusing attention on relevant features to increase the likelihood of the learner's effective action, and modeling advanced solutions or approaches. Pea concludes by acknowledging that scaffolds are not necessarily items or features but "functions of processes that relate people to performances in activity systems over time" (p. 446).

Hard scaffolds have been found to support learners in a variety of ways that Pea (2004) has recommended. Researchers have reported that hard scaffolds impact information seeking (Wolf, 2000), problem-solving (Cho & Jonassen, 2002), reflection (Davis & Linn, 2000), research assistance (Brinkerhoff & Glazewski, 2004; Wolf, 2000), task constraint (Cho & Jonassen, 2002; Simons et al., 2004), concept integration (Davis & Linn, 2000; Saye & Brush, 2002), and knowledge acquisition (Roehler & Cantlon, 1997). However, other researchers suggest that students lack metacognitive awareness to apply scaffolds strategically (Land & Hannafin, 1997; Oliver & Hannafin, 2000).

Overall, research on scaffolding in problem-solving environments has shown varying degrees of impact. On one hand, some studies have demonstrated effectiveness of scaffolds in helping students to manage information, solve problems, and integrate information; on the other hand, others suggest students often fail to use available scaffolds. Thus, further research may offer more insight regarding the role of scaffolding to support student performance in PBL.

Purpose of the current study

The purpose of this study was to examine the role hard scaffolds play in support of middle school learners during the implementation of a problem-based learning unit. In this context, the scaffolds were designed to be either strategic or conceptual in nature, and served as research aids to assist students approaching the task and deciding which information would be most essential.

The independent variables included scaffolding condition (none, optional, and required) and student achievement levels (as measured by the students' grade point averages). Each of five intact middle school classes taught by the same teacher were randomly assigned to a scaffolding condition within the context of an interdisciplinary, hypermedia PBL unit. Two classes were assigned to the *scaffolding required* condition, two classes were assigned to the *scaffolding optional* condition, and one class was assigned to the *no scaffolding* condition (control group). Dependent measures included student projects, student posttests, and an attitude survey. Additional data sources included group notebooks and classroom observations during the implementation.

Four major research questions in this study were as follows:

1. What is the effect of scaffolding condition (none, optional, and required) on student project performance?
2. What is the effect of scaffolding condition (none, optional, and required) and student achievement levels on student posttest performance?

3. What is the effect of scaffolding condition (none, optional, and required and student achievement levels on students' perceptions and attitudes toward the PBL unit, investigation, and open-endedness?
4. How do students in the various learning conditions approach the problem-based tasks?

Method

Participants and setting

Participants were 111 seventh grade students enrolled in one of five sections of nine-week supplemental, but required, course that focused on science, math, and technology. The same teacher taught all five sections. In general, the population at the school is characterized as low performing, as identified by high absence rate, high mobility rates, and below-grade performance on the Stanford 9 achievement test (aggregate reading scores ranked at the fifth-grade performance level). Roughly half of the participants were female (51%) and half were male. Approximately 44% of the students were Hispanic, 41% were White, and the remaining 15% comprised other ethnic minority groups such as Black, Native American or Middle Eastern.

Materials

Up, Up & Away!

The instructional program used in this study was *Up, Up, & Away!*, a hypermedia, PBL unit developed in accordance with the Center for Problem Based Learning operated by the Illinois Mathematics and Science Academy (2002). *Up, Up & Away!* integrates learning goals specifically related to meteorological concepts, math, geography and language arts. At the center of this unit is a problem that guides the learning activities. On the opening screen (see Figure 1), students are given the task of planning a global circumnavigation via balloon, a feat attempted by several teams and accomplished for the first time in 1999.

The opening screen also holds links to three options: *project, resources*, and *hints* (see again Figure 1). The *project* button takes students to a screen detailing the two components expected for the completed project. The components include a description of requirements for *balloon design* and *travel plan*. The balloon design directs students

Figure 1. Opening screen of *Up, Up, & Away!*.

to submit a cut-away drawing or model of their balloon, informs what criteria to address, and solicits a rationale for their design. The travel plan describes criteria for a well-designed launch site and route, and solicits a rationale for their proposed route.

The *resources* button links to informational Web sites related to global ballooning. The informational sites are organized under four topic headings: (1) Prior Attempts, (2) Weather & Geography, (3) News Articles, and (4) Balloon Design. Beneath these headings are links to Web sites containing information relevant to completing the *Up, Up & Away!* challenge. For example, links under Prior Attempts allow students to access web pages of eight different teams attempting to circumnavigate the earth via balloon.

The *hints* button takes students to another screen that provides access to support materials. Students in the no scaffolding condition were provided with access to a glossary of ballooning-related terms while students in the scaffolding optional and scaffolding required conditions were provided with access to the hard scaffolds described below.

Hard scaffolds

For students in the scaffolding optional and scaffolding required groups, the hints section also includes several scaffolds in addition to the glossary (see Figure 2). The hard scaffolds in this unit were developed for three primary purposes: (1) support learners' project

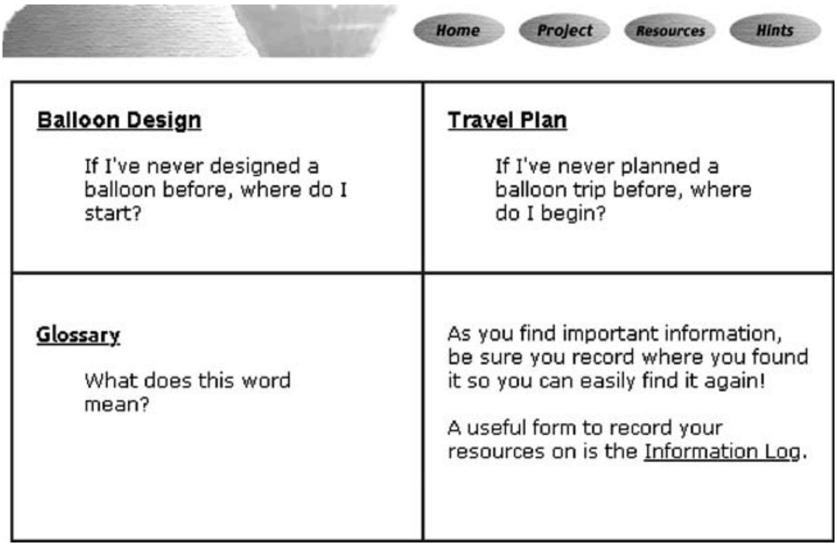

Figure 2. Hints screen for Scaffolding Required and Scaffolding Optional groups.

performance, (2) constrain the task for the learner, and (3) free the teacher to perform additional soft scaffolding.

The opening screen links to two strategic scaffolds in the form of guiding questions and responses, each matching the two main problem components and designed to offer expert advice at the initiation of students' resource gathering. In addition, the opening screen offers a strategic scaffold to students in the form of an expert suggestion that they organize the information they find by keeping track of which sources provide important information, and students can link to and print an Information Sources log which will help them do so.

From the anticipated question related to the balloon design ("If I've never designed a balloon before, where do I start?"), students encounter one strategic and one conceptual scaffold. The strategic scaffold is presented in the form of a text-based response intended to offer expert advice regarding how to begin the balloon design:

> One good place to start is by gathering information about the different kinds of balloons. There are basically three different kinds, but not all of them would be a good choice for trying to fly around the world. That's because each has pros and cons in terms of flying long distances. Another good place to start might be to find out what kinds of balloons other people used when they tried to fly around the world.

After reading the expert advice, students are guided to use the *balloon types* form, which is a conceptual scaffold designed to cue their thinking for the purposes of enabling them to discriminate between essential and non-essential information. This form cues learners to consider the three different types of balloons, components of each, pros and cons of each when it comes to flight, and a rationale for selecting or not selecting each type.

From the anticipated question related to the travel plan (“If I’ve never planned a balloon trip before, where do I begin?”), students link to three strategic scaffolds guiding them to think about this aspect of the problem as a three-step process. Within second step, students also access one conceptual scaffold described in more detail below. The first step presents the following:

> Since there are no roads in the sky, a road map certainly won’t do you any good. Remember that when you’re traveling by balloon, it’s the wind that will push your balloon along. And if you want to fly your balloon around the world, you can’t rely on local winds that only blow over a small part of the Earth. You’ll need to find winds that will blow all the way around the world. To draw your route map you’ll need to find out about these winds and where they are blowing today, then draw the wind pattern onto a map of the world. Maps of wind patterns often show global winds as bands of color.

From this point, students are advised to look at the resources under the “Weather & Geography” section for information about global winds.

Once students have completed step one, they are presented with a second strategic scaffold in step two that advises students to determine which countries to avoid by reading the various news articles about previous attempts. Students are then guided to use the *travel plan* document, which is a conceptual scaffold designed to cue the essential things to consider in the route, such as which hemisphere, length of trip, departure and arrival points, countries to be crossed, and countries to be avoided. Each section also asks students to describe their rationales.

Step three of the travel plan scaffold is a strategic scaffold intended to guide students in finalizing their route map to reflect the countries they will cross over and avoid. Students are presented with a guiding question that states, “Once I’ve figured out which countries to avoid, how can I change the flight map to show that I’d steer around them?”

In response, students are guided to look for information related to means of steering their balloon according to local winds and are instructed to modify their route maps accordingly.

Teacher's guide

Up, Up, & Away! features a detailed teacher's guide designed to enable effective and efficient implementation of the PBL unit. The guide was initially written by the developers, and teacher input from two prior implementations of the program was subsequently incorporated. The teacher is provided with five lesson plans intended to introduce the unit and its central problem, set expectations, review findings related to the problem, and conduct alternative enrichment demonstrations. Embedded within the lesson plans are mini-lectures which the teacher can opt to deliver covering a variety of topics, such as a lecture describing the Jet Stream and its importance to balloonists. Also included are science demonstration ideas related to the learning goals, such as one entitled "Hot Air Rises." Teachers are also given extensive background information, which includes content and strategies for effective implementation of the unit. A section entitled "Group Variations" is embedded within four of the five lesson plans to describe the adaptations for the scaffolding required and scaffolding optional conditions.

The majority of the guide contains content related to covering instructional objectives, but suggestions are also made for implementing cooperative learning, creating bulletin boards to spark interest, and collecting additional books and magazines as resources. Teachers are also advised to give feedback for each strand of the project, and forms are included for this purpose.

Procedures

This study included two treatment groups and a control group. Two intact classes were randomly assigned to both the scaffolding required and scaffolding optional conditions and one intact class was randomly assigned to the no scaffolding condition as a means of control. Student grade point averages (GPA) were obtained from the teacher and used as the measure of achievement in this study. A median split of GPA was calculated; students with a GPA of 2.57 or above were classified as high-achievers. An ANOVA conducted on GPA revealed no significant difference between student achievement levels among the three instructional conditions, $F(2,108) = 1.23$, $p = 0.28$.

The teacher assigned students in each class to collaborative groups each consisting of three or four students. She based group assignments on such criteria as her knowledge of the students' abilities, personalities, gender, and ethnicity. Each group was given a colored folder used to differentiate each class from the next. Each folder contained the *project expectations*, divided sections for the balloon design and travel plan, a blank outline map of the world, and blank paper for recording notes.

A researcher observed each class daily throughout the entire study. The teacher implemented the unit for the duration of 3 weeks in five daily class periods lasting 50 min each. The first day was spent forming student groups, explaining how to access the PBL unit on the computer, and introducing the unit to students. On the second day, the teacher told students in both scaffolding conditions how to obtain the scaffolds and informed those in the scaffolding required group that they were mandatory. Students in all conditions spent the subsequent 6 days working on their balloon designs. Following this, students spent 2 days researching their travel plans. Students compiled the various components for their project portfolio on days 11 through 13. On day 14, students completed the posttest and the attitude survey. The final day was reserved for groups to present their final solutions to the other class members.

All students received virtually the same instruction, except for the presentation of the scaffolds. Students in the no scaffolding group received no modifications to the unit. As only one computer in the classroom provided students with access to a printer, groups in the scaffolding required conditions had a copy of the balloon types form in the balloon design section of their folder and a copy of the travel plan form in the travel plan section. Students in the scaffolding required groups were directed by the teacher to complete these forms as a project requirement. The teacher described these forms to the scaffolding optional students, but informed students they were for optional use.

Data Sources

Group projects

Group projects included a balloon design and a travel plan. The balloon design included a balloon description and a written rationale. The travel plan contained a written travel plan, route map, sample letter of permission to fly over a representative country, and a written rationale. Student projects were evaluated according to a checklist.

The checklist has sections for each major component, and each criterion was graded on a three-point scale ranging from zero to two. Students could earn up to 70 points total: up to 34 points for the balloon design and 36 points for the Travel plan.

Two independent raters scored the projects. They were trained together on the scoring checklist by the researcher, until they obtained agreement of 85% or better on each component. The raters scored the remainder of the projects independently. After all projects had been scored by both raters, the Pearson product-moment correlation coefficient was calculated for each project component, balloon design and travel plan, to determine interrater reliability. For the balloon design, this index was 0.97, and for the travel plan, it was 0.98. Both correlations were significant at the $p = 0.01$ level. Both raters' scores for each project were averaged together to obtain one final project score. This final project score was assigned to each student in the respective groups.

Posttest

A 20-item posttest was used as an individual measure of student achievement. The posttest comprised three parts: multiple choice, matching, and free response. The first part contained nine multiple choice items and covered the major science and meteorology unit objectives such as why winds blow, what the jet stream is, and what the role of winds and the jet stream are as they relate to balloon flight. Part two contained a matching item that asked students to identify a description of how each type of balloon ascends and descends as hot air, helium, or Rozier types. The third part covered the geography objectives, and students were asked eight constructed response questions. The first two questions related to the political issues surrounding balloon fight and countries that do not allow balloonists to fly in their airspace. The third question asked students to label the continents and oceans on a map of the world. The remaining questions focused on information regarding circumnavigation of the Earth via balloon. Students could earn up to 25 points on the posttest. One researcher scored all the posttests according to an answer key. The KR-20 alpha reliability coefficient for the posttest was 0.74.

Attitude and perception survey

A 15-item survey contained three sections measuring student attitudes toward the *Up, Up & Away!* unit, perceptions of Investigation, and perceptions of Open-endedness of the unit. Each section contained five items. The first section measuring attitudes toward the *Up, Up &*

Away! unit contained items such as "I would enjoy working on another project like this again," and "The program included enough help and advice." The second section measuring investigation of the unit was adapted from eight items in the Investigation subscale of the *Technology-Rich, Outcomes-Focused Learning Environment Inventory* (Aldridge et al., 2002). The Investigation subscale measured the extent to which student perceive emphasis is placed on the skills and process of inquiry and their use in problem solving. The revised section contained five items such as "My group looked for evidence to support out solutions in *Up, Up & Away!"* and "My group solved the problem by using information obtained from our research." The final section of the survey measured students' perceptions of the unit's Open-endedness. This section contains five items such as "There are many ways we could have developed the balloon design," and "We were able to work at our own speed." The KR-20 alpha reliability coefficient for the entire attitude survey was 0.84.

Group notebooks

Group notebooks were used to examine how students approached the learning task. Each group's notebook contained student notes taken as they worked through the project and completed the scaffolds (if applicable). In total, 31 group notebooks were examined: seven from the no scaffolding condition, 12 from the scaffolding optional condition, and 12 from the scaffolding required condition.

Observations

Observations were focused on the teacher for the purposes of capturing how she supported student learning throughout the project and examining potential differences between classes or conditions. Specifically observed were the teacher's whole-class discussions and interactions with groups to examine the means in which she supported students.

Research design and data analysis

This research study employed a quasi-experimental, mixed-method design (Creswell, 2002). In this type of design, quantitative and qualitative data are collected simultaneously and results are used to best understand a research problem. Results from multiple data sources are then used to confirm and test conclusions (Creswell, 2002). Criterion measures included individual posttests, student projects, and individual attitude and perception surveys. Additional data sources included student notebooks and observations of the teacher. Different data analyses were used to align with the various data sources, as described in more detail below.

The first research question investigated the impact of instructional condition on student project scores. A one-way multivariate analysis of variance (MANOVA) with balloon design and travel plan as the dependent variables was used to evaluate the effect of scaffolding condition (none, optional, and required) on project performance. Follow-up univariate tests were conducted on each part of the project. Multiple regression was used to examine the effect of scaffolding and student achievement levels on posttest achievement. Student attitudes and perceptions were analyzed with a MANOVA that included each of the three subsections as the dependent variables. Follow-up univariate analysis was conducted on each of those sections where significance was found.

Qualatative analyses were used to examine how students in each condition approached the task. Using a grounded theory approach (Glaser, 1992), the goal was develop substantive theories regarding how students in the various scaffolding conditions initially approached the task. To do so, group notebooks were the primary data source used. Data from the group notebooks were analyzed according to the constant comparative method in which segments of data were compared to determine similarities and differences. Similar data was grouped together into categories, with the overall objective to seek patterns in the data that lead to theory construction.

The observation data was analyzed using a simple trend analysis for the purposes of examining the teacher's implementation and determining her support of students as well as any potential differences of interaction between the treatment groups.

Results

Project scores

The first research question investigated the effect of scaffolding condition on student achievement on the group project. Table 1 shows the mean scores and standard deviations of each condition for the total project and the four separate components of the project: (a) balloon design, (b) balloon design rationale, (c) travel plan, and (d) travel plan rationale. Results reveal that for overall project performance, the

Table 1. Mean scores and standard deviations for project performance

Project component	Points possible		Instructional condition			Overall
			No scaffolding	Scaffolding optional	Scaffolding required	
		n	23	47	41	111
Balloon design	24	*M*	13.30	16.01	16.68	15.70
		SD	7.84	7.25	5.62	6.89
Balloon design rationale	10	*M*	3.50	4.12	4.17	4.01
		SD	0.56	2.12	2.29	1.98
Travel plan*	30	*M*	12.59	19.96	20.33	18.57
		SD	11.55	6.59	4.81	7.92
Travel plan rationale*	6	*M*	0.87	3.31	2.15	2.37
		SD	0.50	0.96	0.98	1.33
Project total*	70	*M*	30.26	43.39	43.33	40.65
		SD	19.17	14.18	8.03	14.47

*$p < 0.001$.

mean score was 40.65 (58%), $SD = 14.47$. When examined by scaffolding condition, the data revealed that students in the no scaffolding condition consistently scored lower on the project and each of its components than students in the scaffolding optional and scaffolding required conditions.

A one-way MANOVA was conducted to determine the effect of the three scaffolding conditions (none, optional, and required) on student project performance. Significant differences were found among the conditions and the dependent measures, Wilks' $\mathrm{M} = 0.44$, $F(8,210) = 13.26$, $p < 0.001$. The multivariate η^2 = based on Wilks' M was relatively strong, 0.34 (Green, Salkind, & Akey, 2000).

Analyses of variance (ANOVA) on each dependent variable were conducted as follow-up tests to the MANOVA. Results revealed significant differences for the project components of travel plan, $F(2,108) = 9.59$, $p < 0.001$, $\eta^2 = 0.15$, travel plan rationale, $F(2,108) = 52.47$, $p < 0.001$, $\eta^2 = 0.49$ and for the overall project total, $F(2,108) = 8.49$, $p < 0.001$, $\eta^2 = 0.14$. Results were not significant for the project components of Balloon Design, $F(2,108) = 1.89$, $p = 0.16$, $\eta^2 = 0.03$, and Balloon Design Rationale, $F(2,108) = 0.96$, $p = 0.38$, $\eta^2 = 0.01$.

Post hoc analyses for the travel plan, travel plan rationale, and project total consisted of conducting pairwise comparisons to find which condition affected performance most strongly. To control for Type I error, each pairwise comparison was tested at the 0.01 level. The no scaffolding group had significantly lower scores on travel plan, travel plan rationale, and project total when compared with either of the other two groups. The scaffolding optional and scaffolding required groups were not significantly different from each other.

Posttest scores

The second research question investigated the effect of scaffolding and student achievement levels on posttest scores. Table 2 presents posttest means and standard deviations by condition and a high–low median-split GPA score of 2.57. A multiple regression analysis with an ordered set of predictors was conducted to examine the effect of achievement levels and condition on posttest performance. Results revealed that student achievement levels accounted for a significant amount of posttest variability, $R^2 = 0.44$, $F(1,109) = 85.91$, $p < 0.001$. High-achieving students performed better than low-achieving students in all conditions. Scaffolding condition did not account for a significant proportion of the posttest variance, $R^2_{\text{change}} = 0.001$, $F(1,108) = 0.13$, $p = 0.715$.

Table 2. Posttest means and standard deviations by condition and achievement

Instructional condition		Achievement		Overall
		High	Low	
No scaffolding	*M*	15.22	11.07	12.70
	SD	2.77	3.56	3.82
	n	9	14	23
Scaffolding optional	*M*	17.74	11.13	15.49
	SD	3.02	3.88	4.57
	n	31	16	47
Scaffolding required	*M*	17.05	11.62	14.27
	SD	3.27	4.28	4.67
	n	20	21	41
Overall	*M*	17.13	11.31	14.46
	SD	3.14	3.90	4.55
	n	60	51	111

Note. The maximum number of points possible on the posttest was 25.

Student attitudes

The third research question focused on the impact of achievement levels and scaffolds on student attitudes toward the *Up, Up, & Away!* program, Investigation, and Open-Endedness. Table 3 displays means for each question by instructional condition. As each of the three sections in the attitude survey measured a distinct attribute, each was evaluated with separate analyses. To control for Type 1 error, all statistical tests were conducted using an alpha level of 0.01.

The first section of the attitude survey measured student attitudes toward the unit. Results revealed that attitudes toward the unit were generally positive. ANOVA was conducted on each item in section one. Results revealed a significant main affect by achievement for item three: "I would enjoy working on another project like this again," $F(1,103) = 8.95$, $p = 0.003$, $\eta^2 = 0.08$. High-achieving students ($M = 1.68$) were significantly more likely to desire working on another unit like *Up, Up & Away!* than low-achieving students ($M = 2.00$). No effect was found for scaffolding condition.

The second section of the attitude survey examined student attitudes toward investigation. Analyses of variance conducted on each question resulted in a significant main effect for achievement for item ten: "My group solved the problem using information obtained from our research," $F(1,103) = 9.45$, $p = 0.003$, $\eta^2 = 0.08$. High-ability students ($M = 1.75$) were significantly more likely than low-achieving students ($M = 2.12$) to indicate they used information obtained from their research to solve the problem. No effect was found for scaffolding condition.

The final section of the attitude survey examined student attitudes toward open-endedness. Analyses of variance for each item did not reveal any statistically significant items by achievement or scaffolding condition.

Student approaches to the learning task

The fourth research question examined students in the various scaffolding conditions approached the learning task. To investigate this question, the primary data source was student notebooks. Each group's notebook containing notes and completed scaffolds (if applicable) was used to examine the ways in which students approached the learning task. An initial examination of the notebooks revealed differences among organizational structure and entry type. A framework

Table 3. Means for student attitude items by condition

Question	Instructional condition*			Overall
	NS	SO	SR	
Section One: *Up, Up & Away!*				
1. It was easy to find the information I needed to complete the project.	2.35	2.29	2.24	2.28
2. I had enough time to complete the *Up, Up, & Away!* project.	2.74	2.49	2.34	2.49
3. I would enjoy working on another project like this again.	2.04	1.78	1.76	1.83
4. The program included enough help and advice.	2.39	2.09	2.07	2.15
5. I learned a lot from this project.	1.78	1.76	1.83	1.79
Section Two: Investigation				
6. I usually found the information I needed.	2.17	2.20	2.17	2.18
7. My group looked for evidence to support our solutions in *Up, Up & Away!*	1.96	2.18	2.07	2.09
8. My group designed our own ways of investigating the balloon design & travel plan.	2.22	2.16	2.07	2.14
9. My group found out answers to our questions through research.	2.22	1.82	2.00	1.97
10. My group solved the problem using information obtained from our research.	2.04	1.82	1.95	1.92
Section Three: Open-Endedness				
11. There are many approaches we could have taken in our balloon design.	2.17	1.96	2.00	2.02
12. There are many approaches we could have taken in our travel plan.	2.04	1.73	2.00	1.90
13. There were many solutions to the problems in *Up, Up & Away!*	2.30	1.93	2.12	2.08
14. We were able to work at our own speed.	2.39	2.44	2.22	2.35
15. If completing this project again, I might choose a different balloon design or travel plan.	2.39	2.76	2.66	2.64

Note. Responses ranged from (1) Strongly Agree to (4) Strongly Disagree.
*NS = No Scaffolding, SO = Scaffolding Optional, SR = Scaffolding Required

was designed to evaluate the notebooks more systematically which contained criteria for classification. Projects were blindly analyzed for the extent to which project notes contained an organizational structure; the entries within were subsequently examined for type of entry, relevance, and accuracy of the information. Finally, results were compared with final project scores to consider conclusions regarding effectiveness of the approaches used. Results are reported below for each scaffolding condition.

No scaffolding

Organization

Seven projects were completed in the no scaffolding condition. Two of the projects emerged as having clear organizational structure. Both contained separate pages for each balloon type with various notes, one page each for each of the three balloon types. In contrast, the remaining five projects in the no scaffolding condition evidenced no formal organizational structure. The types of approaches among the remaining five varied widely. For example, one group started with the travel plan by writing all the countries they wanted to visit but crossed out this initial plan and began to take notes on balloons. Another notebook contained a collection of notes and diagrams in a seemingly random order.

Entry type, relevance, and accuracy

The two more highly organized groups described above made a clear attempt to write the information in their own words, such as entries from one project that read, "gas balloons can stay up for a few days," While both projects contained frequent entries that were not relevant to the tasks, students also summarized the research with statements toward the back that read, "Gas balloons – good for long distances ...Stay up for only a few days." Both of these groups scored above the grand mean ($M = 48.5$, 50).

With the five lower quality groups, virtually all of the entries were chunks of text copied directly from the program. One representative example is as follows: "Pilots can control the amount of fuel burned to maintain a steady altitude or to seek altitudes with advantageous wind directions." While many of the entries from the lower quality groups were relevant to the tasks, students made no obvious attempt to put this information into their own words. Additionally, each of the projects contained large amounts of information that was completely irrelevant to the task. The overall project performance of these five lower quality groups was generally low; while one group scored higher than the grand mean for Project Total ($M = 46$), four of them scored vastly lower ($M = 31$, 10.5, 7.5, 7.0).

Scaffolding optional

Scaffold use and organization
Examination of 14 notebooks revealed that only two groups entered notes on both the travel plan and balloon types scaffold forms. Five groups entered information on only one form (three used the balloon scaffold and two used the travel plan form). In addition, one group took notes from information contained in the hints page. Only one group completed a scaffold form entirely, while the remaining groups completed only portions of the forms. However, two groups drew and completed their own forms that imitated the balloon types form.

A look at the organizational structure of the notebooks revealed that for nine of the projects, entries were not well organized. In general, notes on various topics were scattered throughout the folders; a typical example would be a page containing information about hot air balloons, then the Jet Stream, then information relating to how balloons fly. Students usually placed scaffold forms at the back, each containing a range of 4–8 entries on these forms if they did have information. Three projects from the scaffolding optional condition appeared to be more highly organized than the other projects. These students grouped related information together and each group produced some type of summary, creating lists organized by headings.

Entry type, relevance, and accuracy
A closer examination of the entry types of the notebooks from the scaffolding optional condition revealed that students from all groups generally placed information in their own words; if information was directly copied from the program, it was usually short phrases. The quality of entries from each of the project notebooks was evaluated for relevance and accuracy.

Nine notebooks contained a greater portion of highly relevant entries – the three organized groups described above, and six additional groups. For example, one group entered a heading entitled, "Weathe [Weather] [*sic*] and Danger;" underneath, the information read, "Bad weather, tall mountins [*sic*], unfriendly countries, drift, might get shot down by people." To the side was written, "Travel Plan!!" In contrast, three of the groups' entries were of very poor quality when evaluated for relevance. While it is true that many of the groups with higher quality entries placed non-relevant information in their notebooks, the primary difference is that these three lower quality groups did not have enough relevant information in their folders. In addition, the three lower quality groups' notebooks contained more instances of inaccurate information when compared to the nine higher quality groups, (i.e. Hot air balloons go higher). Overall, the entries from the nine higher quality groups were highly accurate.

Final project scores for the nine higher quality groups showed only one group scoring below the grand mean ($M = 35$), with the remaining scores above the mean (ranging from 42 to 57.5). In addition, final project scores for the three lower quality groups were all well below the grand mean ($M = 3.5$, 24.5, 29).

Scaffolding required

Scaffold use and organization

Twelve projects were completed in the scaffolding required condition. All groups in this condition were required to complete the scaffolds as they conducted their research. All groups provided responses on each of the scaffolds with the exception of one group that did not place an entry on the Information Sources page. Four groups did not fully complete either the balloon types or travel plan scaffold, and one group did not complete either. However, a typical incomplete scaffold usually meant students provided more than 80% entries solicited on the forms.

All except two of the groups in the scaffolding required condition entered notes in addition to completing scaffolds. An examination of organization revealed that the notebooks in general appeared highly organized. Students tended to group information regarding balloons immediately after the balloon types scaffold form. Likewise, they tended to group information related to the Jet Stream and travel route immediately after the travel plan scaffold from.

Entry type, relevance, and accuracy

Eight groups from the scaffolding required group appeared to have higher quality notebooks than the remaining four groups. The majority of entries in all the projects were written in students' own words. Those of higher quality included more entries on their scaffold forms, and had multiple entries related to the same topic. For example, for the "Pros" that relate to hot air balloons, one group entered, "Controllability and cost/No ballast is needed/Cost low – all it needs is inexpensive propane fuel." In contrast, a typical response from one of the lower quality groups for the same topic was, "Its [*sic*] faster."

An examination of the notes not placed on the scaffold forms revealed one commonality among the eight higher quality notebooks: they more consistently recorded a larger amount of relevant entries than the four lower groups. Almost all had headings with related information underneath. In contrast, the additional entries from the lower quality groups were also consistently organized by headings, but the information tended to be less relevant. For example, one group wrote: "*Why we want to go in the southern hemisphere*/We want more adventure."

Additionally, in the four lower quality notebooks, entries were more consistently inaccurate when compared to the higher quality students. For example, one of the lower quality groups wrote the following for the cons that relate to hot air balloons: "We probably wouldn't take a hot air because you can't steer and it goes as fast as the wind blows only;" this characterization is true of all three balloon types. Within the eight higher quality notebooks, the entries were more consistently accurate.

All four of the groups with the lower quality notebooks scored below the grand mean for the Project Total with scores ranging from 24 to 36.5. All the project scores for the eight higher quality groups were higher than the Project Total grand mean; scores ranged from 43.5 to 52.

Observations of the teacher's support of students

The teacher was observed throughout the implementation of *Up, Up & Away!* to capture how she supported student learning throughout the project. On the first day, the teacher introduced the project and the central problem to the students through giving a brief overview of the interface, distributing the group notebooks, and going over the Project Expectations verbally. After the initial introduction, the teacher also described some "ground rules" for the project: she explained the groups would be working mostly independently throughout the process, and they should rely on their group members if they had questions, not her. She recommended they first begin looking through the News Articles to find out what the problem involved.

On day two, the teacher introduced the scaffolds to the scaffolding optional and scaffolding required classes. She described the purpose of each form, stating that the balloon types form would help them decide which balloon would be the best to choose, and the travel plan form would help guide them in the steps necessary to plan a good travel route. For the scaffolding required classes, these forms were already placed in their folders, and students were told they had to complete them. With the scaffolding optional classes, students were told where these forms would be located in the classroom for them to pick up. She continued emphasizing the forms throughout for the next several days of instruction. However, only when introducing the scaffolds did she emphasize the hints button, stating the information would help them decide where to begin looking for information.

During the subsequent 5 days of instruction, the teacher provided no whole class instruction or guidance to the students. She began each day with mainly administrative tasks, such distributing materials. She would then circulate and guide groups that were having difficulty, but avoided intervening. In such instances, she would guide with questions without giving specific answers or direction.

However, throughout these 5 days, students in all conditions began demonstrating difficulty. Most of the groups did not know where to begin, and some started planning a trip to fly over their favorite countries. Others started planning a balloon with features they described as "cool," but these were not representative of the types of balloons actually flown. On day seven of the project, the teacher intervened. With each class, she facilitated discussion about the three types of balloons, and summarized the positives and negatives of each type. She walked them through a problem-solving modeling process in which she described how she would approach the task of selecting a balloon. After writing on the board the positives and negatives of each balloon type, she questioned each of the classes about which would be the best choice, leading them to conclude that one particular type would be the best choice.

Days 8 through 10 were spent on additional research. Days 11 through 14 involved completing the actual project. The students did no further research on the laptops, but worked to assemble the various components of the project. The teacher circulated among the groups. Her main form of assistance was in helping students calculate the number of days it would take each group to travel based on their respective routes. On day 15, each group presented their final balloon design and travel plan solutions to the rest of the class.

Discussion

Student project performance

The first research question examined the effect of scaffolding condition on student performance on four project components: balloon design, balloon rationale, travel plan, and travel plan rationale. Analysis of the project components indicated that students who worked in the scaffolding optional and scaffolding required conditions performed significantly better on the travel plan than students who worked in the no scaffolding condition. However, there were no significant differences between scaffolding conditions for the balloon design. It is likely that these results were influenced by the teacher, who provided direct instruction regarding which balloon to use and why, and required all students to complete a scaffold on balloon design progress that she developed. Furthermore, the teacher did not spend class time discussing the travel plan and did not have students complete a teacher-designed scaffold on this component. Thus, in the absence of consistent soft scaffolding, hard scaffolds may have a positive effect. This is true even among students in the scaffolding optional condition; most of these students completed a portion of the travel plan scaffold. In other words, the support received by students in the scaffolding optional condition appears to have positively impacted achievement.

While students who used scaffolds performed better on the travel plan than those who did not receive scaffolds, overall project performance was low for most groups. There are two possible explanations for such low performance. First, students did not receive expert guidance and feedback throughout the problem-solving process. Even though the teacher guide included these essential components of problem-based learning and the teacher planned to incorporate this support, observation results indicated that the teacher did not implement them. While the scaffolds were meant to support students by augmenting performance, they were not intended to replace teacher support entirely. In fact, as Saye and Brush (2002) point out, hard scaffolds are intended to *ease* the teacher's demands in order to perform a greater amount of soft scaffolding with learners. Second, it is possible that students had difficulty transitioning to more active, less-directed roles. This is consistent with previous findings from other researchers who have also noted such difficulties among students at the early stages of PBL (Herrenkohl & Guerra, 1998; Mammen, 1996).

Participants performed least well on the rationale segments of both the balloon design and travel plan. Other researchers report that students have difficulty constructing quality arguments for their decisions based on evidence and research in open-ended learning environment (Land & Hannafin, 1997; Oliver & Hannafin, 2000; Saye & Brush, 2002). This is frequently attributed to the abstract nature of forming rationales, which usually involves a more advanced skill-set. However, over 90% of the student projects in the current study received at least one point for each rationale; this result is encouraging because it indicates that students attempted to support their decisions with at least one statement based on evidence.

Posttest achievement

The second research question investigated the effect of scaffolding and student achievement levels on posttest achievement. While scaffolds had a significant effect on the travel plan component of the project, they were not an effective means of supporting posttest achievement. Results indicated that only student achievement levels accounted for a significant proportion of posttest variance. However, one of the primary reasons researcher and designers advocate PBL is to help learners gain a deeper, more flexible understanding of content. Clearly, this did not occur within our study.

There are two possible reasons for these results. First, the scaffolds were not intended to support content acquisition, but, rather, to augment problem-solving and students' research efforts throughout the project. Second, the content objectives were not emphasized by the teacher, even though the teacher guide included specific lessons to support students' content learning. Without emphasis on the content objectives, either from the scaffolds or the teacher, overall student performance on the posttest was weak, with a strong positive correlation between student achievement and student posttest performance. Greater emphasis on and support for the unit objectives might have improved posttest performance, especially for lower achievers.

Another reason for the overall poor posttest performance may stem from the difficult, complex nature of the content and the skills involved in mastering the content. Responses to the attitude survey indicated students did not strongly agree that the program included enough help. Furthermore, many low-achieving students responded to the open-ended questions that the project was difficult and that they did not have enough time to complete it. It is likely that for this content, these students needed much more time and help to successfully achieve the targeted objectives.

Other researchers have found that students in PBL settings tend to perform relatively low on tests of content knowledge (Albanese & Mitchell, 1993; Vernon & Blake, 1993). However, few studies have examined the performance of typical students in the context of a general education classroom. These results are compelling because they indicate that while many of the high-achieving students were able to perform quite well, the majority of students were not able to perform in the satisfactory range or above. In short, it appears that many students, those with low-achievement levels in particular, were unsuccessful when it came to researching information that would lead to obtaining content knowledge.

Student attitudes

The third research question focused on student attitudes toward the *Up, Up & Away!* program, Investigation, and Open-endedness. While no effect was found for scaffolding condition, two survey items were found to be significant by achievement level. High-achieving students were more likely than low-achieving students to agree with the item, "I would enjoy working on another project like this again." It is possible that high-ability students felt more successful than low-ability students, which may lead to a greater likelihood of wanting work on this type of project again.

The other item from the attitude survey found to be statistically significant was, "My group solved the problem using information obtained from our research." High-achieving students were more likely than low-achieving students to indicate they used information from research to solve the problem. A plausible explanation for this can be examined in light of the other data sources. Since high-achieving students performed better on the posttest, it is likely they were also the group members driving the research directions. This explanation also appears to be consistent with the open-ended responses to the attitude survey; only a few lower-achieving students mentioned specific content learning as something they liked about the project, while a greater percentage of high-achieving students did so. Thus, it appears the groups' respective research strategies were not necessarily accessible to low achievers.

Student approaches PBL

The fourth research question investigated student approaches to the learning task. Results from the group notebooks suggest two trends related to student approaches to the project. First, it appears that the quality of information students recorded impacted project performance. In general, groups who recorded information in their own words and who wrote relevant information performed better than groups who copied directly from the database. This result is not surprising. While proponents of hypermedia argue its nonlinear structure that mirrors human memory is beneficial (Dede, 1992), researchers also note managing the information provided in a database can be demanding (Bruning et al., 1995). Thus, lower-performing groups do not appear to have devised any means of managing information; this may explain why they either copied large amounts of information from the program or provided numerous entries that were not relevant to the project.

The second trend regarding students' approaches relates to use of scaffolds. It appears that scaffold use may have promoted more effective note-taking. A higher percentage of notebooks from the scaffolding required condition were more highly organized when compared to the other conditions. In addition, notes from the scaffolding required groups tended to be of high quality not only because they were primarily written in students' own words, but because they were relevant and accurate in general.

Overall implications and considerations

This study has implications for both design and implementation of problem-based learning units for the middle school grades. First, scaffolds appear to support student performance, especially under circumstances where teacher support is limited. Results suggest designers of PBL environments should examine means of supporting students given the nature of the content domain and the problem-solving skills involved. However, as is implied by the results of this study, scaffolds are meant to augment teacher support, not replace it. It is important to note that teacher scaffolding throughout the learning process is key, especially for supporting reflection and providing dynamic guidance and feedback (Simons et al., 2004).

Moreover, the results of this study suggest there should be continuing concern for low achievers in complex PBL environments. The performance of these students has not typically been studied in the context of PBL as research has focused primarily on higher-achieving students. However, in this study, low achievers' poor performance was revealed though the posttest. Additionally, the results appear to rather consistently suggest they were left behind throughout the problem-solving process. This implies more effective means of engaging and supporting low achievers are needed. For example, it seems practical to recommend that en route measures of achievement be used to monitor individual student progress and performance. Likewise, it is equally possible to have students complete more self-monitoring tasks, a strategy found to enhance performance in a previous study (Davis & Linn, 2000).

When considering both hard and soft forms of scaffolding, it is important to recognize this introduces a number of tradeoffs in the form of design tensions. One of the biggest tensions reflects the function of constraining students' efforts, but not controlling them to the point that the problem is no longer ill-structured (Reiser, 2004). Instructors *want* students to develop independence in their inquiry. Another apparent tension relates to the function of simplifying components of the task, but not accepting superficial solutions and explanations (Reiser). Students need to understand the complexities and nuances associated with ill-structured problem solving. They need to weigh trade-offs and discuss principles of cause and effect. At some point, designers and teachers need to ensure they do not simplify a domain to the point it is no longer accurately reflected (Ertmer & Simons, 2006).

Limitations

The limitations of this study should not be overlooked. First, there is concern regarding the number of intact classes used in this study. Having only five classes available meant that only one class was assigned to the no scaffolding condition, whereas two classes would have been more desirable to achieve the same number of classes in each condition. Second, while having only one teacher in this study helped ensure the unit was implemented consistently for each condition, this factor makes it difficult to draw conclusions for a wider audience. The fact that she did not implement any lessons from the teacher's guide nor did she support students through any type of consistent or systematic means raises questions regarding how to draw meaningful conclusions for problem-based learning in the middle school grades. Future research with *Up, Up & Away!* will examine supporting teachers' efforts to teach this unit with specific attention given to training teachers to implement the recommended lessons and employ such methods as guiding students and providing feedback.

Summary

The findings from this study have highlighted some important aspects related to problem-based learning in middle school environments. The results suggest scaffolds are not meant to replace the support offered by the teacher. However, the results also suggest that use of scaffolds may positively impact student performance. Scaffolds have been touted as a valuable instructional tool, and within PBL, they appear to have an important role in enhancing student performance.

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