# A Framework for Designing Scaffolds That Improve Motivation and Cognition

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A problematic, yet common, assumption among educational researchers is that when teachers provide authentic, problem-based experiences, students will automatically be engaged. Evidence indicates that this is often not the case. In this article, we discuss (a) problems with ignoring motivation in the design of learning environments, (b) problem-based learning and scaffolding as one way to help, (c) how scaffolding has strayed from what was originally equal parts motivational and cognitive support, and (d) a conceptual framework for the design of scaffolds that can enhance motivation as well as cognitive outcomes. We propose guidelines for the design of computer-based scaffolds to promote motivation and engagement while students are solving authentic problems. Remaining questions and suggestions for future research are then discussed.

A problematic, yet common, assumption among educational researchers and designers is that when teachers provide authentic, problem-based experiences, students will automatically be engaged (Blumenfeld, Kepler, & Krajcik, 2006; Blumenfeld et al., 1991; Parsons & Ward, 2011; Willems & Gonzalez-DeHass, 2012). Evidence shows that this is not always the case, due to such factors as poor connectedness among groupmates (Dolmans & Schmidt, 2006), perceptions of controlling behaviors (Wijnia, Loyens, & Derous, 2011), and poor elicitation and maintenance of interest (W. Hung, 2011).

In this article, we develop a conceptual framework to support the design of scaffolds for problem-based learning (PBL) environments that can improve motivation and cognition. The framework ties together research on scaffolding,

PBL, and motivation to offer an improved theory of how to design scaffolds. It also provides a new lens with which to view motivational research. This article is not meant to be a comprehensive review of the scaffolding or the motivation literature but rather a synthesis of implications of motivation theories for the design of scaffolding. Teachers may find this article useful in suggesting ways to create a culture of inquiry in their classrooms. Motivation and scaffolding researchers should find that the guidelines suggest ideas for conducting design research on motivation theories and principles in authentic settings. Designers of inquiry environments will find a framework guiding the design of scaffolds that can enhance students' motivation over and above current design principles.

The outline of the article is as follows. In the next section we address deficits in design arising from a lack of attention to motivation. Next, we introduce PBL as a potential solution. We then review research on scaffolding and motivation, articulate guidelines for the design of scaffolds that support cognition and motivation, and discuss the framework and provide suggestions for future research.

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## PROBLEMS WITH IGNORING MOTIVATION IN DESIGN

Design is the use of disciplinary knowledge to solve a practical problem (Simon, 1996). To design a solution effectively, one needs to define the problem thoroughly. For example, when a river is impeding people's movement, civil engineers can design a bridge to facilitate easy and safe movement from one side of the river to the other. They need to take into account the daily loads, maximum load, properties of the materials that can be used to construct the bridge, geological characteristics, and so on. In the context of instruction, design is the translation of theories of learning and motivation to create artifacts that can solve learning or performance problems (Sandoval, 2004; Tabak, 2004a).

Scaffold design currently pays little attention to motivation. By *motivation*, we refer to students' desire and willingness to deploy effort toward and persist in the learning task (Schunk, Pintrich, & Meece, 2008). Motivation is influenced, among other factors, by students' judgments of their abilities to complete the task successfully and their perception of the benefits that task completion will bring (Eccles et al., 1993; Pajares, 1996; Wigfield & Eccles, 2000).

Even when attempts are made to design motivational interventions, such attempts are often not clearly linked to motivational theory (Wentzel & Wigfield, 2007). A lack of attention to motivation in the design of instructional materials and school climate can lead to the declines in motivation (Anderman & Maehr, 1994; Eccles et al., 1993; Hasselhuhn, Al-Mabuk, Gabriele, Groen, & Galloway, 2007; Palincsar, Anderson, & David, 1993; Pintrich, 2000; Wigfield, Eccles, & Rodriguez, 1998) and in academic performance (National Middle School Association, 2002) that have been observed among middle school students. The atmosphere, relationship styles (among students and between students and teachers), and goal structures of K–12 schools in the United States rarely mirror what motivation research suggests is best for student achievement (Juvonen, 2007; Schmakel, 2008). For example, teachers often use direct controlling behaviors, which can lead to poor motivation (Assor, Kaplan, Kanat-Maymon, & Roth, 2005).

With poor motivational design, instructional materials may not hold students' interest (Hidi, 2006; Renninger, 2009). Poor motivational design may also lead students to think that (a) they are not able to successfully complete the learning task, or (b) there is no value in completion of the task (Wigfield & Eccles, 2000). Even when students think that they can successfully complete the task and that there is value in it, with poor motivational design, students may attempt to outperform others rather than strive to achieve deep learning.

Academic performance is enhanced when motivation is translated into behavioral, emotional, and cognitive engagement (Fredricks, Blumenfeld, & Paris, 2004; Reeve, 2013). In a school context, positive behavioral engagement means actively participating in academic activities according to classroom norms; positive emotional engagement means exhibiting interest and happiness during academic activities; positive cognitive engagement means actively deploying strategies to understand content, solve problems, or otherwise use information (Fredricks et al., 2004).

Poor motivational design adversely impacts engagement and learning. For example, a design that does not allow students to experience incremental success not only harms expectancy for success but also evokes anxiety (Weiner, 1985). Anxiety influences cognitive engagement by interrupting information processing (Levine & Pizarro, 2004; Linnenbrink, 2006; Schwarz, 2000). Poor information processing diminishes behavioral engagement and in turn achievement (C. Kim & Pekrun, 2014).

Furthermore, recent evidence indicates that by paying insufficient attention to motivation, transfer may be undermined (Nokes-Malach & Mestre, 2013; Perkins & Salomon, 2012). Motivational factors, including achievement goals, can influence how students frame a transfer task, defined as how a student defines a problem and what should be done in response to it (Nokes-Malach & Mestre, 2013). Motivation can also influence students' dispositions to detect opportunities for and elect to apply previously learned knowledge (Perkins & Salomon, 2012).

## PROBLEM-BASED LEARNING

One instructional method proposed for enhancing motivation is providing students authentic problems to solve (Parsons & Ward, 2011; Willems & Gonzalez-DeHass, 2012). Solving authentic problems is a key function in modern life and in most careers (Belland, 2013; Jonassen, 2011). One way to provide authentic problems is through inquiry approaches such as PBL (Helle, Tynjälä, Olkinuora, & Lonka, 2007; Hmelo-Silver, 2004; Pintrich, Marx, & Boyle, 1993). Some scholars, such as those in the medical education field, have very specific ideas about what PBL means (Barrows & Tamblyn, 1980). It is beyond the scope of this article to review all such ideas; rather, we define the term for our purposes. In PBL, students need to develop feasible solutions to authentic, ill-structured problems, defined as real-world problems with no single correct solution or solution path (Hmelo-Silver, 2004; Jonassen, 2003). In PBL at the K–12 level, students typically work in groups of three to five on an authentic problem and carry out the follow tasks: (a) define the problem, (b) determine what they already know, (c) determine what they need to know, (d) find information, (e) synthesize found information to solve the problem, and (f) build an argument in support of their solution (Belland, Glazewski, & Richardson, 2008; Hmelo-Silver, 2004; Torp & Sage, 1998). PBL has been shown to help K–12 and university students in a variety of subjects develop deep conceptual learning, problem-solving ability, and self-directed learning ability (Hmelo-Silver, 2004). For example, compared to a lecture control condition in the middle school context, PBL led to

(a) superior comprehension and application of reasons behind the Columbia Shuttle Disaster (Wirkala & Kuhn, 2011) and (b) superior genetics knowledge and logical thinking (Araz & Sungur, 2007). Success in PBL largely depends on both self-direction of learning (Lohman & Finkelstein, 2000; Loyens, Magda, & Rikers, 2008) and the ability to recognize a need for and seek help (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003; Mercier & Frederiksen, 2007).

## Authentic Problems in PBL

In relation to a particular discipline (e.g., biology), authentic problems are problems that (a) relate to students' lives (Barab, Squire, & Dueber, 2000), (b) require the use of the tools of the discipline in manners similar to professionals in the discipline (Chinn & Malhotra, 2002), and (c) require immersion in the culture of the discipline (Barab et al., 2000; D. Hung & Chen, 2007). Furthermore, authentic problems are ill-structured, which means that they have multiple valid solutions and solution paths (Jonassen, 2011). Authentic problems can take many different forms, which impacts how they can be solved. As an example of a diagnosis–solution problem, consider a PBL unit on the water quality of a local river. Students are assigned a stakeholder perspective such as farmers or common citizens, and need to determine (a) current water quality levels at various points in the river, (b) historical water quality levels, and (c) where and how certain pollutants enter the river. They need to know how high levels of particular pollutants impact entities that depend on the river (e.g., fish, farmers). They need to know methods for correcting water quality problems (e.g., plant trees along riverbanks if turbidity is too high), and new problems that these methods could introduce (e.g., too many leaves fall into river in the fall). Although this problem is potentially engaging in that it is locally relevant and allows students to use the tools of science as professional scientists do, it could also be overwhelming due to its complexity.

## How PBL May Help Counter Deficiencies of Ignoring Motivation in Design

PBL provides a good start in motivating students, in that it incorporates authentic problems, which may capture students' interest (Hidi, 2006; Wijnia et al., 2011) and promote perceived value of the learning task (Belland, Ertmer, & Simons, 2006; Sungur & Tekkaya, 2006). Furthermore, authentic problems have multiple valid solutions and solution paths (Jonassen, 2011); this provides for autonomy, which can promote adaptive motivation (Deci & Ryan, 2000). Having productive small-group discussions may help stimulate interest (Dolmans & Schmidt, 2006) and the sense of belonging (Osterman, 2000), which are all important influences on motivation. Engagement is often found to be higher (a) during PBL than during traditional instruction among the same students (Rotgans & Schmidt, 2011a), and (b) in classes that use PBL than in traditional classes (Ahlfeldt, Mehta, & Sellnow, 2005).

However, if insufficient guidance is provided to students, PBL will not promote student success (Hmelo-Silver, Duncan, & Chinn, 2007). Furthermore, simply using PBL does not ensure adaptive motivation (Dolmans & Schmidt, 2006; W. Hung, 2011; Wijnia et al., 2011). Rather, to succeed in PBL, students need scaffolding (Hmelo-Silver et al., 2007) and motivational support (Edelson, Gordin, & Pea, 1999).

# SCAFFOLDING

## Original Definition

The metaphor of scaffolding was first applied to educational contexts when Wood, Bruner, and Ross (1976) wanted to explain how adults help infants learn to solve problems. They found that adults did not simply tell the infants how to solve the problem or just demonstrate how to do it. Rather, the adults used six strategies—"recruitment, reduction in degrees of freedom, direction maintenance, marking critical features, frustration control, and demonstration"—to temporarily support children's efforts until they gain sufficient skill (Wood et al., 1976, p. 98). Of note, three of the six original scaffolding strategies are motivational (recruitment, direction maintenance, and frustration control) and the other three are cognitive (reduction in degrees of freedom, marking critical features, and demonstration). Thus, scaffolding in its original sense was equal parts motivational and cognitive support.

## Historical Evolution of Scaffolding

*Evolution in contexts.*  From Wood et al. (1976), an enormous diversity of research on scaffolding emerged; such research focused on (a) education levels ranging from preschool to college, (b) students ranging from those with special needs to average-achieving students, (c) many different skills (e.g., argumentation, problem solving, collaboration), and (d) many different subjects (e.g., English, science; Belland, 2014). Such evolution in contexts has not been unproblematic, and has led some authors to call for a reexamination of the metaphor (Pea, 2004; Puntambekar & Hübscher, 2005; Stone, 1998). Notably, such calls largely focused on the cognitive aspects of the process of scaffolding.

*Evolution in form.*  With the move to scaffolding in K–12 classrooms, scholars began to wonder whether the scaffolding function could be fulfilled by technological tools. Limiting scaffolding to what is provided by adults could mean that students in a typical K–12 classroom would receive rather little scaffolding (Belland, 2014). As a result, computer-based scaffolds emerged, which could be developed based on a projection of student difficulties (Saye &

Brush, 2002). Computer-based scaffolds are software programs that use such strategies as question prompts, expert/peer modeling, and data manipulation tools to augment and improve students' conceptual understanding, metacognition, use of strategies, and understanding of procedures (Belland, 2014; Hannafin, Land, & Oliver, 1999; Quintana et al., 2004). Furthermore, computer-based scaffolds are often networked to connect students to other students and/or content. With computer-based scaffolds, students have constant access to scaffolding support provided by a computer program, and they have access to teacher scaffolds when the teacher can come to their desks. Teacher scaffolds consist of dynamic, one-to-one support that is contingent on students' current performance characteristics. Using teacher scaffolds, a teacher might ask a student a probing question and then dynamically generate support appropriate to the student's struggle (Belland, 2014; van de Pol, Volman, & Beishuizen, 2010).

Computer-based scaffolds are meant to complement, not replace, teacher scaffolds (Saye & Brush, 2002). Using both teacher and computer-based scaffolds allows students to benefit from the strengths of each scaffolding type: the contingent nature of teacher scaffolds and the always-on and replicable nature of computer-based scaffolds. Simply put, one needs to have teacher and computer-based scaffolds because without both, students will not get the support that they need to succeed in inquiry (McNeill & Krajcik, 2009; Saye & Brush, 2002).

Some elements of the original definition of scaffolding are often absent from computer-based scaffolds. For example, while praising much of what has been accomplished with computer-based scaffolds, Puntambekar and Hübscher (2005) highlighted the lack of diagnosis, customization, and fading as a particularly problematic characteristic of computer-based scaffolds. This is essentially the same critique offered by Pea (2004).

*Evolution in goal.*    It is clear when examining the literature on scaffolding that what started out as an intervention that was equal parts motivational and cognitive support quickly became conceived as an intervention that provided mostly cognitive support. The exact reasons for this change are not clear. One possibility has to do with the linking of the concept of Zone of Proximal Development (ZPD) to the concept of scaffolding along with the challenges of translation. It is a common misperception that Wood et al. (1976) based their definition of scaffolding on Vygotsky's theory of the ZPD. An account of the intellectual climate at Oxford around the time of the publication of Wood et al. (1976) indicates that Bruner and colleagues were aware of work on the ZPD and that the concept influenced their thinking (Pea, 2004). However, the work was never cited in Wood et al. (1976). ZPD began to become part of the mainstream of educational thought among non-Russian speakers only with the publication of Michael Cole's translation of Vygotsky's work

in 1978 (Pea, 2004). Due to difficulties inherent in translation, ZPD came to mean different things and to support "theoretically incompatible instructional approaches" (Smagorinsky, 1995, p. 193). This multiplicity of meanings of ZPD was also highlighted by Hickey and Zuiker (2005). One meaning that touched on mostly cognition was used in Palincsar and Brown (1984), who defined ZPD as "the distance between the level of performance a child can reach unaided and the level of participation he can accomplish when guided by another more knowledgeable than he" (p. 123). Even though Vygotsky (1962, 1978) focused very much on social context and motives, the ZPD as associated with scaffolding remained a largely cognitive construct.

A search using the keyword "scaffolding" and the area "education/educational research" in the Web of Science showed that of the 10 most highly cited articles, only four even mentioned the word *motivation*, and all such mentions were very much secondary to other considerations in the articles. In one article, authors noted that activity prompts and reflection can motivate students, but no substantiation was given (Davis & Linn, 2000). In another, the authors surmised that honors students may be more motivated than "regular" track students, but no evidence was given (Sandoval & Reiser, 2004). In the third, motivating contexts are briefly mentioned but not described (Young, 1993). The fourth article focused on teacher scaffolds briefly mentioned that teachers had students read and write whole texts, which the authors surmised promoted motivation (Wharton-McDonald, Pressley, & Hampston, 1998).

To get a sense of the level of attention paid to motivation in scaffolding research, one can examine the scaffolding frameworks that provide guidance to scaffold designers. An examination of 14 published scaffolding frameworks (Belland et al., 2008; Choi, Land, & Turgeon, 2005; Ge & Land, 2004; Jonassen & Kim, 2010; Kali & Linn, 2008; Linn, 2000; Pea, 2004; Puntambekar & Kolodner, 2005; Quintana et al., 2004; Quintana, Zhang, & Krajcik, 2005; Reiser, 2004; Sandoval & Reiser, 2004; Sherin, Reiser, & Edelson, 2004; Tabak, 2004b) showed that only four discussed student motivation (Belland et al., 2008; Ge & Land, 2004; Kali & Linn, 2008; Puntambekar & Kolodner, 2005). Motivation was often mentioned only in the section on suggestions for future research (Ge & Land, 2004) and thus not part of guidance for designing scaffolds. Often researchers write that students will be motivated by virtue of engaging in design but without designing scaffolds specifically oriented toward enhancing motivation.

Even when motivation was mentioned in the guidelines, the connection to the literature on motivation was often tenuous. For example, in my scaffolding framework to support argumentation, I (B. R. Belland) noted that scaffold designers should consider motivation (Belland et al., 2008). My rationale was that the literature indicated that often students did not use scaffolds. Regrettably, of the 10 sources I cited in the supporting section, none were from motivation researchers or

otherwise reported research on motivation, nor did I provide any guidelines specific to motivation.

*Motivation and scaffolding.*    It would be reasonable to assume that most scaffolds designed for cognitive support also improve students' motivation through increasing their expectancies for success; scaffolds accomplish this by rendering the learning task more manageable. But it is likely that much more can be done to increase students' expectancies for success beyond what current scaffolds do, and expectancy for success is also far from the only pertinent motivational variable. In short, there is not enough systematic work done to create scaffolds that can support motivation as well as cognition. Rienties et al. (2012) proposed a redesign of scaffolds in light of motivation. However, this work was based on only one motivational theory, and the exact ways in which motivational principles were implemented into the design were not clear. In another study, Alias (2012) discussed the design of a scaffold to raise motivation in online instruction. However, the theory used to design the scaffold was self-regulation theory and the motivation-regulation component of the scaffold did not have a clear foundation in motivation theories. Tuckman (2007) created a virtual study skills support group, which was said to enhance motivation. But the connection to motivational research was not well specified.

## Summary of Why Scaffolding Needs to be Reconnected to Motivation

Reconnection to the roots of an idea is rarely advisable just for its own sake. However, many regrettable consequences ensue when motivation is not addressed in design. Because PBL often spans long periods, it is crucial to develop scaffolds that better enlist student interest, maintain student direction, and control frustration. An examination of the motivation literature can lend insight as to how to work toward these and other motivational goals through scaffold design.

## MOTIVATION AND ENGAGEMENT

Teachers can and do dynamically support motivational needs through teacher scaffolds (Brophy, 1999; Christophel & Gorham, 1995). But not all do, and those who do could often do more (Iachini, Buettner, Anderson-Butcher, & Reno, 2013). Motivational support may be enhanced through embedding motivational support in computer-based scaffolds. There is a wealth of literature on factors that influence motivation and engagement. It is beyond the scope of this article to conduct a comprehensive review of motivation theory. But it is useful to think about motivation in terms of the motivational goals of establishing task value, promoting mastery goals, promoting belonging, promoting emotion regulation, promoting expectancy for success, and promoting autonomy. These are goals that are widely recommended in the motivational literature. Please note that to keep the focus on design

implications of motivational theories, we synthesize work on motivation that has nuances of difference in meaning (e.g., differences between expectancy and self-efficacy). In those cases, we adopt one term (e.g., expectancy); this is meant to simplify terminology.

## Establish Task Value

Task value refers to students' perceptions of the intrinsic value, importance of doing well, usefulness, and cost of completing a learning task (Wigfield & Eccles, 2000). Intrinsic value is the task attribute that promotes intrinsic motivation—the satisfaction that one can obtain simply from the process of participating in a task. The importance of doing well refers to the perceived rewards obtained from performing well. Usefulness refers to perceived new skills and abilities that result from completing the task. Cost is the extent to which participating in the task is unpleasant or keeps the student from completing other desired activities; high cost detracts from task value. Students who perceive high task value in a task have been found to exert greater effort and achieve more than students who perceive low value in the task (Cole, Bergin, & Whittaker, 2008). Furthermore, task value predicts expectancy for success and self-regulation (Wigfield & Cambria, 2010). Therefore, PBL designers should develop scaffolds that promote perception of high task value.

## Promote Mastery Goals

Individuals can have one of at least three goal orientations toward a particular learning task: mastery, performance-approach, or performance-avoid (Covington, 2000). Mastery goal orientations lead individuals to engage in challenging learning tasks to develop their understanding of the task and content (Ames, 1992; Covington, 2000; Pintrich, 2000). Individuals with performance-approach orientations strive to demonstrate their competence and often compare it with that of others (Linnenbrink-Garcia et al., 2012). Performance-avoid goal orientations can lead individuals not to engage in challenging tasks to avoid demonstrating incompetence (Covington, 2000; Lehtinen, Vauras, Salonen, Olkinuora, & Kinnunen, 1995). Recent research indicates that there is a strong warrant for encouraging mastery goals in classroom inquiry contexts[1] (Linnenbrink-Garcia et al., 2012). A great deal of research supports the conclusion that mastery goals promote a broad range of positive outcomes, including persistence, deep processing, and intrinsic motivation (Hulleman,

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[1]For other views on goal-orientations such as relatively recent work on four-goal orientations including mastery-avoidance goals, see Cury, Elliot, Da Fonseca, and Moller (2006); Elliot (1999); Elliot and McGregor (2001); Hulleman, Durik, Schweigert, and Harackiewicz (2008); Linnenbrink-Garcia et al. (2012); and Pintrich (2000). Senko, Hulleman, and Harackiewicz (2011) discussed a positive role for performance goals.

Schrager, Bodmann, & Harackiewicz, 2010). Thus, it is beneficial to promote mastery goals through scaffolds.

## Promote Belonging

Belongingness is a psychological need to perceive connection with others during conduct of tasks (Deci & Ryan, 2000). When students have a sense of belongingness, they are more likely to perceive intrinsic motivation, defined as the desire to engage in a task simply due to enjoyment derived from the activity (Deci & Ryan, 2000; Ryan & Deci, 2000). Hence, scaffolds that promote belonging should be developed.

## Promote Emotion Regulation

Academic emotions (e.g., anger, pleasure) are emotions that arise in school contexts, resulting from students' affective reactions to school tasks (C. Kim & Pekrun, 2014). For example, students may experience anger when they fail an assignment and perceive that it was due to lack of support for learning the covered concepts (C. Kim & Pekrun, 2014; Pekrun, 2006). Academic emotions can influence how students attribute success or failure (Weiner, 1986). In a path analysis model predicting final grades in a university-level Introduction to Psychology course, helplessness negatively predicted mastery goals, and mastery goals positively predicted enjoyment, which in turn positively predicted final grades (Daniels et al., 2009). In a study among fifth-grade students, negative emotions (e.g., frustration) were associated with performance goal orientations, whereas positive emotions (e.g., pride) were associated with mastery goal orientations (Seifert, 1995). Therefore, scaffolds should promote adaptive emotion regulation.

## Promote Expectancy for Success

Much motivation literature maintains that even if they are interested in the learning task, people will not engage if they do not have expectancy for success. Self-efficacy theorists posit that individuals' beliefs in their abilities to perform a task satisfactorily influences their self-regulated learning, defined as the practice of defining and pursuing learning issues in service of a larger learning or performance goal (Bandura, 1977; Locke & Latham, 2006; Pajares, 2002). Self-efficacy develops from mastery experiences, modeling, vicarious experiences, and perceived control (Bandura, 1977; Pajares, 2002). A similar construct from expectancy-value theory, expectancy for success, is influenced by the same factors (Wigfield & Eccles, 2000). According to attribution theory, students' expectancy for success is influenced by the factor (e.g., luck, ability, effort) to which they attributed success or failure on similar tasks (Greene, 1985; Weiner, 2010). For example, students who attribute past successes or failures to luck likely will not have positive expectancies for success; if they attribute past successes to effort or strategy use, they likely will have positive expectancies for success (Greene,

1985; Weiner, 2010). Hence, PBL researchers should design scaffolds that promote expectancy for success.

## Promote Autonomy

Autonomy is generally positively associated with positive learning processes and outcomes such as cognitive flexibility and deep learning (Assor, Kaplan, & Roth, 2002; Deci & Ryan, 1987; Shih, 2013). Autonomy refers to "an inner endorsement of one's actions, the sense that they emanate from oneself and are one's own" (Deci & Ryan, 1987, p. 2). To promote autonomy, not only individual but also social-contextual factors should be considered (Deci & Ryan, 1987). According to self-determination theory, autonomy-supportive environments can lead motivation to be more intrinsic (Ryan & Deci, 2000). Autonomy support can be done through providing opportunities to start self-directed goals and make choices as well as reducing threats and pressures (Assor et al., 2002; Deci & Ryan, 1987; Shih, 2013); thus, such scaffolds in PBL can enhance motivation.

## Summary

In summary, our framework posits that motivation-enhancing scaffolds in PBL should promote these six goals that are broadly supported by motivation theories: establish task value, promote mastery goals, promote belonging, promote emotion regulation, promote expectancy for success, and promote autonomy. Through achieving these motivational goals, students' engagement can be increased because "motivation is a basis for subsequent engagement" (Martin, 2012, p. 305). There are three types of engagement—behavioral (on task behavior), cognitive (deployment of cognitive effort), and emotional (students' affective reactions to learning tasks (Fredricks et al., 2004; Lee & Shute, 2010). Through better motivational scaffolds, all three kinds of engagement can be enhanced.

## DESIGNING SCAFFOLDS TO IMPROVE MOTIVATION

By incorporating motivationally relevant scaffolding into PBL, instructors may be able to improve the motivation of students. But scaffolds need to be designed intentionally to encourage motivation. The main contribution of this article is to provide theory-grounded guidelines for the design of motivational scaffolds. As we have discussed, there has been too little attention in the scaffolding literature to the motivational dimensions of scaffolds.

In the remainder of this article, we focus on computer-based scaffolds. We acknowledge the utmost importance of teacher scaffolds, but discussing them is beyond the scope of this article. However, we note that our recommendations for effective computer-based scaffolds will often suggest analogous teacher scaffolds that could improve motivation. We also

see a focus on computer-based scaffolds as something that could be fruitful to the educational psychology and learning sciences communities. Educational psychologists and learning scientists can readily develop computer systems with contrasting motivational scaffolds to systematically test the effects of these scaffolds on motivation. Thus, a theory of motivational scaffolding lays the groundwork for experimental research testing motivational theories by investigating the predicted effects of motivational scaffolds.

In the section that follows, we present guidelines for the provision of scaffolding to support student motivation and engagement in PBL. Then we explain each guideline's rationale, how it can be implemented in the design of computer-based scaffolds, and discuss any existing computer-based scaffolds that incorporate the guideline.

Table 1 presents our guidelines for designing scaffolds to promote student motivation during PBL. Instructional designers who want to develop scaffolds that can promote motivation and engagement during PBL should ensure that scaffolds establish task value, promote mastery goals, provide for social interaction, promote emotion regulation, promote expectancy for success, and promote autonomy. These are the principal goals emphasized in the motivational theories discussed earlier. Each guideline/strategy addresses at least one of these motivational goals. Many strategies address multiple goals, as indicated in the right column. To illustrate how these guidelines/strategies can be applied, we use a running example of a unit focused on water quality in the Great Salt Lake watershed. The Great Salt Lake watershed consists of a wide range of ecoregions, ranging from mountains as high as 13,000 feet to valleys and wetlands around 5,000 feet (D. White, 2011). These ecoregions provide habitat to a wide range of plants and animals, including migratory birds. Like many other watersheds, the Great Salt Lake watershed experiences many water quality problems from such sources as agricultural and urban runoff. This is exacerbated by predicted decreases in water in the watershed due to climate change (D. White, 2011). A PBL unit could have students investigate the sources of pollution in the watershed, and what can be done to optimize water quality in the watershed while considering the needs of the people who live in the watershed.

## SCAFFOLDS THAT ESTABLISH TASK VALUE

Students will not perceive task value in addressing PBL problems simply by virtue of researchers and teachers believing that the authentic problems and activities within PBL (e.g., argumentation, design) have value. Thus, it is important to consider instructional strategies that establish task value. Two guidelines grounded in the motivation literature are designed to establish task value: fostering interest and establishing attainment value (note that attainment value represents our merger of the expectancy-value constructs of attainment value and usefulness).

Interest theory presents ideas similar to expectancy-value theory on the role of perceived value in motivation. Some students may have an individual interest in a particular area, defined as an enduring propensity to seek out and relish opportunities to learn about the content (Hidi, 2006). A meta-analysis indicated that the mean correlation between interest and academic achievement was .31 (Schiefele, Krapp, & Winteler, 1992). Not every student will have an individual interest related to a particular topic. However, designers can establish situational interest, a state that develops from novelty and complexity in a situation, and which arouses students' curiosity and leads them to concentrate on a given task (Hidi, 2006; Renninger & Hidi, 2011). The initial stages of triggering situational interest are largely a matter of engendering an affective reaction to the stimulus (Renninger & Hidi, 2011). Although designers might establish situational interest through seductive details, such details can take students' attention away from important content and thus harm learning (Hidi, 2006; Renninger & Hidi, 2011). For situational interest to be sustained for any length of time, content knowledge and a belief in task value is required (Renninger & Hidi, 2011). In this way, this guideline depends on Scaffolding Guideline 2 (Establish attainment value). To foster interest, it is also important to connect target content to everyday life (Keller, 1987).

Attainment value is also central to students' decisions to engage in learning tasks (Wang & Eccles, 2013). Attainment value is gauged in part by assessment of relevance. A student who wants to be a professional football player would likely not see investigating water quality problems as having attainment value but a student who wants to be a physician may. The key here is to connect the task to students' current roles as citizens and family members, rather than to a particular profession. All students are citizens and family members; as such, they have a stake in such issues as how the local environment is managed, how the government is run, and how family disputes are resolved.

### Scaffolding Strategies That Foster Interest

The first scaffolding strategy for promoting interest is *prompting students to choose an aspect of the problem that connects to their interests*. One can leverage students' enduring individual interests by making explicit multiple aspects of the problem that students can pursue. Students can select a problem aspect that they find particularly interesting. Research indicates that providing meaningful choice about learning tasks can increase interest (Palmer, 2009; Patall, 2013; Pintrich & Schunk, 1996), although this effect may be limited to (a) students with good interest already (Patall, 2013), and (b) situations in which students have enough prior knowledge about the choices (Palmer, 2009).

This strategy is straightforward for scaffolding designed for a particular context. Designers can list out different aspects of the overall problem in scaffolds and allow students

TABLE 1
Guidelines

| Scaffolding Guidelines | Scaffolding Strategies | Other Motivation Goals Addressed |
|---|---|---|
| **Establish Task Value (ETV)** | | |
| 1. Foster interest | 1a. Prompt students to choose an aspect of the problem that connects to their interests (Palmer, 2009; Patall, 2013). | PMG, PER, PA |
| | 1b. Display driving questions that intrigue students and which can only be addressed through investigating the target material (Barron et al., 1998; Renninger, 2009). | PMG |
| | 1c. Use language that is congruent with students' everyday experiences when describing tasks/content (Albin, Benton, & Khramtsova, 1996; Keller, 1987). | |
| 2. Establish attainment value | 2a. Provide explanatory rationales for relevance to current and future life (Reeve, 2009; Su & Reeve, 2010). | |
| | 2b. Embed expert modeling to illustrate how process is used in authentic settings (Herrington & Oliver, 2000; Powell & Mason, 2013). | PES |
| | 2c. Prompt students to reflect on and articulate attainment value (Kolodner et al., 2003; Turns et al., 2010). | |
| **Promote Mastery Goals (PMG)** | | |
| 3. Encourage short-term goals | 3a. Embed peer modeling of specifying and engaging in subprocesses (Miller & Brickman, 2004; Schunk, 1989; Tabachnick, Miller, & Relyea, 2008). | ETV, PES |
| | 3b. Prompt the creation of short-term goals. (Quintana et al., 2004; Reiser, 2004). | ETV, PES, PA |
| 4. Provide and promote informational feedback | 4a. Highlight the goal of developing competence (Anderman & Maehr, 1994; Kaplan & Maehr, 2007). | |
| | 4b. Focus feedback on substantive elements of student work (Deci et al., 1996; Rakoczy et al., 2013). | |
| | 4c. Embed reminders to self-congratulate for successes (Brophy, 2010). | PES, PER |
| | 4d. Embed recognition of progress, not just normative success (Ames & Archer, 1988; Pintrich & Schunk, 1996). | PES, PER |
| 5. Promote cooperation rather than competition | 5a. Highlight importance of cooperation rather than competition (Ames, 1992; Hmelo-Silver, 2004). | PB |
| 6. Emphasize rational goals | 6a. Provide explanatory rationale for rational goals (Chinn et al., 2013). | |
| | 6b. Provide peer scaffolding framework to enable students to press each other for understanding (Middleton & Midgley, 2002). | PB |
| **Promote Belonging (PB)** | | |
| 7. Encourage shared goals | 7a. Display consensus problem aspect and attainment value, along with groupmates' individual learning goals (Capdeferro & Romero, 2012; Dolmans & Schmidt, 2006). | ETV |
| 8. Accommodate social goals | 8a. Describe how persistence at the shared goal can help students reach social responsibility goals (Brophy, 2010; Tempelaar et al., 2013). | PMG, PER, PES |
| 9. Allow students to co-construct standards | 9a. Embed support for students' co-construction of standards to judge the quality of their scaffold responses and problem solutions (Reeve, 2009; Rogat et al., in press). | PES, PA |
| **Promote Emotion Regulation (PER)** | | |
| 10. Highlight controllability of actions | 10a. Embed peer modeling of constructive response to failure (Pekrun, 2006; Weiner, 1985). | PES |
| | 10b. Explain that failures are a natural part of learning, and encourage students to reflect on causes of past failures, and what could have been done differently (Belland et al., 2008; Simons & Ertmer, 2006). | ETV, PMG, PES |
| 11. Promote reappraisal | 11a. Provide an alternative explanation for negative emotions students may feel while struggling with the task so that students perceive that they belong in the profession (Thoman et al., 2013). | PB, PES, PA |
| **Promote Expectancy for Success (PES)** | | |
| 12. Promote perception of optimal challenge | 12a. Enable students to see that the task is neither too difficult nor too easy through peer modeling (Moos & Azevedo, 2009; Schunk, 2003). | PMG |
| | 12b. Persuade students that they can accomplish the scaffolded task (Bandura, 1997; Britner & Pajares, 2006). | |
| 13. Support productive attribution | 13a. Send teachers alerts based on tracking how students use scaffolding to prompt teacher-provided attributional feedback (Scheuer et al., 2010). | PER |
| 14. Enable identification of reliable processes | 14a. Encourage students to articulate strategy used, associated short-term goal, and whether it was a strategy they would use again, and why (Chinn et al., 2011; Herrenkohl & Cornelius, 2013). | |

TABLE 1
Guidelines *(Continued)*

| Scaffolding Guidelines | Scaffolding Strategies | Other Motivation Goals Addressed |
|---|---|---|
| Promote Autonomy (PA) | | |
| 15. Use noncontrolling language | 15a. Incorporate only noncontrolling language in scaffolding messages (Reeve & Halusic, 2009). | PMG, PER |
| 16. Provide meaningful cognitive choice | 16a. Enable students to choose among a reasonable number of stakeholder position options with the help of choosing criteria (Chinn et al., 2013; Rogat et al., in press). | ETV |
| 17. Help students direct their own learning | 17a. Display processes students identified as reliable, from which students choose to meet shared goals and short-term goals (Weinstein et al., 2011). | |
| | 17b. Embed support for scheduling project segments/processes (Loyens et al., 2008). | PMG, PES |
| | 17c. Embed support for students to self-evaluate strategy use (Loyens et al., 2008). | |

*Note.* When we note that a strategy also addresses another motivational goal, it does not necessarily address the other motivational goal in the same way that the main strategies listed under that goal.

to make choices. For example, if the problem examines the influence of urban water runoff on the Great Salt Lake watershed, multiple aspects of the problem could be examined, including the influence on (a) flora and fauna in the lake, (b) people who live near the lake, (c) intermediary bodies of water (e.g., creeks and rivers), and (d) the chemical makeup of the water. These options, along with a brief explanation of each option can each be listed next to a radio button. Students can then use the radio button to select the aspect that aligns most closely with their individual interests. Designers should take care to ensure that students have some prior knowledge related to the choices (Palmer, 2009) and that the choices are not so numerous as to provoke anxiety among students (Katz & Assor, 2006). In addition, if students are working in groups, different members of the same group can have different interests; in this case, it is necessary for groupmates to negotiate a problem aspect that can serve all of their interests.

Allowing students to choose problem aspects to address is core to PBL. Although providing choices of interesting problem aspects for students is a straightforward means of enhancing interest, this appears to be done mostly during problem setup by teachers. There is, to our knowledge, no computer-based scaffold in the literature that currently implements this strategy.

A second interesting-enhancing strategy is to *display driving questions that intrigue students and that can be addressed only through investigating the target material*. The use of driving questions—overarching questions (e.g., Why does pumice float even though it is a rock?) that focus students' investigations during PBL—has been advocated in project-based learning (Barron et al., 1998; Blumenfeld et al., 1991; Krajcik, McNeill, & Reiser, 2008) and in PBL (Ertmer & Simons, 2006). In project-based learning, driving questions are seen as vehicles to stimulate students' curiosity (Krajcik et al., 2008), allow for choices in approaches to take and artifacts to be produced (Blumenfeld et al., 1991), and make explicit the content to be learned (Barron et al., 1998). Ertmer and Simons (2006) advocated driving questions as a way to

remind students at all times of the central problem in PBL. Although these are all good reasons to have a driving question, it is especially important to craft the driving question such that it elicits students' curiosity and triggers their interest (Keller, 2010). One can do this through establishing cognitive conflict (Keller, 2010; Limón, 2001; Pintrich & Schunk, 1996). Also, making explicit the content to be learned may promote learning (Barron et al., 1998), which has been identified as a major source of interest (Palmer, 2009).

Driving questions build on situated interest but without employing seductive details. Reminding students of the overall purpose of the unit through continued display of the question can help establish coherence, which in turn can promote interest (Clinton & van den Broek, 2012; Sadowski, 2001).

Ertmer and Simons (2006) described how a teacher wrote the driving question and what students need to do on the top of all materials during a PBL unit. This general idea can be followed in computer scaffolds: The driving question can be placed at the top of each scaffold screen, along the aspect of the problem that students chose (Strategy 1a). Because the problem aspect that students chose would be recorded in database, this selection can be displayed on all pages. To continue the water quality example, a driving question may ask, "How does water affect the people, plants, and animals of the Great Salt Lake watershed?" This one question can frame everything that students do during the unit, even if they select different problem aspects to investigate, as suggested in Strategy 1a. This can help promote learning and interest. For example, students may be surprised to think that there could be water quality problems in mountain streams that lead to the Great Salt Lake.

To the best of our knowledge, no current computer-based scaffolds do this. But we did find one paper-based scaffold that does this. In the Driving Question Board, the teacher posts the unit's driving question on a posterboard (Weizman, Shwartz, & Fortus, 2008). Students write related questions that they perceive as relevant on Post-It notes. The teacher then writes subquestions related to the driving

question, and students need to arrange their Post-It notes underneath a related subquestion. At the start and end of each class session, the class revisits the board. Students perceived that this process helped them to make connections with what they were learning and to break questions into smaller chunks.

The third interest-enhancing scaffolding strategy is *use language that is congruent with students' everyday experiences when describing tasks/content*. In one study, teachers' cognitive congruence, defined as "the ability to express oneself in a language students can understand, using concepts they use and explaining concepts in ways easily grasped by students," was the most significant predictive factor for students' situational interests in a PBL classroom (Rotgans & Schmidt, 2011b, p. 38). Thus, helping students see how learning tasks/content are connected to their own experiences can facilitate interests in learning.

To continue with the Great Salt Lake watershed example, scaffolds could use language that alludes to how members of the students' community use water in everyday life. It is easy to forget just how essential water is to many facets of life, and such a scaffold would students make these connections. Some existing computer-based scaffolds may do this, but we could find no evidence of a deliberate attempt grounded in the motivation literature to do this.

## Strategies That Establish Attainment Value

The first scaffolding strategy that establishes attainment value is *providing explanatory rationales for relevance to current and future life*. Telling students "This is important to you!" would likely be counterproductive, as it is a form of controlling language—language that pressures students to complete tasks, thereby reducing autonomy (Reeve, 2009). From a self-determination theory perspective, providing an explanatory rationale for why solving the problem is relevant to students' current and future lives can serve the dual functions of helping students perceive value in the learning task (Brophy, 2008; Jang, 2008; Pintrich & Schunk, 1996; Reeve & Halusic, 2009) and increasing autonomy (Jang, 2008; Reeve, 2009; Su & Reeve, 2010). From an expectancy-value theory perspective, students will not be motivated to engage in the task without perceiving the task to have value, even if they expect to be successful at it (Wigfield & Eccles, 2000).

Continuing with the water quality example, scaffolds can explain why investigating the problem is a worthwhile activity. Such a rationale needs to focus on how addressing the problem helps students meet their own needs of relatedness, competence, and autonomy (Deci & Ryan, 2000). The rationale could focus on how the people of the intermountain west depend on the rivers that feed the Great Salt Lake, and how solving the problem can help the students fulfill social responsibility goals. In addition, the rationale can communicate how solving the problem will help students develop problem-solving, collaboration, and self-directed learning skills, as well as important content knowledge, that will serve them now and in the future. It is important to highlight how and in what situations such processes can be used (Brophy, 1999; Reeve & Halusic, 2009). Next, the rationale can communicate that students will be able to make choices and direct their own learning while solving the problem. Furthermore, the rationale can paint a picture of how students would address common problems in real life before and after completing the unit (Keller, 2010).

To our knowledge, no current computer-based scaffolds provide an explanatory rationale for relevance to current and future lives. Many inquiry environments emphasize relevance (e.g., Linn, Clark, & Slotta, 2003; Sadler & Donnelly, 2006) but do this in the problem setup rather than in computer-based scaffolds. Work has been done on stand-alone interventions that do so. For example, C. Kim (2012) proposed guidelines for support that highlights the value of learning mathematics. Such support allows students to choose preformed examples of how specific knowledge applies to their own lives (e.g., using algebra to compare cell phone monthly plans). The design of such support was partly based on previous work in which personalized e-mail messages provided a rationale for the relevance of archaeology content to university students in an archaeology course (C. Kim & Keller, 2008). Students who received these messages had higher confidence than students who received nonpersonalized messages. In a regression involving five predictor variables, the extent to which students perceived relevance of learning content explained the greatest amount of variance of positive feelings about schoolwork and behavioral and cognitive engagement among middle school and elementary school students among (Assor et al., 2002).

The second scaffolding strategy that establishes attainment value is *embedding expert modeling to illustrate how the process is used in authentic settings*. Expert modeling can help students see why the target content is important, and when and how it is used (Brophy, 1999). Expert modeling has a long history in scaffolding design. For example, in Alien Rescue, an expert describes how he would go about selecting a suitable planet in our solar system for a particular stranded alien (Pedersen & Liu, 2002). The intended purpose of such expert modeling is typically to demonstrate a good strategy for solving the problem. But motivational goals are also achieved. By viewing expert performance, students can see that what they are doing is similar to what a real scientist/historian/humanist would do in professional practice (Herrington & Oliver, 2000; Powell & Mason, 2013). This is important because one element of authenticity is the use of the tools of the discipline in authentic ways (Chinn & Malhotra, 2002). Fundamentally, what is important to motivation is not that the content to be learned be universally authentic, because this is not possible, but rather that the student perceives it as authentic.

Expert modeling is often packaged as video. In such videos, experts can introduce themselves, explain their job and what they do on a daily basis, and recap a problem-solving process in which they engaged recently. Such a video should not be long but should clearly indicate how the process is used in authentic settings, and why it is important to the expert's job. This should not be the same problem that students will solve but a problem that students can understand. As an alternative, an animation could be created with a tool like Adobe Edge that represents the problem-solving process along with text explaining the steps. Yet another option is to provide text narrative.

Existing scaffolds that employ expert modeling appear to do so to provide cognitive rather than motivational support to students as they learn to perform the scaffolded task. As just noted, Alien Rescue is one example. Another example was reported by H. Kim and Hannafin (2011), who used video cases to introduce preservice teachers to authentic teaching-learning situations confronted by practicing teachers. Problems were presented and illustrated in video vignettes, whereas analysis was scaffolded using teacher reasoning models. Preservice teachers were provided access to the materials and approaches considered by the experienced teachers as well as the method of resolution and assessment of how the problem might be approached differently in the future. The preservice teachers went from thinking about technology integration in technocentric terms at the beginning of the study to thinking about the use of technology to address authentic teaching problems. One possible conclusion is that the expert modeling helped them to see the problems as authentic. However, further research is needed to isolate motivational effects of these scaffolds.

The third scaffolding strategy that establishes attainment value is *prompting students to reflect on and articulate attainment value*. Students need to not only have a chance to read an explanatory rationale and view expert modeling but also reflect on and articulate the attainment value from their own perspectives. Reflecting on the attainment value of problem and project-based learning experiences may cause students to raise their estimation of the attainment value of the experiences (Turns, Cuddihy, & Guan, 2010). Furthermore, reflection in PBL can lead to enhanced learning and transfer (Hmelo-Silver, 2004; Kolodner et al., 2003; B. Y. White & Frederiksen, 1998).

PBL systems could incorporate prompts that encourage students to reflect on the attainment value, as well as text boxes in which students can type their reflections. Because many computer-based scaffolds are linked to a database, this reflection on the attainment value can be sent to the database and can be displayed in future stages of the scaffold. In this way, students can see why they should persevere in the face of challenges.

At present, few to no current computer-based scaffolds employ this strategy. However, this strategy is implemented in some stand-alone interventions. For example, a study intervention prompted students to reflect on the value of learning mathematics (C. Kim & Bennekin, in press). Subsequently, students were prompted to select a real-world problem that could be solved using mathematics (e.g., comparing cell phone plans). Students who received the intervention had significantly larger positive changes in perception of intrinsic value. In another example, students were invited to write an essay in which they reflected on the value of learning a mathematics technique (Hulleman, Godes, Hendricks, & Harackiewicz, 2010). Experimental students exhibited and maintained higher situational interest than control students.

## SCAFFOLDS THAT PROMOTE MASTERY GOALS

PBL performance may be enhanced when students adopt mastery goals. Recent research on transfer has shown that the adoption of mastery goals rather than performance goals during initial learning promotes transfer of learned knowledge (Nokes-Malach & Mestre, 2013; Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2009). In addition, mastery goals are more supportive of group work than performance goals (Yamaguchi, 2001). Due to these reasons, we focus on promoting mastery goals as a key motivational goal of scaffolds in PBL.

Four guidelines grounded in the motivation literature are designed to promote mastery goals: encourage short-term goals, provide and promote informational feedback, promote cooperation rather than competition, and emphasize rational goals. Short-term goals are waypoints that students can establish for themselves and that bring them one step closer to fulfilling the overall goal of solving the problem. Pursuing short-term goals in addition to longer term goals engenders effective self-regulation and engagement (Miller & Brickman, 2004; Zimmerman & Kitsantas, 1996). A meta-analysis indicated a strong association between self-regulated learning and mastery goals (Cellar et al., 2011). Informational feedback (defined as feedback that focuses on substantive elements of student work) is another important influence on students' decisions to pursue mastery goals (Elliott & Dweck, 1988). Informational feedback can also support students' autonomy (Levesque, Zuehlke, Stanek, & Ryan, 2004; Reeve, 2009). Cooperation rather than competition can also promote adoption of mastery goals (Wigfield et al., 1998). Cooperative learning may improve motivation through means such as fulfilling a need for connectedness (Deci & Ryan, 2000; Johnson & Johnson, 1985; Osterman, 2000) and allowing groupmates to learn from each other (Johnson & Johnson, 1985; Schunk et al., 2008). Mastery goals lead to deeper processing than performance goals (Pugh et al., 2009; Sins, van Joolingen, Savelsbergh, & van Hout-Wolters, 2008). In turn, deeper processing is associated with pursuing rational goals (Chinn & Buckland, 2012).

## Scaffolding Strategies That Encourage Short-Term Goals

The first scaffolding strategy that encourages short-term goals is *embedding peer modeling of specifying and engaging in subprocesses*. In the water quality example, a peer could model the subprocesses in which she would engage to address the overall goal, including measuring phosphate and nitrate concentrations, comparing collected data to historical data and standards, looking for reliability in data, and comparing to other streams with similar characteristics. Peer modeling also helps increase students' expectancies for success doing the modeled activities (Hsu, 1999; Schunk & Hanson, 1985). It is important to break peer modeling into smaller segments of the problem-solving process. In this way, students will see that it is possible to break the overall task into smaller processes, and these smaller processes as well as the overall task are doable.

Before beginning to put together such peer modeling, the designer needs to engage in a cognitive process analysis of solving the central PBL problem to determine the major components of the overall process that students will need to complete. The designer also needs to determine a similar problem on which the modeling can be based. Video or narrative of similarly abled peers solving this similar problem can be provided. The rationale for why the peer chose to break the overall process into the subprocesses also should be conveyed.

The *Connection Log* is a computer-based scaffold designed according to a framework describing the process by which middle school students create evidence-based arguments during PBL (Belland, 2010; Belland et al., 2008). It is database driven, and students work in groups, first addressing questions individually and then coming to consensus with their groupmates. In a recent redesign of the *Connection Log*, we developed an example of how two groups of students create persuasive arguments about whether the government should take steps to avert climate change. The modeling is portrayed in text form according to segments for each screen in the *Connection Log*. Students can click a section help button on a page to load the example for that page. Informal feedback from a recent unit indicated that it helped students get a better grasp of how to use the *Connection Log*. We anticipate that the example may also help students see how they can break the overall task into smaller subprocesses.

The second strategy that encourages adoption of short-term goals is *prompting the creation of short-term goals*. Articulation in scaffolds helps students make sense of data and manage their processes (Quintana et al., 2004), improve comprehension (Belland et al., 2008), and justify their reasoning (Reiser, 2004). This can also promote students' autonomy.

Students can be given prompts and a problem space in which they can break the overall goal into short-term goals. Such prompts can allude to the peer modeling and suggest ways that the overall goal can be broken down. However, such prompts should not tell students exactly how to break the problem down. First, this would lead students to believe that there is just one correct way to solve the problem, which would defeat the purpose of PBL. Second, this would impede students' perceptions of task value and autonomy.

We are unaware of any current computer-based scaffold that prompts the creation of short-term goals. The study reported by C. Kim and Bennekin (in press) was not in a PBL context, but it involved the process of setting short-term goals within a mathematics course in which students was taking. In the study intervention (i.e., volitional control support), a virtual change agent, an animated 3D character, prompted students to type their short-term goals in the course in the support system. Students who received the intervention (a) perceived the intrinsic value of learning mathematics and (b) experienced significantly more enjoyment and less anxiety, anger, and boredom.

## Strategies That Provide and Promote Informational Feedback

The first strategy that provides and promotes informational feedback is *highlighting the goal of developing competence*. Scaffold prompts should not use controlling language to, for example, portray that students need to complete a task to compare themselves to others or because the teacher requires them to. Rather, scaffolds should help students see that what they are doing is designed to help them increase their competence.

Scaffolds should help illustrate exactly how competence can be raised by engaging in the tasks. This harkens back to the foundational definition of scaffolding, which indicated that comprehension of the solution is necessary to learn the strategy for arriving at a solution (Wood et al., 1976). Students need to understand exactly what will result when they learn the strategy promoted by the scaffold. This can be done by describing students' capabilities both before and after unit or task completion (Keller, 2010).

Few if any existing computer-based scaffolds do this. Illustrating how competence can be raised by engaging in the tasks can allow students to keep a focus on mastery rather than performing better than peers (Anderman & Maehr, 1994; Kaplan & Maehr, 2007).

The second strategy that provides and promotes informational feedback is *focusing feedback on substantive elements of student work*. Substantive feedback can lead students to adopt mastery goals (Elliott & Dweck, 1988). Furthermore, high school students perceived substantive feedback to be more competence-supportive than comparative feedback (Rakoczy, Harks, Klieme, Blum, & Hochweber, 2013). Among university students, the amount of substantive feedback provided predicted expectancy for success (Duijnhouwer, Prins, & Stokking, 2010).

Teachers are well positioned to focus feedback on substantive elements of students' work. However, teachers are often too pressed for time to give continuous feedback during

PBL. Thus, alerts can be set up in the scaffolding system when student responses to scaffolds differ substantially from norms (e.g., much longer or much shorter). Such alerts can tell the teacher to go see the identified group and state what about their performance was different from the norm. Teachers can then use that information to know when to approach particular groups to see what they are working on and what they have found. The teacher can then give informational feedback targeted to substantive elements of the students' work. Peer feedback can also help. For example, one inquiry project supports students as they rate the quality of evidence (e.g., how strong the methodology is; Chinn & Buckland, 2012). A computer-based system could monitor students' evidence quality evaluations; when good evidence is rated as poor, and vice versa, alerts may be set up to provide substantive feedback to students.

Feedback is a central component of scaffolding (Chi, 1996; van de Pol et al., 2010). And it is well known from research from a cognitive perspective that feedback that simply indicates whether a student is right or wrong is not overly helpful to learning (Shute, 2008). Thus much feedback in scaffolds is informational, but this may be due to researchers paying heed to the volume of research on feedback. We are not aware of any computer-based scaffolds that focus feedback on substantive elements of student work expressly to promote mastery goals.

The third  strategy that provides and promotes informational feedback is *embedding reminders to self-congratulate for successes*. It is difficult for unaided K–12 students to keep track of the big picture during PBL units, which often run for multiple weeks (Belland, 2010). Left to their own devices, they may accomplish a fair amount on a particular day, but exactly what they accomplished and just how much closer they are to the problem solution are not clear in their minds (Belland, 2010). By helping them see what they have accomplished, students may be able to stay focused on working toward mastering the distal goal of problem solution, rather than just doing what they think is required to get a good grade.

Scaffold  prompts can encourage students to articulate what they found at the end of each day. Students can then see what they have accomplished, and the prompts can encourage them to recognize themselves for their progress. This may help students overcome the urge to quit when they experience failure, and may promote transfer (Perkins & Salomon, 2012).

There are few to no computer-based scaffolds that embed reminders to self-congratulate for successes. Given that self-congratulations for successes do not involve social comparisons, there is reason to believe that it would not promote performance goals (Brophy, 2010). Next, self-congratulating for successes may help students perceive that they have had a mastery experience, which can improve their expectancy for success (Bandura, 1977).

The fourth strategy that provides and promotes informational feedback is *embedding recognition of progress, not just normative success*. When feedback focuses only on normative success, this can promote performance goals, which are maladaptive in PBL environments (Yamaguchi, 2001). Scaffolds can display what the group has found for each day side by side, both in the student view of the scaffolds and the teacher view. For example, when students set a short-term goal to assess the health of bug populations in a stream, they can see how their findings progressively get them closer to addressing the short-term goal. This way, students and teachers can both see progress that is being made. The teacher can then come to the group to commend them on their developing ideas, making sure to focus on specific ways in which the ideas are improving. Students can also reinforce themselves for their progress.

At present, embedding recognition of progress is not a commonly used scaffolding strategy. However, mastery goal research indicates that doing this will help to strengthen mastery goals and will not promote performance goals (Brophy, 2010).

## Scaffolding Strategies That Promote Cooperation Rather Than Competition

One strategy grounded in the motivation literature promotes cooperation rather than competition: *highlight the importance of cooperation rather than competition*. Working cooperatively on learning tasks can promote mastery goals (Ames & Ames, 1984). Furthermore, effective cooperation is key to success in PBL (Belland, Glazewski, & Ertmer, 2009; Hmelo-Silver, 2004). Effective cooperation can help ensure that all groupmates contribute effectively toward meeting the group's shared goals. Each groupmate can contribute his or her strengths, and together, students can reach better solutions than they could alone.

Scaffolds should provide an explanatory rationale for why cooperation helps students reach individual and shared goals more effectively, as well as meet the needs for competence, relatedness, and autonomy. Students also should be encouraged to reflect on how working collaboratively with their groupmates can help them to achieve personal goals. To date, however, computer-based scaffolds have not highlighted the value of cooperation to student motivation.

## Scaffolding Strategies That Emphasize Rational Goals

One can emphasize rational goals by *providing an explanatory rationale for rational goals*. Rational goals can be defined as the aim to engage with content and processes in epistemically authentic ways. This means using evidence to explain phenomena, making claims and backing such with evidence, understanding causality, and evaluating arguments and information with reference to rational criteria (e.g., is the evidence logically coherent?; Chinn, Duncan, Dianovsky, & Rinehart, 2013). Pursuing rational goals is a natural extension

of mastery goals in PBL environments (Chinn et al., 2013), is core to solving authentic problems (Jonassen, 2011), and is indeed at the very core of what PBL researchers desire to foster among students (Barrows & Tamblyn, 1980; Hmelo-Silver, 2004). Most people, even adults, struggle pursuing rational goals (Kuhn, 1991). Thus, additional scaffolding support for pursuing rational goals is likely to be profitable.

Scaffolds can explain to students that and help them see why the goal is to fully understand the variables that are at play, and how they interrelate. Depending on the specific learning goals that the designer wants to foster, the scaffolds can stress what students need to explain. Emphasis needs to be on why rational goals are important, and how learning to pursue such can help them accomplish what they want and need in the present and the future. Such a rationale can allude to the importance of solving authentic problems in everyday life, and how learning how to apply rational criteria can help with this.

Although not providing an explanatory rationale for rational goals, the *PRACCIS* project (Promoting Reasoning and Conceptual Change in Science) helps science students link evidence to models and provide justifications accordingly (Chinn et al., 2013). The scaffolds embedded in PRACCIS appear to hold great promise for the promotion of rational goals. Promoting rational goals is an emergent strategy among computer-based scaffolds. This strategy promotes deep processing, which is associated with mastery goals (Pugh et al., 2009; Sins et al., 2008).

The second strategy that emphasizes rational goals is *providing a peer scaffolding framework to enable students to press each other for understanding*. Press for understanding refers to checking and encouraging understanding during schoolwork. Press for understanding is positively related to the pursuit of mastery goals, self-efficacy, and self-regulation, and negatively related to help avoidance (Levpušček, Zupančič, & Sočan, 2013; Middleton & Midgley, 2002). Teachers can press for understanding, but in PBL, students do not interact with the teacher constantly. Instead, they do interact regularly with their groupmates. Groupmates can help play a central role in promoting a press for understanding. This process is akin to the idea of peer scaffolding, which is scaffolding provided by peers rather than computers or teachers (Belland, 2014). Such interactions require that students know the type of questions to ask to check understanding, and the types of things to say to encourage understanding. Computer-based scaffolds can provide a framework by which students can provide peer scaffolding and prompt students to check for and encourage understanding among their groupmates (Belland, 2014).

For example, computer-based scaffolds can provide (a) checklists with questions students can use to evaluate their groupmates' understanding, and (b) suggested prompts to help their groupmates delve deeper. For example, returning to the Great Salt Lake watershed example, a checklist might prompt students to consider whether their groupmates have taken into account all possible sources that feed into the Great Salt Lake, how different animals and plants use the water, and so on. This has the potential to promote the kind of extensive dynamic feedback that can facilitate substantial learning gains (Ruiz-Primo & Furtak, 2006).

Evidence indicates that pressing for understanding impacts engagement and performance. One scaffold that promotes peer scaffolding to help students press each other for understanding is *Knowledge Forum*, in which students can post explanations and peers can comment on these to press for understanding (Van Aalst & Truong, 2011). Elementary students were able to progressively move from scientifically inaccurate explanations of reproduction to sophisticated, scientifically accurate explanations by virtue of peer feedback (van Aalst & Truong, 2011). The practice "challenge student thinking" was used by all highly engaging teachers and no moderately or low engaging teachers in the Raphael, Pressley, and Mohan (2008) study.

## SCAFFOLDS THAT PROMOTE BELONGING

As groupwork is core to PBL, belongingness is a crucial variable to promote. Simply put, students who are alienated from each other are unlikely to work effectively together (Kreijns, Kirschner, & Vermeulen, in press). Belonging can be enhanced by encouraging shared goals, accommodating social goals, and allowing students to co-construct shared standards. Shared goals are goals that two or more people have committed to pursuing together (Tomasello, Carpenter, Call, Behne, & Moll, 2005). Working toward shared goals can promote belonging (Tomasello et al., 2005) and autonomy (Gagné, 2009). Furthermore, holding shared goals positively predicts the adoption of mastery goals (Summers, 2006). To develop a shared goal, it is crucial that all group members' ideas and interests be taken into account. If one group member unilaterally chooses a goal for the group to address, this can hinder his or her groupmates' work processes (Yamaguchi, 2001) and relatedness (Capdeferro & Romero, 2012). Working toward shared goals can also promote positive interdependence in that no group member can succeed without all succeeding (Johnson & Johnson, 2008). Students with positive interdependence exert greater effort and engage in higher quality interaction with their groupmates (Johnson & Johnson, 2008; Slavin, 1980) and achieve at a higher level (Johnson & Johnson, 2008; Kagan & Kagan, 1994; Slavin, 1980) than students without positive interdependence.

Social goals refer to goals students pursue in social interactions with others, such as a desire to help others and compliance with requests from the teacher (Dowson & McInerney, 2003; Wentzel, 1998). Social goals can be held along with other goals, like mastery goals, and such goals can be either complementary or conflicting (Dowson & McInerney,

2003). Social goals include social development goals (i.e., to improve social skills), social demonstration goals (i.e., to demonstrate success in social pursuits), and social responsibility goals (i.e., to help others; Rodkin, Ryan, Jamison, & Wilson, 2013; Wentzel, 1998). Social goals can conflict with authentic inquiry when aimed at demonstrating success in social pursuits (Wentzel, 1998). But not all social goals are harmful; social goals can serve as motivators to help students complete tedious tasks so that they can then go out with friends (Wentzel, Baker, & Russell, 2012). Furthermore, social responsibility goals can cause students to not want to let their group down, and thus work hard at the group task (Hijzen, Boekaerts, & Vedder, 2007; Nelson & DeBacker, 2008). Some research indicates that female individuals tend to hold social goals that align with a desire to help their group more than male individuals (Patrick, Hicks, & Ryan, 1997; Tempelaar et al., 2013; Wentzel et al., 2012).

## Scaffolding Strategies That Encourage Shared Goals

Shared goals can be encouraged through this strategy: *display consensus problem aspect and attainment value, along with groupmates' individual learning goals*. Within PBL, the central problem often asks students to do things like explain phenomena with evidence (Sandoval & Reiser, 2004) and create and refine models of systems (Stratford, Krajcik, & Soloway, 1998). Thus, it is important to encourage students to create shared goals that align with the central problem. Teachers should be informed of students' shared goals so that these can be checked for alignment with the overall unit goal.

Because students will all have individual goals in relation to the unit, it is important to have them each articulate such goals. Once everyone has done this, the computer-based scaffolds can display from the database the consensus problem aspect that the group chose to investigate, as well as each groupmate's individual goal and attainment value. Then the groupmates can discuss all articulated ideas and come to consensus on an appropriate group goal. In this process, students need to be reminded that the most vocal member should not necessarily win, but they should assemble the group goal from the best elements of each groupmate's ideas.

In *Optima*, university students working in groups of 12 propose learning goals on a discussion board (Rienties et al., 2012). Groupmates then needed to indicate if posted learning goals are worth pursuing, and those goals that get at least three votes are pursued. The impact of this feature was not isolated, but there was no difference in quality of interaction between high-autonomy students and low-autonomy students who used the *Optima* Design; however, there was a difference in quality of interaction between high-autonomy and low-autonomy students who used a previous version of the scaffold. The *Connection Log* helps middle school stu-

dents to establish shared goals for research (Belland, 2010; Belland, Glazewski, & Richardson, 2011). Students first define learning issues and make claims individually, and then they come to consensus with their groupmates. By creating shared goals, groups were able to define what information they needed to find and coordinate their efforts to find such (Belland, 2010).

## Scaffolding Strategies That Accommodate Social Goals

Social goals can be accommodated by scaffolds that *describe how persistence at the shared goal can help students reach social responsibility goals*. Although some students may have at the forefront of their minds the social goal of demonstrating success in social pursuits, they likely have other social goals. For example, students who want to be popular probably do not want to be antisocial at the same time. Rather, they likely still want to satisfy the need of relatedness (Deci & Ryan, 2000), and to do so they need to pay heed to others' goals. Indeed, some research indicates that having social goals in addition to shared goals can lead to superior self-assessments of group functioning, as compared to PBL groups that only pursued shared goals (Tempelaar et al., 2013). Just saying that social goals and shared goals can coexist will not make them do so. Rather, one needs to help students balance such goals. One way to do this is to remind students of their groups' shared goals and mention that students rely on their groupmates for help in achieving the shared goals, thus invoking social responsibility goals.

Computer-based scaffolds can display the attainment value of the activity as articulated by each group member along with a statement that to help their groupmates reach those goals, completion of the learning task is necessary. This is a simple matter in computer-based scaffolds that are linked to a database. As they read their groupmates' attainment values for the unit, they can see that even if the topic of the unit has little value for themselves, it does for their groupmates. In this way, they may be persuaded that solving the central problem has value. These same strategies may be helpful in getting students with performance-avoid orientations to embrace solving the problem. To the best of our knowledge, no current scaffolds do this.

## Scaffolding Strategies That Allow Students to Co-Construct Standards

Scaffolds should *facilitate students' co-construction of standards to judge the quality of their scaffold responses and problem solutions*. Promoting co-construction of standards can help students feel that they belong to a shared community of inquirers, and it is also autonomy supportive. As discussed earlier, students need to use criteria to judge the quality of and improve their own products and those of groupmates.

Externally imposing such standards would inhibit autonomy (Reeve, 2009).

Designers might provide a starter list of criteria, to which students can add and modify, or they might encourage students to develop their own criteria based on studying better and worse examples, such as developing criteria for good models on the basis of examples of better or worse models (Rogat, Witham, & Chinn, in press). Exactly what type of criteria is developed will depend on the goal of the scaffold system. If the scaffold supports argumentation, then among the criteria should be criteria to evaluate an argument, and what makes evidence or premises relevant to a claim. The form of the starter criteria will depend also on the age of the target students.

Chinn et al. (2013) noted success in helping students to co-construct standards. Helping students co-construct standards rather than impose such standards on students is autonomy-supportive (Reeve, 2009).

## Scaffolds That Promote Emotion Regulation

Everyone experiences failure or other unpleasant situations at some point. This is no less true in PBL, which involves high degrees of challenge and unclear goals (Kolodner et al., 2003). Learning environments are never perfect for everyone (C. Kim, 2012). Thus, students will sometimes experience negative emotions and need to learn to regulate their emotions, defined as focusing on positive emotions and resolving negative emotions (C. Kim & Pekrun, 2014; Gross, 2008; Pekrun, 2006). When students recognize that they control learning processes and outcomes, their emotions can be more positive (Weiner, 1985). For example, sometimes mathematics courses address only formulas without illustrating how the formulas can be used to address personal goals. In this case, students can regulate their boredom or frustration by generating their own examples to understand the potential usefulness of the course. Not all academic emotions are harmful to learning. For example, feeling pride due to success on an exam may lead a student to continue the studying strategies that led her to be successful. Also, the emotion of shame can lead to resilience and improvement in achievement (Turner & Husman, 2008; Turner & Schallert, 2001).

The literature on motivation and emotion suggests two strategies to promote emotion regulation: highlight controllability of actions and promote reappraisal of failure. Controllability refers to the perception of what they can control themselves. Even when locus of control for a cause is internal (e.g., effort), this does not mean the cause is perceived as controllable (Weiner, 1985). And when controllability is not recognized, negative emotions can occur (Weiner, 1985). Reminding students that they can control what happens in learning environments is crucial because negative academic emotions can impede cognitive processes and affect how memories are encoded (C. Kim & Pekrun, 2014; Pekrun, 2006). Reappraisal refers to the process of reflecting on the context in which failure or success is experienced, and revalu-

ating the causal structure that leads to success or failure, what factors are attended to and drive action, and the response to the success or failure (Gross, 2008).

Promoting reappraisal of failure is crucial to enhance students' perception of controllability and thus positive emotions, because students may experience negative emotions if they struggle during PBL. Student struggle during PBL is very common, because their initial strategies will often not work. Negative emotions (e.g., fear of failing) that occur during struggle in a class can promote withdrawal (Roseman, Wiest, & Swartz, 1994). This often is influenced by stereotype threat, in which performance is adversely affected by a fear of confirming a negative stereotype of the individual's group (Appel & Kronberger, 2012; Smith, 2004; Thoman, Smith, Brown, Chase, & Lee, 2013). A key symptom of stereotype threat is the attribution of failure to weaknesses purported in a stereotype about one's group. For example, when reminded of the stereotype that girls are not good at math, girls have been found to perform worse on math exams (Thoman et al., 2013). The negative effects of stereotype threat extend beyond performance on exams and include negative effects on situational interest, expectancy, and sense of belonging, as well as increased incidence of performance-avoid goal orientations (Smith, 2004; Thoman et al., 2013). One can do this by providing an alternative explanation for negative emotions students may feel while struggling with the task.

## Scaffolding Strategies That Highlight Controllability of Actions

The first scaffolding strategy that highlights controllability of actions is *embedding peer modeling of constructive responses to failure*. Constructive response to failure includes analyzing the causal structure of the learning context, and thus determining what could have been done differently to lead to success. If scaffolds are designed to model constructive responses, students' failures would not lead to negative emotion but help them use their failures as formative feedback to improve their learning.

Scaffolds can include checklists that prompt students to make a list of what they would do if they go back to the time they performed the task that they failed. The list will also become a checklist for their next trial to check off what they do to succeed.

This has not been a central focus of computer-based scaffolds. In a recent study including an emotion regulation intervention (C. Kim & Bennekin, in press), a virtual change agent (a 3D animated character) was designed not only to exhibit characteristics (age, ethnicity) to which the majority of students can relate but also to model constructive responses to failure by sharing stories of (a) her (i.e., the virtual change agent) own experiences of anxiety and fear from failing in mathematics, and (b) how she overcame these negative emotions. The experimental group exhibited positive changes in emotions such as more enjoyment and less anxiety, anger,

and boredom than the control group. Further optimization of the agent is under way, and further studies are planned to investigate the influence on emotion regulation.

The second strategy that highlights controllability of actions is *portraying that failures are a natural part of learning*. The most debilitating goal orientation—performance-avoid—arises when students have been conditioned to avoid all possibility of failure. This can happen when students judge failure as a reflection of self-worth or low ability. PBL inevitably involves student struggle, which can feel like failure to students, but it is really just a natural part of the process of PBL (Belland et al., 2008; Simons & Ertmer, 2006).

Scaffolds can explain why the failure of a peer model was a natural part of learning. This explanation can emphasize that when one addresses authentic problems, it is natural to fail, but that failing does not prevent the successful addressing of the problem.

We know of no current computer-based scaffolds that do this. But there are other interventions that use similar strategies. For example, in a study aiming to improve mathematics learning (C. Kim & Keller, 2010), college students who were provided customized motivational and volitional messages that contained explanatory rationales that incremental effort despite failures rather than natural ability is required to learn calculus studied more hours than students who received non-customized messages and those who did not receive such messages.

### Scaffolding Strategies That Promote Reappraisal

Scaffolds can promote reappraisal of failure by *providing an alternative explanation for negative emotions students may feel while struggling with the task so that students perceive that they belong in the profession*. It is important to give students the skill to reassess the causal structure of the task on which they struggled to see (a) that failure was due to factors under the student's control, and (b) what could have been done differently to arrive at success. Furthermore, computer-based scaffolds can explain that (a) professionals in the field include many people from many different backgrounds, and (b) failure is normal for these professionals, and does not prevent success in the long term.

Students who have been on the same scaffold page for longer than was deemed reasonable can be given feedback that they need to try harder. The amount of time spent on individual pages can be automatically determined by a computer checking timestamps in the database linked with the scaffold.

We are not aware of any current scaffolds that do this. But it is promising in that attribution is a key influence on expectancies for success and positive emotions (Weiner, 1986), and teachers in PBL would be hard pressed to provide sufficient attributional feedback to all of their students by themselves.

### SCAFFOLDS THAT PROMOTE EXPECTANCY FOR SUCCESS

Almost all computer-based scaffolds are designed to provide support that enhances objective success, which in turn can promote mastery experiences and expectancies for success (Britner & Pajares, 2006). Thus, computer-based scaffolds in PBL can be viewed as having the goal of promoting expectancies for success. But we believe that existing scaffolds have not capitalized on some of the available avenues for promoting expectancies of success. Three avenues that have not been explored for promoting expectancy for success using scaffolds are promoting the perception of optimal challenge, supporting productive attribution, and enabling the identification of reliable processes. We elaborate on these next.

### Scaffolding Strategies to Promote the Perception of Optimal Challenge

By ensuring that tasks have the potential to be optimally challenging, designers can promote (a) the desire to succeed (Csikszentmihalyi & LeFevre, 1989; Deci, Ryan, & Williams, 1996), (b) task enjoyment (Abuhamdeh & Csikszentmihalyi, 2012; Csikszentmihalyi & LeFevre, 1989), and (c) feelings of competence (Deci et al., 1996). The first scaffolding strategy to promote the perception of optimal challenge is *enabling students to see that the task is neither too difficult nor too easy through peer modeling*. To enhance motivation, students need to perceive the learning task to be optimally challenging (Abuhamdeh & Csikszentmihalyi, 2012; Ryan & Deci, 2000; Schweinle, Turner, & Meyer, 2008; Sungur & Senler, 2010; Vansteenkiste et al., 2010). When judging the challenge of a task, students refer to an assessment of what it takes to complete the task (e.g., actions required, cognition required) and their ability (Kolodner, 1993; Schank, 2004). Using peer modeling to show how students of similar ability were successful, engaged, and relaxed while solving a similar problem can provide a reference point for such assessments (Moos & Azevedo, 2009; Schunk, 2003).

Modeling has long been used in computer-based scaffolding, but the modeling has most often been by experts (e.g., Ge & Land, 2003; Lin, Hmelo, Kinzer, & Secules, 1999; Liu & Bera, 2005). The purpose of expert modeling is often to show highly efficacious strategies that can be used to solve the target problem. However, peer modeling can be used to show that a similarly abled peer can accomplish the task successfully without being bored or overwhelmed (Bandura, 1997; Moos & Azevedo, 2009; Schunk, 2003). Obviously, the qualification "similarly abled peer" requires that more than one such peer be introduced in the scaffolding, so that students of differing ability levels can each find a similarly abled peer.

When designing scaffolds, one can portray narratives of peers who struggled solving a similar problem, but then succeeded. These narratives could be in writing or video, and

should portray (a) the level of the peer, (b) the actions and cognitions required to solve the problem, (c) that the peer struggled (but not too much), and (d) the peer succeeded by exerting persistent effort with his or her groupmates.

Peer modeling is used in scaffolding, but it is most often intended to help students learn how to complete procedures and implement strategies rather than to gauge problem difficulty (Moos & Azevedo, 2009). We do not know of any current computer-based scaffolds that employ peer modeling to help students gauge problem difficulty.

The second scaffolding strategy to promote the perception of optimal challenge is *persuading students that they can accomplish the scaffolded task*. Perceiving that one can complete a task successfully is a first step to perceiving optimal challenge.

Persuading students that they can accomplish the scaffolded task can help increase their expectancies for success at the scaffolded task. But it is important that this persuasion be genuine and tied to specific feedback (Britner & Pajares, 2006).

In the water quality example, computer-based scaffolds could list the skills that students have already demonstrated successfully in the class, and how these skills would be applied in the target problem. Students could then be invited to reflect on how this information influences their expectancies for success.

## Scaffolding Strategies That Support Productive Attribution

Recent research suggests that attribution to ability is not desirable, as this can lead to low resilience and academic performance; rather, it is desirable that students attribute to effort and strategy use (Yeager & Dweck, 2012). For example, students are more likely to exert more effort for future exams when their exam failure is attributed to lack of effort than when the failure is attributed to poor luck. Thus, productive attribution in this article means ascribing the cause of success or failure to effort and strategy use. By tracking students' activities, teachers can be alerted so that they can provide attributional feedback to students (Lyden, Chaney, Danehower, & Houston, 2002; Schunk, 1983). Attributional feedback led elementary students (Craven, Marsh, & Debus, 1991), middle school students (Dresel & Haugwitz, 2008), and university students (Lyden et al., 2002) to have more positive motivation and self-concepts than control students. Thus, teachers' feedback can include comments attributing students' success to their hard work and effective strategy use, and lack of success to insufficient effort and poor strategy use.

When students' work in PBL varies substantially from the norm, computer-based scaffolds can alert the teacher to read the target students' articulated ideas, and discuss how the students arrived at those ideas; the teacher can then provide appropriate attributional feedback (Scheuer, Loll, Pinkwart, & McLaren, 2010). For example, if a student articulates only a word or two where a whole paragraph was required, database checks can indicate this and an alert can be sent to the teacher. But this can apply also when students articulate much more than required. These alerts can be saved in a queue, and prioritized according to the extent to which the performance fell below or above standards. This is an underdeveloped area of computer-based scaffolding.

## Scaffolding Strategies to Enable Identification of Reliable Processes or Strategies

By reliable processes, we refer to individual and group strategies and processes (we use the terms *process* and *strategy* interchangeably here) that consistently lead to good results when deployed to address a particular goal. For example, argumentation is a process that can reliably lead to good ideas (Chinn, Buckland, & Samarapungavan, 2011; Herrenkohl & Cornelius, 2013). Identifying reliable processes can have at least three key benefits. First, it stands to reason that when students use strategies that are reliable, they will have high expectancy for success. Second, by using reliable processes and being successful, students will have mastery experiences, which in turn can raise their expectancies for success when engaging in similar tasks (Bandura, 2004; Usher & Pajares, 2008). Third, knowing that knowledge was generated using reliable processes enhances the credibility of the knowledge (Chinn et al., 2011).

The first strategy to enable identification of reliable processes is *facilitating reflection on the efficacy of strategies*. Because PBL problems have many possible solutions and solution paths, effective strategies to address them can vary substantially (Jonassen, 2000). Finding effective strategies may seem overwhelming to K–12 students. Computer-based scaffolds and teacher scaffolds can suggest strategies for students to use. Once students use these, they can reflect on how the strategies worked and why. Reflection can lead to many positive outcomes, such as flexible thinking (Lin et al., 1999) and transfer of learning to new domains (Salomon & Perkins, 1989). Prompts for reflection in scaffolding led middle school students to be more likely to use principles to back up their explanations than students who used scaffolding that did not require reflection (Davis & Linn, 2000). Engaging in argumentation with classmates about theories and predictions helped elementary students see argumentation as a reliable process for arriving at good ideas (Herrenkohl & Cornelius, 2013).

One way to do this is to encourage students to reflect at the end of the day about what strategies they used, what the goal was, and whether it was a strategy that they would use again and why or why not. Students could do this individually by entering the strategy they used in a text box, selecting the corresponding short-term goal, and selecting whether

they would use it again with a radio button. Students might use criteria for effective strategies, such as efficiency and whether the strategy produced information that addressed the short-term goal. Once all groupmates finish reflecting on the efficacy of strategies, all students in the class can collectively examine all such strategies, and use a check box to indicate which strategies were reliable. A possible criterion to provide would be that the strategy needs to have worked two or more times. Once a strategy is identified as a reliable process, it can then be moved to a "toolbox" in the scaffold system, which would be accessible to the entire class.

Computer-based scaffolds have not implemented this strategy completely. But one computer system facilitates reflection on the efficacy of strategies: *STAR LEGACY*, a template for the organization of learning environments that employ scaffolding (Schwartz, Lin, Brophy, & Bransford, 1999). Central to this approach is the encouragement to reflect back on processes and outcomes, articulating what worked and why. Educational psychology students completed a *STAR LEGACY* module, with half completing the reflection activity and half not. When they evaluated how much they had learned in class 2 months later, those who engaged in reflection rated their learning significantly higher than those who did not reflect (Schwartz, Brophy, Lin, & Bransford, 1999).

## SCAFFOLDS THAT PROMOTE AUTONOMY

Most PBL environments support cognitive choice, as authentic problems have many possible solutions and solution paths (Jonassen, 2000), and students are usually encouraged to explore their own ideas. However, some evidence indicates that PBL is not always autonomy supportive. For example, in some PBL environments, scaffolding overly constricts cognitive choice, which negatively influences autonomy (Wijnia et al., 2011). This makes sense in that a key goal of scaffolding is to reduce the degrees of freedom just enough so that students can address the problem successfully (Reiser, 2004; Wood et al., 1976). But in so doing, scaffolding also reduces the degree to which students can make choices, a key aspect of autonomy. Thus, it is important to embed strategies to promote autonomy in computer-based scaffolds.

Three guidelines grounded in the motivation literature are designed to promote autonomy: use noncontrolling language, provide meaningful cognitive choice, and help students direct their own learning. We discuss these next.

Noncontrolling language should be used in any discourse directed at students. This means that language that directs students to act in a particular way through pressure or a threat (e.g., assignment of a bad grade) should be avoided (Reeve, 2009). This is because controlling language hinders the development of interest and self-regulation of learning (Deci et al., 1996). Explanatory rationales should be used to help students see why doing the target action will benefit them (Reeve, 2009; Su & Reeve, 2010). This can be accomplished

in two ways: incorporate only noncontrolling language in scaffolding messages and portray the learning of scaffolded processes as beneficial to self-development.

Second, one can build students' perceptions of autonomy by providing cognitive choice (Guthrie, McRae, & Klauda, 2007; Katz & Assor, 2006; Stefanou, Perencevich, DiCintio, & Turner, 2004). This way, students can feel that they are in control of their own actions.

In PBL, students need to be able to direct their own learning: identify learning issues, identify and deploy strategies to address the learning issues, and assess the efficacy of such strategies (Hmelo-Silver, 2004; Loyens et al., 2008). Self-direction of learning also promotes autonomy (Deci & Ryan, 2000; Reeve, 2009) and is an important skill to develop to promote success in life (Bolhuis, 2003). Self-direction of learning does not come naturally to students, and so they need to be supported in this process (Loyens et al., 2008).

### Scaffolding Strategies to Use Noncontrolling Language

Rather than attempt to externally control students' actions through the use of controlling language in scaffolding messages, designers should use noncontrolling language. For example, a scaffolding message that uses controlling language is "As a group, look over the list below. For each item, discuss the following questions . . ." It would be more autonomy supportive written like this: "Below is the list of information items your group decided to find. Before finding the information, it may be helpful to discuss the following questions . . ."

There are many computer-based scaffolds that use noncontrolling language, though perhaps not as a deliberate strategy. We are not aware of any study that isolated the effect of noncontrolling language in scaffolding. But there is clear evidence that using noncontrolling language leads to such positive outcomes as increased intrinsic motivation and interest (Deci et al., 1996) and engagement (Jang, Reeve, & Deci, 2010). More attention needs to be paid to the use of noncontrolling language in computer-based scaffolds.

### Scaffolding Strategies That Provide Meaningful Cognitive Choice

Almost all PBL environments by nature provide many cognitive choices in comparison to traditional environments. However, more can be done. Computer-based scaffolds can further increase cognitive choice and thereby enhance autonomy by *enabling students to choose among a reasonable number of stakeholder position options with the help of choosing criteria*. As mentioned earlier, allowing students to choose among options that are most personally relevant enhances autonomy (Katz & Assor, 2006). But it is also important to not give too many choices, as this can overwhelm students and lead to lower motivation (Katz & Assor, 2006).

Scaffolds can provide a reasonable number of stakeholder positions from which to choose, along with a brief explanation of the stakeholder and his or her relation to the problem. Students can use a radio button to select the stakeholder who is closest to their own interests. Scaffolds invite students to use criteria that they have developed themselves to help make their decision.

Many scaffolds provide meaningful cognitive choice, but few if any currently provide choice in stakeholder positions. But other interventions provide other kinds of cognitive choice. For example, in a study on hypermedia, elementary students who had complete control over the video order and were given advice that they could choose to accept or not perceived significantly less controlling task motivation than students who had complete control but no advice and those for whom the system controlled the order (Gorissen, Kester, Brand-Gruwel, & Martens, 2013).

## Scaffolding Strategies That Help Students Direct Their Own Learning

The first scaffolding strategy that helps students direct their own learning is *displaying processes students identified as reliable, from which students choose to meet shared goals and short-term goals*. Once students establish goals, one cannot expect them to know how to address such goals without further support. At the same time, it would harm autonomy to tell students the exact strategies they should use (Reeve, 2009) and would be misleading, because PBL problems can be addressed through deployment of a variety of strategies (Jonassen, 2011).

This strategy works in conjunction with Strategy 14b—facilitate articulation of reliable processes. By going to the toolbox that shows reliable strategies and what goals were successfully addressed with the strategies, students can select reliable strategies to help them meet their shared and short-term goals.

We are unaware of any existing computer-based scaffold that does this. But the idea of the importance of students having access to a set of reliable strategies has a long history in the self-regulated learning literature (Weinstein, Acee, & Jung, 2011). The idea is that having access to such a list can help students themselves select the appropriate strategy to accomplish a goal. This can enhance self-regulated learning (Weinstein et al., 2011), which is a similar construct to self-directed learning (except that the latter concept also includes identification of learning issues; Loyens et al., 2008). Selecting reliable strategies to fulfill goals may lead students to feel greater expectancy for success.

The second scaffolding strategy is *embedding support for scheduling project segments/processes*. For many K–12 students, it is difficult to plan out a 4-week project. Trying to determine what needs to get done when so that the whole project comes together on time, and remembering the tar-get dates for each subgoal, can be very challenging without support.

Prompts can encourage students to assign target completion dates to each short-term goal that they established. The short-term goals can be displayed, and students can add a target completion date to be stored with the short-term goal in the database. All such goals and target dates can be displayed on the initial page when students log into the scaffold. As students complete short-term goals, checkmarks can appear in the overall scheme to show what has already been completed.

We know of no current scaffolds that do this. But there is a clear warrant for embedding such support from the self-regulated learning and self-directed learning literatures (Loyens et al., 2008).

The third scaffolding strategy is *facilitating students' self-evaluation of strategies*. For students to direct their own learning, they need to be able to judge the adequacy of their work. K–12 students have many difficulties doing this (Puntambekar & Hübscher, 2005). Facilitating the identification of a rubric by which they can assess their own work can help students evaluate their work (Loyens et al., 2008; Rogat et al., in press; B. Y. White & Frederiksen, 1998).

Designers can provide rubrics by which students can judge the quality of their own responses and those of classmates. This rubric will be that developed in Strategy 9a (facilitating students' co-construction of standards to judge the quality of their scaffold responses and problem solutions).

When high school students were asked to reflect on their inquiry work, they produced conclusions with significantly better rationales than students who did not need to self-evaluate (Toth, Suthers, & Lesgold, 2002). Using their *ThinkerTools* system, B. Y. White and Frederiksen (1998) found that group self-evaluation of processes used during inquiry promoted both learning and motivation. We anticipate that using self-created standards to self-evaluate will further enhance autonomy.

## DISCUSSION

Motivation has largely been neglected in research and development to date on computer-based scaffolds. Most current computer-based scaffolds support expectancies for success by making learning tasks more manageable. But simply promoting expectancies for success will not optimize motivation. For example, one cannot simply expect students to perceive value in learning processes because researchers think these processes are important. One cannot expect students to be autonomous without setting up the learning environment to support this. It is unreasonable to expect students to perceive belongingness, pursue mastery goals, and regulate emotions effectively without supporting these processes. This article has described an array of scaffolds that designers can use to address these important motivational

goals. The scaffolding guidelines that we have proposed are focused on computer-based scaffolds, but the guidelines also provide suggestions for developing scaffolds to be provided by teachers or embedded in noncomputer environments.

Embedding motivational support in computer-based scaffolds is important because computer-based scaffolds are currently largely divorced from motivational support. When students engage in PBL units for weeks at a time, it is crucial to help them see that (a) solving the problem is worthwhile, (b) they can in fact do it, (c) they should press for understanding because it will help them gain important skills, (d) they belong in the classroom community and in the profession, (e) they can respond to negative emotions in constructive ways, and (f) they can do all of this while maintaining control over their own destiny. Simply expecting the teacher to take care of this through teacher scaffolds is unreasonable when one considers that in most K–12 classrooms, there is one teacher and 20 to 30 students, and in PBL these students would each be working in small groups.

This article also raises some important questions that suggest avenues for future research. We discuss these next.

### Testing Motivational Theories in Authentic Contexts

Just as this article reconnected scaffolding with its roots, in supporting both motivation and cognition, it also promotes new ways to conduct critical research at the frontier of cognition and motivation. Motivation research often relies on correlations among items in self-report surveys. Although there is an important role for such studies in understanding student motivation, when it becomes the predominant form of research on a topic, it may be problematic. Within this article, we have proposed many guidelines grounded in motivation research. Although we are by no means the first to attempt to synthesize these theories, we are the first to our knowledge to do so to inform scaffold design. We encourage learning scientists/instructional technologists and educational psychologists to team up to implement these guidelines in computer-based scaffolds. First, this could lead to very productive and fundable research. Next, this research can be used to test motivational theories in authentic contexts. Last, and perhaps most important, this has the potential to greatly improve students' learning experiences.

### Balance Between Teacher and Computer-Based Scaffolds to Support Cognition, Motivation, and Engagement

Although this article focuses on how to design computer-based scaffolds, students will not succeed in PBL without adequate teacher support (Hmelo-Silver et al., 2007; Saye & Brush, 2002). For example, students often struggle evaluating sources (Eisenberg & Berkowitz, 1990), managing their strategies (Simons & Klein, 2006), and creating effective arguments (Jonassen & Kim, 2010). Teachers also need to support student motivation during PBL. The guidelines we provided in this article can also guide teachers in their provision of teacher scaffolds. However, the strategies by which these guidelines are implemented in teacher scaffolds will often vary. For example, a crucial role of teachers in supplementing motivational support in computer-based scaffolds is providing attributional feedback. As suggested in this article, computer-based scaffolds can alert the teacher when, for example, students write only one word where they should have written much more given the prompt. In response, the teacher can go to the students, find out what is going on, and provide appropriate attributional feedback. Experienced, effective PBL teachers never just sit back as students work during the unit; rather, they actively approach groups to do things like press for understanding by asking open-ended questions, direct students to particularly important problem elements, and get students back on track (Belland, 2012; Hmelo-Silver & Barrows, 2006; van de Pol et al., 2010).

### Peers and PBL

The model introduced in this article relies heavily on student articulation of responses to scaffolds and the careful consideration of those responses by groupmates. But the question of how scaffolds can be designed to encourage that the articulated responses figure into group decision making is not entirely resolved. Written articulation seems to avoid the problem of quiet students not being heard, but being heard and having your ideas be a part of group decision making may not be one and the same. More research is needed to determine the best way to craft scaffolds such that students factor all articulated responses into group decision making. More research is also needed to determine the best way to craft scaffolds so that truly dialectical decision making occurs, instead of "pick a winning idea" decision making.

### Transfer and/of Motivation

There has been much discussion about whether cognitive skills learned in authentic problem solving can be transferred to new contexts. New approaches to the conceptualization of transfer have highlighted the ideas of transfer as a preparation for learning new content more efficiently (Bransford & Schwartz, 1999) and of students ascertaining similarities between the original problem and the new one to apply their learning (Lobato, 2003). These new models allow one to consider many routes by which what is learned in one context can be applied to new contexts. Perkins and Salomon (2012) argued that motivation plays a big role in students' ability to transfer knowledge, especially to very different contexts and real-life settings. Unfortunately little attention is given to the role of motivation in transfer (Perkins & Salomon, 2012; Pugh & Bergin, 2006). Clearly, much more research

is needed along these lines. An interesting line of research would involve designing scaffolds to enhance motivation during authentic problem solving and investigating the influence of using such scaffolds on transfer, and to examine how motivation mediates transfer.

## IMPLICATIONS

In designing scaffolds one needs not choose between supporting cognition and motivation. Motivation has always been central to teacher scaffolds (Wood et al., 1976), but it has been largely ignored in computer-based scaffolds. In the rare occasions that designers do attempt to integrate motivation into computer-based scaffold designs, they often only consult one motivation theory, if at all. A theory of scaffold design that draws more broadly on the motivation and emotion literature will likely have more potency in the design of scaffolds that promote motivation. We encourage researchers and designers to pay greater heed to motivation in scaffolding, both in design and in research on the motivational and cognitive effects of the resulting scaffolds. Such research and design holds great potential for broadening knowledge of how to support learning and engagement in authentic settings.

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