# Chapter 3
# Context of Use of Computer-Based Scaffolding

**Abstract** The contexts in which computer-based scaffolding is used can vary widely. Such variation is by learner population (e.g., grade level and other characteristics such as achievement level and socioeconomic status), subject matter (i.e., science, technology, engineering, and mathematics), and instructional model with which scaffolding is used (e.g., design-based learning and problem-based learning). I describe these variations, and note accompanying variations in effect size estimates. Notably, scaffolding had its strongest impact when students were (a) at the adult level, (b) engaged in project-based learning or problem solving and (c) from traditional learner populations.

**Keywords** Case-based learning · Context of use · Design-based learning · Education level · Education population · Grade level · Instructional model · Inquiry-based learning · Modeling/visualization · Problem-based learning · Problem-centered instruction · Project-based learning · STEM discipline · Student demographics

## 3.1 Rationale for this Chapter

To begin this chapter, it is important to discuss the need for a consideration of the context of use of computer-based scaffolding. After all, in its original definition, scaffolding was provided on a one-to-one basis to toddlers who engaged in unstructured problem-solving (Wood, Bruner, & Ross, 1976). All structure to the problem-solving activity was provided by the scaffolding process itself. This was practical when there was one teacher for each student, but lost its practicality as a single source of support when using scaffolding in formal schooling. After all, when a teacher can work on a one-to-one basis with one student for an unlimited time span, the teacher can continually assess what structure is needed, and provide it. This is hard to beat in terms of effectiveness. But in formal school settings, teachers very rarely have this opportunity. So, as researchers turned their attention to how instruction could be centered on problem-solving in formal education, it was important to think about additional ways to provide structure to student learning in

B. R. Belland, *Instructional Scaffolding in STEM Education*,
DOI 10.1007/978-3-319-02565-0_3

this context (Palincsar & Brown, 1984; Schmidt, Rotgans, & Yew, 2011). This was often accomplished by pairing scaffolding with formal problem-centered instructional models (e.g., inquiry-based learning and problem-based learning; Crippen & Archambault, 2012; Hmelo-Silver, Duncan, & Chinn, 2007; Kolodner et al., 2003). Such formal, problem-centered instructional models needed to be paired with support for students' reasoning abilities, and instructional scaffolding (one-to-one and, later, computer-based and peer scaffolding) fit such a need nicely.

A natural question is whether the specific problem-centered instructional model with which scaffolding is used influences scaffolding's efficacy. This is an empirical question. It is beyond the scope of this book to investigate variations in the efficacy of one-to-one scaffolding and peer scaffolding based on the specific problem-centered instructional model with which it is used. But I do investigate how the efficacy of computer-based scaffolding varies based on the problem-centered instructional model with which it is used.

Deploying scaffolding in formal education environments also entailed an expansion of the age groups with which scaffolding was used. Computer-based scaffolding is now used among learner populations at the elementary school, middle school, high school, university, graduate school, and adult levels. It is natural to question whether an instructional approach that was originally designed for toddlers, and then modified to allow it to be delivered via a computer-based tool, would be efficacious among these new learner populations, and how the efficacy compares among the different learner groups. This is again an empirical question.

Along with age/grade level, it is also important to consider the area of STEM in which scaffolding was used. Computer-based scaffolding is used in science, technology, engineering, and mathematics education. Is scaffolding more effective when used in the context of one of the STEM disciplines than the remaining STEM disciplines? This is an empirical question that I address in this chapter.

Another important empirical question related to the expansion of the scaffolding metaphor to formal education is whether the efficacy of scaffolding varies depending on the specific characteristics of the learners who use it. For example, does the influence of scaffolding vary according to prior achievement, socioeconomic status (SES), or other factors? Some research suggests that it does (Belland, 2010; Belland, Glazewski, & Richardson, 2011; Belland, Gu, Armbrust, & Cook, 2015; Cuevas, Fiore, & Oser, 2002). Knowing the answer to this question would help scaffolding researchers know where further research is needed to improve outcomes among all students, an important goal to ensure that STEM is for all students (Lynch, 2001; Marra, Peterson, & Britsch, 2008; National Research Council, 2007).

In the next sections, I first discuss research on computer-based scaffolding with an eye on grade level of the learner population, and then summarize the results of meta-analysis regarding differences in effect sizes of scaffolding according to grade level. Next, I discuss variations in the use of scaffolding according to STEM discipline, and differences in effect sizes on that basis. Subsequently, I discuss scaffolding literature in light of student demographics, and then note meta-analysis findings regarding differences in scaffolding's effect according to student demographics. Next, I discuss how scaffolding is used in the context of different problem-centered instructional approaches, and note any according variations in scaffolding's effectiveness.

## 3.2 Grade Level

In a large expansion from the original grade level among which instructional scaffolding was used in its original conceptualization—preschool (Wood et al., 1976)—scaffolding has come to be used at the primary, middle, secondary, college, graduate, and adult levels (see Fig. 3.1). This likely makes sense in light of Adaptive Character of Thought-Rational (ACT-R) theory, which does not limit the scope of learners with whom it concerns itself. But this also makes sense in light of activity theory. While one traditionally may associate activity theory with learning among the pre-K-12 population, it is clear that the founders of activity theory never intended such a limitation in scope (Leont'ev, 1974; Luria, 1979). Rather, much of the core empirical research supporting activity theory involved adult populations (Luria, 1976). And the idea that one learns in interaction with others, in part by assimilating cultural knowledge, resonates with much other research on adult learning (Coryell, 2013). One may find the most clear such delimitation of a scaffolding-related learning theory in knowledge integration, which generally focuses on the learning of K-12 students (Linn, 2000). However, research from the knowledge integration tradition has been applied to older populations, and it is clear that there is a need for integrated mental models at all levels of education, and that many students at the college, graduate, and adult levels lack this (Ifenthaler & Seel, 2013; Johnson-Laird, 2001).

At the same time, one would be remiss to think that adults and elementary school students, for example, would respond in exactly the same way to computer-based scaffolding. Computer-based scaffolding used among these different populations often varies to a great extent, but sometimes researchers use the same scaffolding for distinctly different student populations, such as graduate and middle school

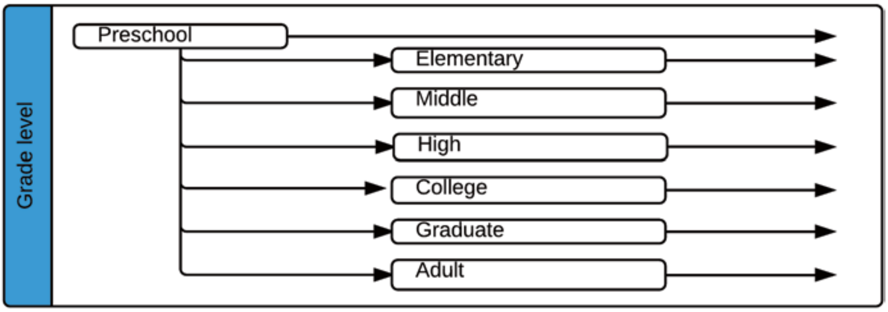

**Fig. 3.1** The expansion of grade levels with which scaffolding is used from its original context of use (preschool)

students (Fretz et al., 2002; B. Zhang, Liu, & Krajcik, 2006) or college and middle school students (Kyza & Edelson, 2005; Land & Zembal-Saul, 2003).

It is natural to question whether scaffolding has an effect of similar magnitude among learners at different grade levels.

### *3.2.1 Results from the Meta-Analysis*

The scaffolding meta-analysis (Belland, Walker, Kim, & Lefler, In Press) included outcomes from the following levels: primary ($n_{outcomes} = 28$), middle ($n_{outcomes} = 108$), high school ($n_{outcomes} = 53$), college ($n_{outcomes} = 132$), graduate school ($n_{outcomes} = 11$), and adult ($n_{outcomes} = 1$) (See Table 3.1). Scaffolding had a statistically significantly greater effect among adult learners than among college learners, high school students, middle level students, and primary students, $p < 0.01$. Caution is warranted as the effect size estimate for adult learners is based on one outcome. Still, this is intriguing, in that one might have ventured to guess that the effect would be lowest among adults, given that scaffolding was originally developed for use among toddlers. At the same time, it is important to recall that in its original definition, instructional scaffolding referred to one-to-one interactions (Wood et al., 1976).

Due to the higher sample size of effect sizes among middle level students than among graduate level learners, the 95 % confidence interval for scaffolding's effect among middle level learners (0.29–0.46) was tighter than it was for scaffold's effect among adult learners (0.20–1.52). Thus, the true effect size for adult learners may be lower than 0.86. From an activity theory perspective, scaffolding aims to help learners gain the cultural knowledge that helps to solve target problems effectively (Belland & Drake, 2013; Jonassen & Rohrer-Murphy, 1999). This is certainly something that graduate students and adults need to do. Still, the exact reason the effect size estimate is significantly greater among adult learners than among other age groups is unclear.

It is important to recall that the fact that scaffolding had a statistically significantly greater effect among adult learners than among students from other age groups

**Table 3.1** Table of results of moderator analyses on the effect of education level on cognitive outcomes

| Level | *n* outcomes | Effect size estimate | 95 % Confidence interval | |
|---|---|---|---|---|
| | | | Lower limit | Upper limit |
| Adult | 1 | 0.86 | 0.20 | 1.52 |
| Graduate | 11 | 0.61 | 0.22 | 1.00 |
| College | 132 | 0.49 | 0.42 | 0.57 |
| High school | 53 | 0.48 | 0.34 | 0.62 |
| Middle school | 108 | 0.37 | 0.29 | 0.46 |
| Elementary | 28 | 0.55 | 0.40 | 0.67 |

does not mean that scaffolding's effect was negative or inconsequential among the latter. Indeed, the effect size estimates of scaffolding used by elementary, middle, high school, college, and graduate level learners range from 0.37 to 0.61, which is above the threshold suggested for practical significance (Gall, Gall, & Borg, 2003), is substantially larger than the average effect of educational technology interventions for mathematics education ($ES = 0.16$; Cheung & Slavin, 2013), and is significantly greater than zero. Furthermore, it is similar to the average effect of interventions designed to enhance critical thinking abilities among a wide range of learners ($ES = 0.341$; Abrami et al., 2008), and higher than that of interventions designed to enhance critical thinking abilities among college students ($ES = 0.195$; Niu, Behar-Horenstein, & Garvan, 2013). In short, scaffolding led to effect sizes that were significantly greater than zero, and practically significant, among individuals at the elementary, middle, secondary, college, graduate, and adult levels. For one intervention to be so robust to differences in student populations, and to so uniformly lead to positive effects, is rare in educational research.

One may ask if the scaffolding interventions in the included research were similar enough to all be called scaffolding. The lack of precision in the term scaffolding that had emerged throughout its expansion has been widely lamented (Pea, 2004; Puntambekar & Hübscher, 2005). The scaffolding definition that guided the underlying meta-analysis was

> Support that assists students as they generate solutions to complex and ill-structured tasks, problems, or goals, and increases and helps students integrate higher-order competencies, including problem solving skills, deep understanding of content (knowledge integration), or argumentation.

This definition was applied strictly. For example, articles in which the intervention was given to students before they engaged in the problem were excluded, as were articles in which students were not addressing authentic, ill-structured problems or tasks. But there is clearly room for variation in the scaffolding interventions provided that they met the scaffolding definition.

## 3.3 STEM Discipline

Though STEM content was not central to the original instructional scaffolding definition (See Fig. 3.2), scaffolding has grown to be a central instructional strategy used in conjunction with problem-centered instruction in STEM education (Crippen & Archambault, 2012). The problem-centered instructional models used in each of these disciplines often vary. For example, modeling/visualization tends to be used most often in engineering and mathematics education (Lesh & Harel, 2003; Vreman-de Olde & de Jong, 2006). Design-based learning tends to be used most often in engineering education or in science education integrated with engineering content (Gómez Puente, Eijck, & Jochems, 2013; Kolodner et al., 2003; Mehalik, Doppelt, & Schuun, 2008). Problem-based learning is often used in science and en-

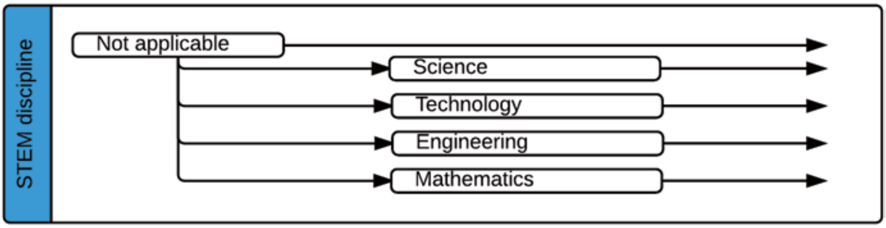

**Fig. 3.2** The expansion of disciplines of instruction in which scaffolding is used, going from non-STEM to science, technology, engineering, and mathematics

gineering education (Belland, 2010; Carr, Bennett, & Strobel, 2012; Hmelo-Silver, 2004). Furthermore, the types of skills being supported and content being developed varies among the disciplines. For example, design-based learning is prominent in engineering education because engineering places such a strong emphasis on the design of solutions to address problems.

### *3.3.1 Results from the Meta-Analysis*

Outcomes from science ($n_{outcomes}=208$), technology ($n_{outcomes}=51$), engineering ($n_{outcomes}=30$), and mathematics education ($n_{outcomes}=44$) were included (See Table 3.2; Belland et al., In Press). Results indicate that there was no difference in scaffolding's effect on the basis of discipline. This suggests that scaffolding is a robust intervention that is highly effective when used solving problems in a variety of subject matters.

## 3.4 Student Demographics

The original scaffolding description was developed among traditional, middle class students (See Fig. 3.3; Wood et al., 1976). In the scaffolding literature, one often sees variations in cognitive outcomes from scaffolding based on student factors such as achievement level, SES, and other factors associated with underrepresenta-

**Table 3.2** Table of results of moderator analyses on the effect of STEM discipline on cognitive outcomes

| Level | *n* outcomes | Effect size estimate | 95% Confidence interval | |
|---|---|---|---|---|
| | | | Lower limit | Upper limit |
| Science | 208 | 0.42 | 0.36 | 0.48 |
| Technology | 51 | 0.51 | 0.36 | 0.67 |
| Engineering | 30 | 0.58 | 0.42 | 0.73 |
| Mathematics | 44 | 0.54 | 0.42 | 0.65 |

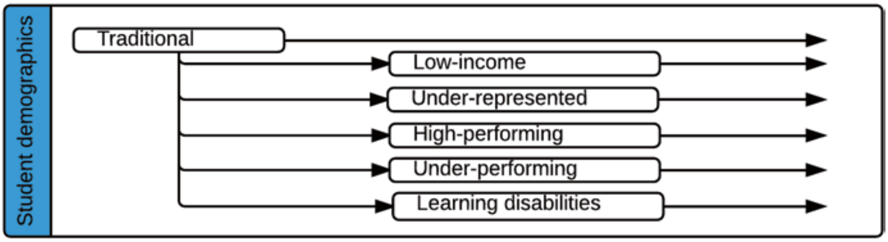

**Fig. 3.3** The expansion of student populations with which instructional scaffolding is used, from traditional to traditional, low-income, underrepresented, high-performing, underperforming, and student with learning disabilities

tion in STEM (Azevedo, Winters, & Moos, 2004; Belland, 2010; Belland et al., 2011; Belland, Gu, Armbrust, et al., 2015; Belland, Gu, Kim, Turner, & Weiss, 2015; Cuevas et al., 2002; Simons & Klein, 2006). It is important to investigate the extent to which scaffolding's influence varies according to these variables to guide future scaffolding research and development, so as to help ensure that STEM is for all (Lynch, 2001; National Research Council, 2007).

### *3.4.1 Results from the Meta-Analysis*

Outcomes from the following learner populations were included: traditional ($n_{outcomes} = 279$), low income ($n_{outcomes} = 11$), underrepresented ($n_{outcomes} = 17$), high-performing ($n_{outcomes} = 8$), and underperforming ($n_{outcomes} = 18$) (See Table 3.3; Belland et al., In Press). Students from traditional learner populations had a statistically significantly higher average effect size ($g = 0.48$) than underperforming students ($g = 0.28$), $p < 0.05$. This is concerning, as it is very important to maximize success opportunities in STEM for students from underrepresented groups (Ceci, Williams, & Barnett, 2009; National Research Council, 2011; Thoman, Smith, Brown, Chase, & Lee, 2013). Further research is needed to examine how to design and deploy computer-based scaffolding so as to increase its efficacy among underrepresented groups. There may also be a need to develop versions of scaffolds that draw on strategies known to be effective among the underrepresented groups (Cuevas et al., 2002; Lynch, 2001; Marra et al., 2008). It is clear from the literature that this is possible, as some studies have shown that specific scaffolds are more effective among lower-achieving and lower-SES middle school students than among higher-achieving and average-to-higher-SES students (Belland et al., 2011; Belland, Gu, Armbrust, et al., 2015; Belland, Gu, Kim, et al., 2015).

**Table 3.3** Table of results of moderator analyses on the effect of student demographics on cognitive outcomes

| Level | *n* outcomes | Effect size estimate | 95 % Confidence interval | |
|---|---|---|---|---|
| | | | Lower limit | Upper limit |
| High performing | 8 | 0.36 | 0.07 | 0.66 |
| Low income | 11 | 0.51 | 0.32 | 0.70 |
| Traditional | 279 | 0.48 | 0.42 | 0.53 |
| Underperforming | 18 | 0.28 | 0.12 | 0.45 |
| Underrepresented | 17 | 0.41 | 0.17 | 0.66 |

## 3.5 Instructional Model with Which Scaffolding is Used

In the original formulation of the scaffolding definition, no thought was given to the instructional model with which scaffolding was used, as it was centered on one-to-one tutoring of toddlers learning to build pyramids with wooden blocks (Wood et al., 1976). But as scaffolding was applied to formal education, one needed to consider the problem-centered instructional model with which scaffolding would be used (See Fig. 3.4). Scaffolding can be used in the context of such instructional strategies as problem-based learning, case-based learning, design-based learning, inquiry-based learning, project-based learning, and other instructional approaches that engage students in problem-solving. It is natural to question whether scaffolding's effectiveness varies according to the problem-centered instructional model with which it is used. There is reason to believe that it may, because different problem-centered models have different levels of structure and support for students built into their approach. The underlying support of the instructional model could interact with the support of scaffolding in a positive or negative way.

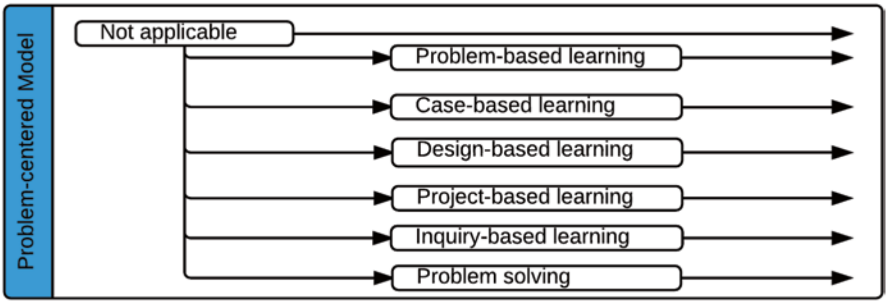

**Fig. 3.4** The expansion of formal, problem-centered models with which to use instructional scaffolding, from none to problem-based learning, case-based learning, design-based learning, project-based learning, inquiry-based learning, and problem-solving

### 3.5.1 Problem-Based Learning

Problem-based learning is an instructional approach in which students are presented with an authentic, ill-structured problem, and need to determine what they already know about the problem and what they need to know (learning issues; Barrows & Tamblyn, 1980; Hmelo-Silver, 2004). Typically, teachers present a driving question such as, "How does water quality affect the flora and fauna of X valley?" to which students can refer throughout the unit, and which reminds them of the fundamental reason they are addressing the problem (Ertmer & Simons, 2006). After being presented with the problem, defining it, and generating learning issues, students proceed to address their learning issues, and then develop a potential solution and back it up with evidence (Belland, Glazewski, & Richardson, 2008; Hmelo-Silver, 2004). They then need to defend their solution (Belland et al., 2008).

Originally developed in the medical school context, problem-based learning is still used extensively there (Barrows & Tamblyn, 1980; Gijbels, Dochy, Van den Bossche, & Segers, 2005; Kalaian, Mullan, & Kasim, 1999). In this setting, simulated patients often present with an unidentified illness, and students need to research what might cause such symptoms, triangulate such with test results, and propose a diagnosis and treatment (Barrows, 1985; Hmelo et al., 2001). Problem-based learning is also used in other university contexts such as business (Arts, Gijselaers, & Segers, 2002; Giesbers, Rienties, Tempelaar, & Gijselaers, 2013) and teacher education (Hmelo-Silver, Derry, Bitterman, & Hatrak, 2009; McCormick Peterman, 2012), as well as in various K-12 contexts. For example, in high school social studies, students addressed historical problems in the civil rights era (Saye & Brush, 2002). Middle school science students addressed a problem related to genetic testing and its relationship with such issues as medical insurance and public health (Belland, 2010; Belland et al., 2011). Furthermore, middle school students addressed the evolution of water quality in a local river, and what should be done about it (Belland, Gu, Armbrust, et al., 2015; Belland, Gu, Kim, et al., 2015). College statistics students investigated the extent to which claims related to a presented problem were supported by statistics (Karpiak, 2011). Preservice teachers investigated typical classroom problems, and developed solutions using educational psychology content (Hmelo-Silver et al., 2009). In these settings, problems are often presented through text-based or video-based synopses of the problem (Hmelo-Silver, 2004; Hung, Jonassen, & Liu, 2007).

In problem-based learning, students most often work in small groups. Though the sizes of the groups sometimes vary, 3–4 students is often posited as an ideal size in terms of promoting maximum student discussion (Arts et al., 2002; Lohman & Finkelstein, 2000). Different members of groups often perform different roles based on their individual strengths, and this can serve to extend each student's capabilities (Belland, Glazewski, & Ertmer, 2009; Helle, Tynjälä, & Olkinuora, 2006). However, there is some evidence that problem-based learning can be effective even when students work individually (Pease & Kuhn, 2011).

Problem-based learning both requires the use of strong self-regulated learning skills on the part of students, and can often lead to the enhancement of self-regulated learning skills (Evensen, Salisbury-Glennon, & Glenn, 2001; Loyens, Magda, & Rikers, 2008). But it also requires that students identify learning issues related to what they need to know to solve the problem (Hmelo-Silver, 2004; Loyens et al., 2008). Many K-12 students lack sophisticated self-regulated and self-directed learning skills and so need to be supported in these areas through scaffolding (Azevedo, 2005; Loyens et al., 2008). Similar struggles with self-directed learning can be seen among college students (Lekalakala-Mokgele, 2010) and medical students (Lohman & Finkelstein, 2000). Perhaps due to problem-based learning's focus on self-regulated learning, being exposed to problem-based learning and accompanying one-to-one scaffolding led seventh grade science students to develop significantly and substantially more enhanced epistemic beliefs (Belland, Gu, Kim, et al., 2015).

Problem-based learning leads to strong learning outcomes. For example, meta-analyses indicate that problem-based learning has a strong effect on principles-level (Gijbels et al., 2005) and application-level (Walker & Leary, 2009) outcomes and long-term retention (Strobel & van Barneveld, 2009). At the principles level, students performed on average 0.795 standard deviations better than their control counterparts (Gijbels et al., 2005). The advantage at the application level was 0.334 standard deviations (Walker & Leary, 2009). Given that the Strobel and van Barneveld's (2009) paper was a meta-synthesis, a quantitative estimate of the effect size difference is not available. Problem-based learning has often been found to lead to weaker immediate recall than lecture (Albanese & Mitchell, 1993; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Kalaian et al., 1999) but better long-term retention and deep content learning than lecture (Belland, French, & Ertmer, 2009; Pourshanazari, Roohbakhsh, Khazaei, & Tajadini, 2013; Strobel & van Barneveld, 2009).

### *3.5.2 Case-Based Learning*

Case-based learning is often used in the law school and business school contexts. But it also has been used in such STEM disciplines as medicine (Thistlethwaite et al., 2012) and physics (J. Zhang, Chen, Sun, & Reid, 2004). Lectures on the necessary content to understand the case often precede the presentation of cases. The premise is that by providing cases, instruction can help students build up a repertoire of cases upon which learners can draw when encountering similar problems in the future (Jonassen & Hernandez-Serrano, 2002; Kolodner, 1993). Cases can also provide concrete contexts in which the new content can be applied. Cases can represent a business transition or response to a problem or a particularly cogent legal case/argument/decision. Cases are often presented in a group discussion context, but can also take the form of a video summary or an online case presentation (Thistlethwaite et al., 2012). In it, learning content to be covered in the case (often via listening to a lecture) happens before students engage with the case. Typically, there is not much content to be learned after being presented with the case, but rather students need to reason based on what they have already learned (Srinivasan, Wilkes, Stevenson, Nguyen, & Slavin, 2007). Furthermore, faculty give students more active guidance than they would in a problem-based learning approach (Srinivasan et al., 2007). In this way, on the continuum of problem-centered approaches to instruction, case-based learning is closer to the more guided side than to the less guided side (Srinivasan et al., 2007). While cases represent authentic problems, they are typically more context bound than problem-based learning problems (Jonassen, 2000; Savery, 2006). In addition, cases are used to assess learning and promote application, rather than to drive learning (Savery, 2006).

The relative sophistication of students' epistemic beliefs influence their ability to perform well in a case-based learning environment, with students with sophisticated epistemic beliefs performing better and benefitting more from scaffolding than students with unsophisticated epistemic beliefs (Demetriadis, Papadopoulos, Stamelos, & Fischer, 2008; Peng & Fitzgerald, 2006). Some evidence indicates that case-based instruction can also help students develop more sophisticated epistemological beliefs (Çam & Geban, 2011).

Systematic reviews of the literature on the use of case-based learning in medical education indicates that students and instructors like the method very much, but how its impact on learning compares with that of other methods is not conclusive (Srinivasan et al., 2007; Thistlethwaite et al., 2012).

### *3.5.3 Design-Based Learning*

In design-based learning, students are presented with an authentic, ill-structured problem, but rather than develop a conceptual solution, they need to design/engineer a product that addresses the problem (e.g., a levee to prevent erosion on a barrier island (Kolodner et al., 2003), an alarm to address a problem that students identified (Silk, Schunn, & Cary, 2009)). Such problems are usually drawn from students' immediate communities, and students often have an opportunity to identify a specific subproblem on which they want to work (Doppelt & Schunn, 2008; Duran, Höft, Lawson, Medjahed, & Orady, 2014). The central problem in this approach is often termed a design challenge (Brophy, Klein, Portsmore, & Rogers, 2008). To address design challenges, it is important to consider the goals as envisioned by various project stakeholders, as well as constraints governing the design of a solution (Brophy et al., 2008). For example, design challenges can include preventing erosion on barrier islands and designing a model car that can go up and down hills on a track (Kolodner et al., 2003). In another approach to design-based learning, students generate a design challenge related to security alarms, taking into account where they personally need an alarm system (e.g., to remind someone to take medicine or to alert that something has been stolen (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008)). In the process of designing the product, students need to address learning issues (Chandrasekaran, Stojcevski, Littlefair, & Joordens, 2013; Kolodner et al., 2003; Silk et al., 2009).

To my knowledge, the effect of design-based learning has not been investigated through meta-analysis. But individual empirical studies indicate that design-based learning leads to many beneficial outcomes. For example, middle school students engaged in design-based learning have been found to learn science content and problem-solving skills more effectively than typical instruction controls (Kolodner et al., 2003) and gain substantially in science inquiry skills from pre to post (Silk et al., 2009). Furthermore, design-based learning led to significant increases in content knowledge and core STEM process skills among high school students (Duran et al., 2014).

### *3.5.4 Inquiry-Based Learning*

Inquiry-based learning is characterized by overt foci on students (a) posing their own questions early in the process (Edelson, Gordin, & Pea, 1999) and (b) designing and carrying out an experimental technique to address the generated questions (Abd-El-Khalick et al., 2004; Gibson & Chase, 2002). In this way, inquiry-based learning differs markedly from the "rhetoric of conclusions" approach to science labs used in many science classes, in which students are presented a question for which scientists know the answer quite well and given experimental procedures to follow to address that question (Chinn & Malhotra, 2002; Duschl, 2008). Rather, in inquiry-based learning, students need to identify variables, state hypotheses, design and carry out tests of those hypotheses, and interpret and explain the results (Edelson et al., 1999; Jong, 2006; Minner, Levy, & Century, 2010). There is substantial guidance from teachers and technology along the way, for example, for identifying pertinent variables and formulating testable hypotheses (Jong, 2006; Keys & Bryan, 2001). For example, high school students were invited to interact with a climate visualization, in which they could identify questions they wanted to address and manipulate variables to see how that affected dependent variables (Edelson et al., 1999). In another example, high school students interacted with an astronomy visualization with which they could address ten questions by manipulating variables (Taasoobshirazi, Zuiker, Anderson, & Hickey, 2006).

According to a recent meta-analysis of the literature on inquiry-based instruction in science, the model led to an average effect of 0.5, a medium-large effect (Furtak, Seidel, Iverson, & Briggs, 2012). Notably, the effect sizes in the review were twice as big when teacher support was highest (Furtak et al., 2012). According to another review, it may not be inquiry-based learning per se that leads to strong learning outcomes, but the extent to which students need to analyze authentic data and generate conclusions (Minner et al., 2010).

Examined individually, empirical studies indicate that inquiry-based learning can help students develop inquiry skills, as well as deep content learning (Crippen & Archambault, 2012; Edelson et al., 1999; Marx et al., 2004). Inquiry-based learning can be a good strategy to help students in underperforming districts perform at a higher level, when deployed as part of systematic reform (Marx et al., 2004).

Furthermore, inquiry-based learning can promote enhanced and sustained interest in science (Gibson & Chase, 2002). An extensive review of the inquiry-based learning literature indicated that it may be the extent to which students need to actively think, rather than the model of inquiry-based learning in and of itself, that leads to enhanced content learning (Minner et al., 2010).

### *3.5.5 Project-Based Learning*

In project-based learning, students address a problem, but the central focus is on the product that students need to create (Helle et al., 2006; Krajcik et al., 1998). Some examples of products are a video, a PowerPoint presentation, or a report. In developing project-based learning curricula, designers list academic standards, specify what students should be able to do according to the standard, and devise a performance (project) that would provide evidence of mastery of the skill (Barron et al., 1998; Krajcik et al., 1998). For example, a project-based learning unit in middle school invited students to design blueprints for a playhouse, given a set of donated materials (Barron et al., 1998). Students then work toward the project, which is typically contextualized in some sort of problem that students have the potential to find engaging (Krajcik, McNeill, & Reiser, 2008). As with problem-based learning, a driving question typically guides student learning in project-based learning (Barron et al., 1998). A primary purpose of a driving question in this case is to keep student focus on the content being learned and the issues being addressed, rather than on the project per se (Barron et al., 1998). While the parameters of the project deliverable are given to students at the beginning of the unit, students typically have a substantial amount of freedom in determining the exact features of the deliverable, as well as the route to get there (Helle et al., 2006). However, project-based learning is typically more structured than problem-based learning in that its deliverable is more well-specified (Savery, 2006). At the end of project-based learning, students typically produce the target product, and then engage in some sort of reflection, which can include the creation of a portfolio (Turns, Cuddihy, & Guan, 2010).

Research on project-based learning is often focused more on curricular design than on student learning (Helle et al., 2006). However, an examination of the project-based learning literature can lead one to some observations. First, project-based learning can lead to strong gains in design skills on the part of elementary school students (Barron et al., 1998) and college students (Dym, Agogino, Eris, Frey, & Leifer, 2005). It is also an instructional approach that can be very motivating (Blumenfeld et al., 1991; Helle, Tynjälä, Olkinuora, & Lonka, 2007). However, project-based learning does not necessarily promote motivation in and of itself; rather, designers should take care to design projects so as to enhance and sustain motivation (Blumenfeld et al., 1991) and to design scaffolding that supports motivation (Belland, Kim, & Hannafin, 2013).

### 3.5.6 Other Instructional Approaches

Scaffolding can be incorporated into other instructional approaches that incorporate authentic problem-solving but do not fit the above labels. This approach will be called *problem-solving instruction* for the purposes of this book. For example, much work in intelligent tutoring systems does not fit within any of the above instructional models, as it is grounded in the ACT-R theory of learning (Anderson, Matessa, & Lebiere, 1997). However, much of it does involve authentic problem-solving. As noted in Chap. 2 (this volume), intelligent tutoring systems focus on delivering knowledge chunks to students that they can then apply to problems that are provided in sequence. Scaffolding within Intelligent Tutoring Systems focuses on helping students apply the content to the problems, and in the process generate production rules. Production rules are defined as rules governing the application of declarative content to problems that can be applied without conscious control to similar problems in the future (Koedinger & Corbett, 2006; Self, 1998).

Many intelligent tutoring systems are used in mathematics. For example, the *Geometry Cognitive Tutor* presents a series of geometry problems along with diagrams (Aleven & Koedinger, 2002). Students need to calculate things like angles and type explanations of how they got their answer. They are given feedback on the basis of their answer and explanations (for the most common mistakes, detailed feedback is provided). Students can also request hints.

### 3.5.7 Results from the Meta-Analysis

The meta-analysis included outcomes in which scaffolding was used in the context of problem-based learning ($n_{outcomes}=38$), case-based learning ($n_{outcomes}=15$), modeling/visualization ($n_{outcomes}=42$), project-based learning ($n_{outcomes}=5$), design-based learning ($n_{outcomes}=4$), inquiry-based learning ($n_{outcomes}=69$), and problem-solving ($n_{outcomes}=160$) (See Table 3.4; Belland et al., In Press). Results indicated that scaffolding utilized in the context of project-based learning had a higher average effect size ($g=1.33$) than scaffolding used in the context of problem-based

**Table 3.4** Table of results of moderator analyses on the effect of problem-centered model on cognitive outcomes

| | | | 95 % Confidence interval | |
|---|---|---|---|---|
| Level | *n* outcomes | Effect size estimate | Lower limit | Upper limit |
| Case-based learning | 15 | 0.28 | 0.04 | 0.53 |
| Design-based learning | 4 | 0.30 | −0.12 | 0.82 |
| Inquiry-based learning | 69 | 0.42 | 0.33 | 0.52 |
| Modeling/visualization | 42 | 0.51 | 0.34 | 0.68 |
| Problem-based learning | 38 | 0.27 | 0.11 | 0.43 |
| Problem-solving | 160 | 0.53 | 0.45 | 0.58 |
| Project-based learning | 5 | 1.33 | 1.03 | 1.63 |

learning ($g = 0.27$), problem-solving ($g = 0.53$), modeling/visualization ($g = 0.51$), design-based learning ($g = 0.30$), inquiry-based learning ($g = 0.42$), and case-based learning ($g = 0.28$), $p < 0.01$. Furthermore, scaffolding used in the context of problem-solving had a higher effect size estimate ($g = 0.53$) than scaffolding used in the context of problem-based learning ($g = 0.27$), $p < 0.01$. Still, this difference is borderline, as the 95 % confidence intervals overlap.

Of note, most studies that used the "problem-solving" instructional approach involved intelligent tutoring systems informed by the ACT-R theory (Anderson et al., 1997; Corbett & Anderson, 2001; Koedinger & Corbett, 2006). A previous meta-analysis found that step-based intelligent tutoring systems led to an average effect size of 0.76 (VanLehn, 2011), which is considerably larger than the average effect size of computer-based scaffolding from the current, underlying, scaffolding meta-analysis ($g = 0.46$). This does not mean that intelligent tutoring systems are superior to other scaffolding types, as they target a different form of learning than other scaffolding types and hold different assumptions about learning and ways to help people learn most effectively. Notably, intelligent tutoring systems are the most highly structured instructional programs that involve scaffolding, in that they carefully script all student actions, and what happens when students do particular actions (Koedinger & Aleven, 2007; Koedinger & Corbett, 2006). The only exception to this is typically the inclusion of a hint button, which students can choose to press or not. It may be that the structure of intelligent tutoring systems in conjunction with scaffolding helps produce effects of a larger magnitude. It is important to note that this inclusion of a very tight structure means that intelligent tutoring systems tend to minimize opportunities for self-directed learning. For further discussion of the theoretical bases of scaffolding, please see Chap. 2 (this volume).

It is notable that the effect size estimate for computer-based scaffolding used in the context of inquiry-based learning ($g = 0.42$) is below that of inquiry-based learning found in a recent meta-analysis ($ES = 0.50$) by Furtak et al. (2012). However, it is reasonably close. One may imagine that not all studies covered in the latter meta-analysis included computer-based scaffolds. Further research is needed to disentangle the effect of computer-based scaffolding and that of inquiry-based learning in this context.

That the effect size of computer-based scaffolding was lowest when paired with problem-based learning may be explained by the open-ended nature of problem-based learning. Problem-based learning requires self-directed learning perhaps to the greatest extent among the covered problem-centered instructional approaches (Lohman & Finkelstein, 2000; Loyens et al., 2008; Savery, 2006). Problem-based learning students are responsible not only for defining the problem, but also determining what they need to know to come up with a solution, finding the information, and synthesizing the information to determine a solution (Belland et al., 2008; Hmelo-Silver, 2004; Loyens et al., 2008). In short, students have less structure from the inherent nature of problem-based learning than they would have from inquiry-, case-, project-, or design-based learning. Thus, they need to be relatively autonomous. This can be particularly challenging for K-12 students who have little experience with autonomy in school (Jang, Reeve, & Deci, 2010; Rogat, Witham,

& Chinn, 2014; Stefanou, Perencevich, DiCintio, & Turner, 2004). Furthermore, if teachers do not provide appropriate autonomy support, defined as the provision of meaningful choice in academic tasks and explanation when choice is not possible, students may not strive to achieve mastery, but rather, strive to perform better than other students (Ciani, Middleton, Summers, & Sheldon, 2010; Deci & Ryan, 2000). The nature of scaffolding used in the context of problem-based learning is thus uniquely targeted toward the need for students to be self-determined (Belland et al., 2008; Hmelo-Silver et al., 2007).

What problem-based learning students can propose as a solution is typically more open-ended than in case-based learning, project-based learning, design-based learning, modeling/visualization, and inquiry-based learning (Hmelo-Silver, 2004; Savery, 2006). That is, possible deliverables include conceptual solutions to the problem, persuasive presentations, artifacts, or some combination of products. In this way, problem-based learning may be seen as more loosely structured than other problem-centered instructional models (Hung, 2011; Savery, 2006).

## References

Abd-El-Khalick, F., BouJaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., Niaz, M., Treagust, T., & Tuan, H. (2004). Inquiry in science education: International perspectives. *Science Education, 88*(3), 397–419. http://doi.org/10.1002/sce.10118.

Abrami, P. C., Bernard, R. M., Borokhovski, E., Wade, A., Surkes, M. A., Tamim, R., & Zhang, D. (2008). Instructional interventions affecting critical thinking skills and dispositions: A stage 1 meta-analysis. *Review of Educational Research, 78*(4), 1102–1134. http://doi.org/10.3102/0034654308326084.

Albanese, M. A., & Mitchell, S. (1993). Problem-based learning—a review of literature on its outcomes and implementation issues. *Academic Medicine, 68*(1), 52–81.

Aleven, V., & Koedinger, K. R. (2002). An effective metacognitive strategy: Learning by doing and explaining with a computer-based cognitive tutor. *Cognitive Science, 26*(2), 147–179. http://doi.org/10.1207/s15516709cog2602_1.

Anderson, J. R., Matessa, M., & Lebiere, C. (1997). ACT-R: A theory of higher level cognition and its relation to visual attention. *Human-Computer Interaction, 12*(4), 439–462. http://doi.org/10.1207/s15327051hci1204_5.

Arts, J. A. R., Gijselaers, W. H., & Segers, M. S. R. (2002). Cognitive effects of an authentic computer-supported, problem-based learning environment. *Instructional Science, 30*(6), 465–495. http://doi.org/10.1023/A:1020532128625.

Azevedo, R. (2005). Using hypermedia as a metacognitive tool for enhancing student learning? The role of self-regulated learning. *Educational Psychologist, 40*(4), 199–209. http://doi.org/10.1207/s15326985ep4004_2.

Azevedo, R., Winters, F. I., & Moos, D. C. (2004). Can students collaboratively use hypermedia to learn science? The dynamics of self- and other-regulatory processes in an ecology classroom. *Journal of Educational Computing Research, 31*(3), 215–245. http://doi.org/10.2190/HFT6-8EB1-TN99-MJVQ.

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem- and project-based learning. *Journal of the Learning Sciences, 7*(3–4), 271–311. http://doi.org/10.1080/10508406.1998.9672056.

Barrows, H. S. (1985). *How to design a problem-based curriculum for the preclinical years*. New York: Springer.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York: Springer.

Belland, B. R. (2010). Portraits of middle school students constructing evidence-based arguments during problem-based learning: The impact of computer-based scaffolds. *Educational Technology Research and Development, 58*(3), 285–309. http://doi.org/10.1007/s11423-009-9139-4.

Belland, B. R., & Drake, J. (2013). Toward a framework on how affordances and motives can drive different uses of computer-based scaffolds: Theory, evidence, and design implications. *Educational Technology Research & Development, 61*, 903–925. http://doi.org/10.1007/s11423-013-9313-6.

Belland, B. R., Glazewski, K. D., & Richardson, J. C. (2008). A scaffolding framework to support the construction of evidence-based arguments among middle school students. *Educational Technology Research and Development, 56*(4), 401–422. http://doi.org/10.1007/s11423-007-9074-1.

Belland, B. R., Glazewski, K. D., & Ertmer, P. A. (2009). Inclusion and problem-based learning: Roles of students in a mixed-ability group. *Research on Middle Level Education, 32*(9), 1–19.

Belland, B. R., French, B. F., & Ertmer, P. A. (2009). Validity and problem-based learning research: A review of instruments used to assess intended learning outcomes. *Interdisciplinary Journal of Problem-Based Learning, 3*(1), 59–89. http://doi.org/10.7771/1541-5015.1059.

Belland, B. R., Glazewski, K. D., & Richardson, J. C. (2011). Problem-based learning and argumentation: Testing a scaffolding framework to support middle school students' creation of evidence-based arguments. *Instructional Science, 39*(5), 667–694. http://doi.org/10.1007/s11251-010-9148-z.

Belland, B. R., Kim, C., & Hannafin, M. (2013). A framework for designing scaffolds that improve motivation and cognition. *Educational Psychologist, 48*(4), 243–270. http://doi.org/10.1080/00461520.2013.838920.

Belland, B. R., Gu, J., Kim, N., Turner, D. J., & Weiss, D. M. (2015). *The relationship between problem-based learning, epistemic beliefs, and argumentation in middle school science*. Presented at the Annual Meeting of the American Educational Research Association, Chicago.

Belland, B. R., Gu, J., Armbrust, S., & Cook, B. (2015). Scaffolding argumentation about water quality: A mixed method study in a rural middle school. *Educational Technology Research & Development, 63*(3), 325–353. http://doi.org/10.1007/s11423-015-9373-x.

Belland, B. R., Walker, A. E., Kim, N., & Lefler, M. (In Press). Synthesizing results from empirical research on computer-based scaffolding in STEM education: A meta-analysis.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3–4), 369–398. http://doi.org/10.1080/00461520.1991.9653139.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education, 97*(3), 369–387. http://doi.org/10.1002/j.2168-9830.2008.tb00985.x.

Çam, A., & Geban, Ö (2011). Effectiveness of case-based learning instruction on epistemological beliefs and attitudes toward chemistry. *Journal of Science Education & Technology, 20*(1), 26–32. http://doi.org/10.1007/s10956-010-9231-x.

Carr, R. L., Bennett, L. D., & Strobel, J. (2012). Engineering in the K-12 STEM standards of the 50 U.S. states: An analysis of presence and extent. *Journal of Engineering Education, 101*(3), 539–564. http://doi.org/10.1002/j.2168-9830.2012.tb00061.x.

Ceci, S. J., Williams, W. M., & Barnett, S. M. (2009). Women's underrepresentation in science: Sociocultural and biological considerations. *Psychological Bulletin, 135*(2), 218–261. http://doi.org/10.1037/a0014412.

Chandrasekaran, S., Stojcevski, A., Littlefair, G., & Joordens, M. (2013). Project-oriented design-based learning: Aligning students' views with industry needs. *International Journal of Engineering Education, 29*(5), 1109–1118.

Cheung, A. C. K., & Slavin, R. E. (2013). The effectiveness of educational technology applications for enhancing mathematics achievement in K-12 classrooms: A meta-analysis. *Educational Research Review, 9*, 88–113. http://doi.org/10.1016/j.edurev.2013.01.001.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175–218. http://doi.org/10.1002/sce.10001.

Ciani, K. D., Middleton, M. J., Summers, J. J., & Sheldon, K. M. (2010). Buffering against performance classroom goal structures: The importance of autonomy support and classroom community. *Contemporary Educational Psychology, 35*(1), 88–99. http://doi.org/10.1016/j.cedpsych.2009.11.001.

Corbett, A. T., & Anderson, J. R. (2001). Locus of feedback control in computer-based tutoring: Impact on learning rate, achievement and attitudes. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 245–252). New York, NY, USA: ACM. http://doi.org/10.1145/365024.365111.

Coryell, J. E. (2013). Collaborative, comparative inquiry and transformative cross-cultural adult learning and teaching: A western educator metanarrative and inspiring a global vision. *Adult Education Quarterly, 63*(4), 299–320. http://doi.org/10.1177/0741713612471420.

Crippen, K. J., & Archambault, L. (2012). Scaffolded inquiry-based instruction with technology: A signature pedagogy for STEM education. *Computers in the Schools, 29*(1–2), 157–173. http://doi.org/10.1080/07380569.2012.658733.

Cuevas, H. M., Fiore, S. M., & Oser, R. L. (2002). Scaffolding cognitive and metacognitive processes in low verbal ability learners: Use of diagrams in computer-based training environments. *Instructional Science, 30*(6), 433–464. http://doi.org/10.1023/A:1020516301541.

de Jong, T. (2006). Technological advances in inquiry learning. *Science, 312*(5773), 532–533. http://doi.org/10.1126/science.1127750.

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*(4), 227–268. http://doi.org/10.1207/S15327965PLI1104_01.

Demetriadis, S. N., Papadopoulos, P. M., Stamelos, I. G., & Fischer, F. (2008). The effect of scaffolding students' context-generating cognitive activity in technology-enhanced case-based learning. *Computers & Education, 51*(2), 939–954. http://doi.org/10.1016/j.compedu.2007.09.012.

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction, 13*(5), 533–568. http://doi.org/10.1016/S0959-4752(02)00025-7.

Doppelt, Y., & Schunn, C. D. (2008). Identifying students' perceptions of the important classroom features affecting learning aspects of a design-based learning environment. *Learning Environments Research, 11*(3), 195–209. http://doi.org/10.1007/s10984-008-9047-2.

Doppelt, Y., Mehalik, M. M., Schunn, C. D., Silk, E., & Krysinski, D. (2008). Engagement and achievements: A case study of design-based learning in a science context. *Journal of Technology Education, 19*(2).

Duran, M., Hö,ft, M., Lawson, D. B., Medjahed, B., & Orady, E. A. (2014). Urban high school students' IT/STEM learning: Findings from a collaborative inquiry- and design-based afterschool program. *Journal of Science Education and Technology, 23*(1), 116–137. http://doi.org/10.1007/s10956-013-9457-5.

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education, 32*(1), 268–291. http://doi.org/10.3102/0091732X07309371.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103–120. http://doi.org/10.1002/j.2168-9830.2005.tb00832.x.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences, 8*(3–4), 391–450. http://doi.org/10.1080/10508406.1999.9672075.

Ertmer, P. A., & Simons, K. D. (2006). Jumping the PBL implementation hurdle: Supporting the efforts of K–12 teachers. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 40–54. http://doi.org/10.7771/1541-5015.1005.

Evensen, D. H., Salisbury-Glennon, J. D., & Glenn, J. (2001). A qualitative study of six medical students in a problem-based curriculum: Toward a situated model of self-regulation. *Journal of Educational Psychology, 93*, 659–676. http://doi.org/10.1037/0022-0663.93.4.659.

Fretz, E. B., Hsin-Kai, Wu, Zhang, BaoHui, Davis, Krajcik, E. A., J, S., & Soloway, E. (2002). An investigation of software scaffolds supporting modeling practices. *Research in Science Education, 32*(4), 567–589. http://doi.org/10.1023/A:1022400817926.

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. *Review of Educational Research, 82*(3), 300–329. http://doi.org/10.3102/0034654312457206.

Gall, M. D., Gall, J. P., & Borg, W. R. (2003). *Educational research: An introduction* (7th edn.). Boston: Pearson.

Gibson, H. L., & Chase, C. (2002). Longitudinal impact of an inquiry-based science program on middle school students' attitudes toward science. *Science Education, 86*(5), 693–705. http://doi.org/10.1002/sce.10039.

Giesbers, B., Rienties, B., Tempelaar, D., & Gijselaers, W. (2013). Investigating the relations between motivation, tool use, participation, and performance in an e-learning course using web-videoconferencing. *Computers in Human Behavior, 29*(1), 285–292. http://doi.org/10.1016/j.chb.2012.09.005.

Gijbels, D., Dochy, F., Van den Bossche, P., & Segers, M. (2005). Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of Educational Research, 75*(1), 27–61. http://doi.org/10.3102/00346543075001027.

Gómez Puente, S., Eijck, M., & Jochems, W. (2013). A sampled literature review of design-based learning approaches: A search for key characteristics. *International Journal of Technology & Design Education, 23*(3), 717–732. http://doi.org/10.1007/s10798-012-9212-x.

Helle, L., Tynjälä, P., & Olkinuora, E. (2006). Project-based learning in post-secondary education—theory, practice and rubber sling shots. *Higher Education, 51*(2), 287–314. http://doi.org/10.1007/s10734-004-6386-5.

Helle, L., Tynjälä, P., Olkinuora, E., & Lonka, K. (2007). 'Ain't nothin' like the real thing'. Motivation and study processes on a work-based project course in information systems design. *British Journal of Educational Psychology, 77*(2), 397–411. http://doi.org/10.1348/000709906X105986.

Hmelo, C. E., Ramakrishnan, S., Day, R. S., Shirey, W. E., Brufsky, A., Johnson, C., Baar, J., & Huang, Q. (2001). Oncology thinking cap: Scaffolded use of a simulation to learn clinical trial design. *Teaching and Learning in Medicine, 13*(3), 183–191. http://doi.org/10.1207/S15328015TLM1303_8.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266. http://doi.org/10.1023/B:EDPR.0000034022.16470.f3.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99–107. http://doi.org/10.1080/00461520701263368.

Hmelo-Silver, C. E., Derry, S., Bitterman, A., & Hatrak, N. (2009). Targeting transfer in a STEL-LAR PBL course for pre-service teachers. *Interdisciplinary Journal of Problem-Based Learning, 3*(2), 24–42. http://doi.org/10.7771/1541-5015.1055.

Hung, W. (2011). Theory to reality: A few issues in implementing problem-based learning. *Educational Technology Research and Development, 59*(4), 529–552. http://doi.org/10.1007/s11423-011-9198-1.

Hung, W., Jonassen, D. H., & Liu, R. (2007). Problem-based learning. In J. M. Spector, M. D. Merrill, J. van Merrienboer, & M. P. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd edn.). New York: Routledge.

Ifenthaler, D., & Seel, N. M. (2013). Model-based reasoning. *Computers & Education, 64*, 131–142. http://doi.org/10.1016/j.compedu.2012.11.014.

Jang, H., Reeve, J., & Deci, E. L. (2010). Engaging students in learning activities: It is not autonomy support or structure but autonomy support and structure. *Journal of Educational Psychology, 102*(3), 588–600. http://doi.org/10.1037/a0019682.

Johnson-Laird, P. N. (2001). Mental models and deduction. *Trends in Cognitive Sciences, 5*(10), 434–442. http://doi.org/10.1016/S1364-6613(00)01751-4.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63–85. http://doi.org/10.1007/BF02300500.

Jonassen, D. H., & Hernandez-Serrano, J. (2002). Case-based reasoning and instructional design: Using stories to support problem solving. *Educational Technology Research and Development, 50*(2), 65–77. http://doi.org/10.1007/BF02504994.

Jonassen, D. H., & Rohrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. *Educational Technology Research and Development, 47*(1), 61–79. http://doi.org/10.1007/BF02299477.

Kalaian, H. A., Mullan, P. B., & Kasim, R. M. (1999). What can studies of problem-based learning tell us? Synthesizing and modeling PBL effects on National Board of Medical Examination performance: Hierarchical linear modeling meta-analytic approach. *Advances in Health Sciences Education: Theory and Practice, 4*(3), 209–221. http://doi.org/10.1023/A:1009871001258.

Karpiak, C. P. (2011). Assessment of problem-based learning in the undergraduate statistics course. *Teaching of Psychology, 38*(4), 251–254. http://doi.org/10.1177/0098628311421322.

Keys, C. W., & Bryan, L. A. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching, 38*(6), 631–645. http://doi.org/10.1002/tea.1023.

Koedinger, K. R., & Aleven, V. (2007). Exploring the assistance dilemma in experiments with cognitive tutors. *Educational Psychology Review, 19*(3), 239–264. http://doi.org/10.1007/s10648-007-9049-0.

Koedinger, K. R., & Corbett, A. (2006). Cognitive tutors: Technology bringing learning sciences to the classroom. In K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 61–78). Cambridge, UK: Cambridge University Press.

Kolodner, J. L. (1993). *Case-based reasoning*. San Mateo, CA, USA: Morgan Kaufmann.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design(tm) into practice. *Journal of the Learning Sciences, 12*(4), 495–547. http://doi.org/10.1207/S15327809JLS1204_2.

Krajcik, J., Blumenfeld, P. C., Marx, R. W., Bass, K. M., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *Journal of the Learning Sciences, 7*, 313–350. http://doi.org/10.1080/10508406.1998.9672057.

Krajcik, J., McNeill, K. L., & Reiser, B. J. (2008). Learning-goals-driven design model: Developing curriculum materials that align with national standards and incorporate project-based pedagogy. *Science Education, 92*(1), 1–32. http://doi.org/10.1002/sce.20240.

Kyza, E., & Edelson, D. C. (2005). Scaffolding middle school students' coordination of theory and practice. *Educational Research and Evaluation: An International Journal on Theory and Practice, 11*(6), 545–560. http://doi.org/10.1080/13803610500254857.

Land, S. M., & Zembal-Saul, C. (2003). Scaffolding reflection and articulation of scientific explanations in a data-rich, project-based learning environment: An investigation of progress portfolio. *Educational Technology Research and Development, 51*(4), 65–84. http://doi.org/10.1007/BF02504544.

Lekalakala-Mokgele, E. (2010). Facilitation in problem-based learning: Experiencing the locus of control. *Nurse Education Today, 30*(7), 638–642. http://doi.org/10.1016/j.nedt.2009.12.017.

Leont'ev, A. N. (1974). The problem of activity in psychology. *Soviet Psychology, 13*(2), 4–33. http://doi.org/10.2753/RPO1061-040513024.

Lesh, R., & Harel, G. (2003). Problem solving, modeling, and local conceptual development. *Mathematical Thinking and Learning, 5*(2–3), 157–189. http://doi.org/10.1080/10986065.2003.9679998.

Linn, M. C. (2000). Designing the knowledge integration environment. *International Journal of Science Education, 22*(8), 781–796. http://doi.org/10.1080/095006900412275.

Lohman, M. C., & Finkelstein, M. (2000). Designing groups in problem-based learning to promote problem-solving skill and self-directedness. *Instructional Science, 28*, 291–307. http://doi.org/10.1023/A:1003927228005.

Loyens, S. M. M., Magda, J., & Rikers, R. M. J. P. (2008). Self-directed learning in problem-based learning and its relationships with self-regulated learning. *Educational Psychology Review, 20*(4), 411–427. http://doi.org/10.1007/s10648-008-9082-7.

Luria, A. R. (1976). *Cognitive development: Its cultural and social foundations*. (Trans: M. Cole, Ed., M. Lopez-Morillas, & L. Solotaroff). Cambridge, MA, USA: Harvard University Press.

Luria, A. R. (1979). *The making of mind: a personal account of Soviet psychology*. In M. Cole & S. Cole (Eds.). Cambridge, MA, USA: Harvard University Press.

Lynch, S. (2001). "Science for all" is not equal to "one size fits all": Linguistic and cultural diversity and science education reform. *Journal of Research in Science Teaching, 38*(5), 622–627. http://doi.org/10.1002/tea.1021.

Marra, R. M., Peterson, K., & Britsch, B. (2008). Collaboration as a means to building capacity: Results and future directions of the National Girls Collaborative Project. *Journal of Women and Minorities in Science and Engineering, 14*(2), 119–140. http://doi.org/10.1615/JWomenMinorScienEng.v14.i2.10.

Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., Fishman, B., Soloway, E., Geier, R., & Tal, R. T. (2004). Inquiry-based science in the middle grades: Assessment of learning in urban systemic reform. *Journal of Research in Science Teaching, 41*(10), 1063–1080. http://doi.org/10.1002/tea.20039.

McCormick Peterman, D. (2012). Implications of constructivist pedagogy in teacher education: A comparison of problem-based learning vs. non-problem-based learning in teacher education programs (Ed.D. Dissertation. Tennessee State University). United States—Tennessee. Retrieved from ProQuest Dissertations & Theses Full Text. (Publication number 3540771).

Mehalik, M. M., Doppelt, Y., & Schuun, C. D. (2008). Middle-school science through design-based learning versus scripted inquiry: Better overall science concept learning and equity gap reduction. *Journal of Engineering Education, 97*(1), 71–85. http://doi.org/10.1002/j.2168-9830.2008.tb00955.x.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474–496. http://doi.org/10.1002/tea.20347.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades k-8*. Washington, DC: National Academies Press. Retrieved from http://www.nap.edu/catalog/11625/taking-science-to-school-learning-and-teaching-science-in-grades.

National Research Council. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: National Academies Press. Retrieved from http://www.nap.edu/catalog/13158/successful-k-12-stem-education-identifying-effective-approaches-in-science.

Niu, L., Behar-Horenstein, L. S., & Garvan, C. W. (2013). Do instructional interventions influence college students' critical thinking skills? A meta-analysis. *Educational Research Review, 9*, 114–128. http://doi.org/10.1016/j.edurev.2012.12.002.

Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and Instruction, 1*(2), 117–175. http://doi.org/10.1207/s1532690xci0102_1.

Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *Journal of the Learning Sciences, 13*(3), 423–451. http://doi.org/10.1207/s15327809jls1303_6.

Pease, M. A., & Kuhn, D. (2011). Experimental analysis of the effective components of problem-based learning. *Science Education, 95*(1), 57–86. http://doi.org/10.1002/sce.20412.

Peng, H., & Fitzgerald, G. E. (2006). Relationships between teacher education students' epistemological beliefs and their learning outcomes in a case-based hypermedia learning environment. *Journal of Technology & Teacher Education, 14*(2), 255–285.

Pourshanazari, A. A., Roohbakhsh, A., Khazaei, M., & Tajadini, H. (2013). Comparing the long-term retention of a physiology course for medical students with the traditional and problem-based learning. *Advances in Health Sciences Education, 18*(1), 91–97. http://doi.org/10.1007/s10459-012-9357-0.

Puntambekar, S., & Hübscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist, 40*, 1–12. http://doi.org/10.1207/s15326985ep4001_1.

Rogat, T. K., Witham, S. A., & Chinn, C. A. (2014). Teachers' autonomy-relevant practices within an inquiry-based science curricular context: Extending the range of academically significant autonomy-supportive practices. *Teacher's College Record, 116*(7), 1–46.

Savery, J. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 9–20. http://doi.org/10.7771/1541-5015.1002.

Saye, J. W., & Brush, T. (2002). Scaffolding critical reasoning about history and social issues in multimedia-supported learning environments. *Educational Technology Research and Development, 50*(3), 77–96. http://doi.org/10.1007/BF02505026.

Schmidt, H. G., Rotgans, J. I., & Yew, E. H. (2011). The process of problem-based learning: What works and why. *Medical Education, 45*(8), 792–806. http://doi.org/10.1111/j.1365-2923.2011.04035.x.

Self, J. (1998). The defining characteristics of intelligent tutoring systems research: ITSs care, precisely. *International Journal of Artificial Intelligence in Education (IJAIED), 10*, 350–364.

Silk, E. M., Schunn, C. D., & Cary, M. S. (2009). The impact of an engineering design curriculum on science reasoning in an urban setting. *Journal of Science Education and Technology, 18*(3), 209–223. http://doi.org/10.1007/s10956-009-9144-8.

Simons, K. D., & Klein, J. D. (2006). The impact of scaffolding and student achievement levels in a problem-based learning environment. *Instructional Science, 35*(1), 41–72. http://doi.org/10.1007/s11251-006-9002-5.

Srinivasan, M., Wilkes, M., Stevenson, F., Nguyen, T., & Slavin, S. (2007). Comparing problem-based learning with case-based learning: Effects of a major curricular shift at two institutions. *Academic Medicine, 82*(1), 74–82. http://doi.org/10.1097/01.ACM.0000249963.93776.aa.

Stefanou, C. R., Perencevich, K. C., DiCintio, M., & Turner, J. C. (2004). Supporting autonomy in the classroom: Ways teachers encourage student decision making and ownership. *Educational Psychologist, 39*(2), 97–110. http://doi.org/10.1207/s15326985ep3902_2.

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. *Interdisciplinary Journal of Problem-Based Learning, 3*(1), 44–58. http://doi.org/10.7771/1541-5015.1046.

Taasoobshirazi, G., Zuiker, S. J., Anderson, K. T., & Hickey, D. T. (2006). Enhancing inquiry, understanding, and achievement in an astronomy multimedia learning environment. *Journal of Science Education and Technology, 15*(5–6), 383–395. http://doi.org/10.1007/s10956-006-9028-0.

Thistlethwaite, J. E., Davies, D., Ekeocha, S., Kidd, J. M., Macdougall, C., Matthews, P., Purkis, J., & Clay, D. (2012). The effectiveness of case-based learning in health professional education. A BEME systematic review: BEME Guide No. 23. *Medical Teacher, 34*(6), e421–e444. http://doi.org/10.3109/0142159X.2012.680939.

Thoman, D. B., Smith, J. L., Brown, E. R., Chase, J., & Lee, J. Y. K. (2013). Beyond performance: A motivational experiences model of stereotype threat. *Educational Psychology Review, 25*(2), 211–243. http://doi.org/10.1007/s10648-013-9219-1.

Turns, J., Cuddihy, E., & Guan, Z. (2010). I thought this was going to be a waste of time: Using portfolio construction to support reflection on project-based experiences. *Interdisciplinary Journal of Problem-Based Learning, 4*(2), 63–93. http://doi.org/10.7771/1541-5015.1125.

VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist, 46*(4), 197–221. http://doi.org/10.1080/00461520.2011.611369.

Vreman-de Olde, C., & de Jong, T. (2006). Scaffolding learners in designing investigation assignments for a computer simulation. *Journal of Computer Assisted Learning, 22*(1), 63–73. http://dx.doi.org/10.1111/j.1365-2729.2006.00160.x.

Walker, A., & Leary, H. (2009). A problem based learning meta analysis: Differences across problem types, implementation types, disciplines, and assessment levels. *Interdisciplinary Journal of Problem-Based Learning, 3*(1), 12–43. http://doi.org/10.7771/1541-5015.1061.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89–100. http://doi.org/10.1111/j.1469-7610.1976.tb00381.x.

Zhang, J., Chen, Q., Sun, Y., & Reid, D. J. (2004). Triple scheme of learning support design for scientific discovery learning based on computer simulation: Experimental research. *Journal of Computer Assisted Learning, 20*(4), 269–282. http://doi.org/10.1111/j.1365-2729.2004.00062.x.

Zhang, B., Liu, X., & Krajcik, J. S. (2006). Expert models and modeling processes associated with a computer-modeling tool. *Science Education, 90*(4), 579–604. http://doi.org/10.1002/sce.20129.