Project-Based Learning
A Literature Review

Working Paper

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Abstract

The concept of project-based learning (PBL) has garnered wide support among a number of K-12 education policy advocates and funders. This working paper builds on and updates a seminal literature review of PBL published in 2000. Focused primarily on articles and studies that have emerged in the 17 years since then, the working paper discusses the principles that underlie PBL, how PBL has been used in K-12 settings, the challenges teachers have confronted in implementing it, how school and district factors influence its adoption, and what is known about its effectiveness in improving students' learning outcomes.

PBL is grounded in cross-cutting "design principles" often related to what is taught, how it is taught, and how students should be evaluated in a PBL classroom. PBL design principles emphasize the importance of the project as the central vehicle of instruction and of students as active participants in the construction of knowledge. There is little consensus among developers of PBL design principles, however, about how PBL fits in with other instructional methods, how long a PBL unit should last, the roles of student choice and collaborative learning, and how learning should be assessed. The lack of a uniform vision complicates efforts to determine whether PBL is being implemented with fidelity and to evaluate its effects.

PBL can be introduced into classrooms in a number of ways: Teachers and schools can make use of externally developed PBL curricula, they can develop their own PBL approaches, or PBL can be part of a whole-school reform effort. Implementing PBL is often challenging. It requires that teachers modify their roles (from directors to facilitators of learning) and that they tolerate not only ambiguity but also more noise and movement in the classroom. Teachers must adopt new classroom management skills and learn how best to support their students in learning, using technology when appropriate. And they must believe that their students are fully capable of learning through this approach. Given these challenges, professional development — both initial training and continuing support — is likely to be essential to the successful implementation of PBL.

The working paper suggests that the evidence for PBL's effectiveness in improving students' outcomes is "promising but not proven." Evaluations of its effectiveness have been hampered by the paucity of valid, reliable, and readily usable measures of the kinds of deeper learning and interpersonal and intrapersonal competencies that PBL aims to promote. Many studies, too, have used evaluation designs that leave open the possibility that factors other than PBL were responsible for the outcomes that were found. This said, some studies have found positive effects associated with the use of PBL curricula in science and social studies classes. Evidence for its effectiveness in math and literacy classes is more limited. In particular, it has been noted that math teachers have found it difficult to integrate PBL into their instruction.

Some studies in schools that follow PBL approaches have pointed to positive effects on students' engagement, motivation, and beliefs in their own efficacy, although the specific PBL model and the intensity of its use have varied across these schools.

The working paper concludes with recommendations for advancing research and knowledge about PBL.

Contents

Appendix

List of Exhibits

Table

Introduction

As policymakers, philanthropists, and practitioners consider bringing project-based learning (PBL) to scale in K-12 educational settings, it is essential that they understand what PBL means, how it is implemented, and when, why, and for whom existing PBL models and programs have been effective. The goal of this literature review is to synthesize the PBL research that attempts to address these issues.

In 2000, the Autodesk Foundation commissioned John Thomas (2000) to conduct a literature review of PBL approaches in K-12 settings as well as of research on PBL's implementation and effectiveness. Thomas's widely cited review summarized a number of studies suggesting a positive relationship between PBL approaches and the quantity and quality of student learning. His review of the implementation literature also identified some common challenges that teachers face when implementing PBL.

In the 17 years since Thomas's review, the research literature on the defining features of PBL, the implementation of PBL, and the effectiveness of existing PBL approaches has significantly expanded. In the current review, MDRC describes how PBL has been defined in the research literature and enacted in K-12 settings, assesses the PBL implementation and effectiveness research published since Thomas's (2000) comprehensive review, and recommends priorities for advancing the PBL research literature further. The MDRC review is organized into six sections:

Section I, Background provides a brief overview of the history of PBL and summarizes the review criteria.

Section II, Core PBL Design Principles and Implications for the Field synthesizes the PBL design principles presented in the research literature, noting areas of consensus and areas of debate regarding the defining elements of a PBL instructional approach.

Section III, A Scan of PBL Approaches in K-12 Educational Settings uses descriptions of PBL practices to illustrate the ways in which PBL can enter K-12 educational settings, making clear when these approaches align with the design principles that have been espoused in the research literature and/or are supported by evaluation research.

Section IV, PBL Implementation Research synthesizes the published research on how PBL influences teachers' beliefs and practices, highlighting the implementation challenges found in the literature and researchers' recommendations for overcoming those challenges.

Section V, PBL and Student Outcomes provides an overview of quantitative studies on the effect of PBL on students' cognitive and intra- and interpersonal competencies, as well as the effectiveness of PBL for particular student subgroups.

Section VI, Key Findings and Recommendations for Future Research summarizes key points from the preceding sections and recommends next steps for future research.

Section I: Background

PBL is rooted in the progressive education movement, which advocated for more student-centered and experiential approaches to education that support "deeper learning"[1] through active exploration of real-world problems and challenges (Pellegrino and Hilton, 2012; Peterson, 2012). Inspired by the philosophies of John Dewey, William Heard Kilpatrick developed the "project method," which is cited as the first formalization of a PBL model (Peterson, 2012).[2] For Kilpatrick, the key to the "project method" lay in its being "an activity undertaken by students that really interested them" (Ravitch, 2000, p. 179). Kilpatrick's ideas were disseminated widely among teachers and administrators during the progressive education movement but have been significantly revised since.

Notably, PBL and other student-centered and inquiry-based approaches have historically encountered resistance and criticism by those who emphasize the importance of students' developing specific content knowledge in traditional subject areas (Kirschner, Sweller, and Clark, 2006; Loveless, 2013; Peterson, 2012; Ravitch, 2000). However, PBL and other instructional approaches that emphasize deeper learning and the development of skills needed for success in college, career, and civic life have become increasingly popular (Huberman, Bitter, Anthony, and O'Day, 2014; Scardamalia, Bransford, Kozma, and Quellmalz, 2012).[3]

There are a number of reasons for the appeal of PBL and other deeper learning strategies among education reform advocates and practitioners, particularly in the last decade. First, despite decades of reform, poor postsecondary outcomes for high school graduates persist, particularly for low-income students (Bailey and Dynarski, 2011). Large numbers of students who graduate from high school and enroll in college fail to pass the mathematics and English/language arts placement tests, requiring them to enroll in remedial classes before being deemed "college- ready." It has been estimated that around 60 percent of community college students enroll in remedial courses (Bailey, Jeong, and Cho, 2010). This trend has contributed to a low completion rate in postsecondary education for academically underprepared and low-income students. Fewer than half of the students who begin public two-year colleges earn a credential or transfer to a four- year institution within six years of their initial enrollment

[1]In this review, "deeper learning" is defined as the process through which students develop 21st century competencies. This definition of "deeper learning" is consistent with the National Research Council's (NRC) (Pellegrino and Hilton, 2012) definition. The 21st century competencies refer to "transferable knowledge" and the skills to know "how, why and when to apply this knowledge" (Pellegrino and Hilton, 2012, p. 6). The NRC organized 21st century competencies into three domains: cognitive, interpersonal, and intrapersonal. More detail on the NRC's definition of deeper learning and 21st century learning competencies can be found in the outcomes section and Appendix B.

[2]Historians have found evidence that the concept of "learning through projects" was developed in the 17th and 18th centuries (Knoll, 1997).

[3]Scardamalia and colleagues (2012) reviewed the literature on "knowledge-creating organizations" in order to identify the types and levels of "21st century skills" that students will need in order to participate in such organizations. In their literature review, they found that employers feel students are lacking in multiple 21st century skills, underscoring the importance of deeper learning in K-12 settings.

(Radford, Berkner, Wheeless, and Sheperd, 2010). PBL is theorized to be an approach that could address these problems by enhancing students' motivation, conceptual knowledge, and problem-solving skills (Blumenfeld et al., 1991; Darling-Hammond, 2008a; Thomas, 2000).

Recent shifts in the education reform movement may also be contributing to the popularity of PBL. Education reformers and policymakers increasingly support a more expansive and holistic vision for public education that aligns with the deeper learning goals of PBL. For example, the emphasis of both the Common Core State Standards and the Next Generation Science Standards on students' developing conceptual knowledge and deeper learning skills aligns well with the goals of PBL. Additionally, advocates of and researchers in PBL have long argued that technology can support successful PBL implementation and enhance its effectiveness (Blumenfeld et al., 1991; ChanLin, 2008; Krajcik and Shin, 2014; Ravitz and Blazevski, 2014); recent innovations in educational technology could enhance the implementation and effectiveness of PBL and may contribute to its appeal.

Review Criteria

This review unfolded in two phases. The first phase was commissioned by Lucas Education Research (LER) of the George Lucas Educational Foundation to inform LER's long-term goal of identifying, assessing, and scaling up promising approaches to PBL while building knowledge of and evidence for the efficacy of these approaches. During that phase, MDRC consulted with LER to identify key topics of interest and an initial list of sources. The identified topics included a synthesis of PBL design principles, a scan of PBL programs in K-12 educational settings, a review of the research on the implementation of PBL in K-12 settings, and a review of the research on the effectiveness of PBL. Since Thomas's (2000) literature review was comprehensive and widely cited in the PBL literature, MDRC's work during the first phase focused primarily on studies published between 2000 and early 2015. The initial review was published in May 2016.

In the second phase, the review was updated to include studies published between 2015 and 2017. The literature reviewed for this update is narrower in scope. The focus of the update is on studies that shed new light on implementation issues and that bring new evidence to bear on PBL's effects on student outcomes. The studies of PBL's effectiveness had to include a comparison or control group of students who were taught the subject matter using other instructional modalities. In both phases, the review primarily focused on studies of PBL but not the many "close cousins" of PBL, such as problem-based and inquiry-based learning.[4] MDRC prioritized studies in peer-reviewed journals and published books but also searched for articles and reports from government agencies, research firms, and educational nonprofits.

[4]As discussed in footnote 5, some see problem-based learning as synonymous with PBL. Notably, others contend that problem-based learning units are often shorter than PBL units. We included studies of problem-based learning in our review of the implementation and effectiveness research when studies investigated a problem-based learning intervention that implicitly or explicitly aligned with the PBL design principles reviewed for this paper.

Section II: Core PBL Design Principles and Implications for the Field

In his review of the literature, Thomas (2000) noted that no universally accepted set of practices constituted PBL, nor was there an agreed-upon distinction between PBL and other student-centered, inquiry-based approaches such as inquiry-based learning, problem-based learning, place-based learning, and service learning.[5] In an attempt to clarify what PBL is (and is not), some PBL researchers and practitioners offer PBL "design principles" that describe the essential components of a PBL approach.[6] This section presents the design principles suggested by Thomas (2000) and other principles developed since the publication of his review. A complete list of PBL design principles reviewed for this paper (Darling-Hammond et al., 2008; Grant, 2002; Krajcik and Shin, 2014; Larmer and Mergendoller, 2015a;[7] Parker et al., 2011, 2013;[8] Ravitz, 2010; Thomas, 2000) can be found in Appendix A. The design principles chosen for this review were selected because they are frequently found in the literature and/or because they help illustrate the diversity of PBL design principles cited in the literature.[9] In keeping with the review criteria, only design principles published after 2000 are included here. It is important to note, however, that work published before 2000, as described in Thomas's (2000) review, helped to lay the foundation for much of the theory and research described in this manuscript.

[5]There is some debate in the literature about the distinction between project- and problem-based learning. PBL scholars distinguish between the two (Ertmer and Simons, 2006) and acknowledge that the two concepts have different histories, but also argue that problem-based learning is a type of project-based learning (Larmer, 2014). Similarly, Thomas (2000) noted that although problem-based learning typically includes more "tutorial" components in order to promote deductive reasoning, the essential components of problem-based learning align with his five PBL criteria. Others have argued that it is important to clarify the differences between the two concepts since some approaches to project-based learning, unlike problem-based learning, require that teachers specify the final product and provide guidance on the students' approach to creating the product (Savery, 2006).

[6]The concept of "design principles" differs from a definition of PBL because design principles are specific guidelines intended to help people know when they are observing or doing PBL. MDRC is using the language of PBL "design principles," but these are sometimes alternatively referred to as PBL "principle components," PBL "criteria," "essential elements" of PBL, an "exposition" of the PBL model, or a PBL "approach" being evaluated by a researcher. MDRC refers to all of these concepts as PBL "design principles" throughout this paper.

[7]As noted in the introduction, MDRC has focused on published papers in peer-reviewed journals and reports from government agencies, research firms, or educational nonprofits. However, MDRC has included the design principles cited on the Buck Institute for Education's website because the principles were adapted from a book on PBL instruction (Larmer, Mergendoller, and Boss, 2015).

[8]The design principles developed by Parker and colleagues (2011, 2013) for their approach to PBL in Advanced Placement U.S. Government and Politics classrooms contained two additional principles not reviewed in this section. This is because the additional principles were related specifically to the design-based research project conducted by the researchers and were not necessarily deemed as critical to a PBL approach. These two principles are listed in Appendix A.

[9]Barron et al. (1998) developed an influential list of design principles that is not included in this review because Barron co-authored a more recent work with Darling-Hammond and colleagues (2008) in which design principles for supporting inquiry-based approaches are listed.

Although the PBL design principles reviewed are intended to clarify the meaning of PBL and help teachers identify the difference between project-based *learning* and simply "doing projects" (Thomas, 2000, p. 2), a review of this literature reveals a continuing lack of consensus in the field on what must be present in a classroom for it to be considered a PBL classroom. While there are some benefits to the dynamic and adaptable nature of the PBL concept, the lack of clear and defining features presents drawbacks for the research and practitioner communities. The following paragraphs provide a summary of PBL design principles, with special attention paid to the areas of curriculum, instruction, and assessment. This section concludes with a discussion of the positive and negative implications of a lack of consensus in the field on what it means to do PBL.

Curriculum Design Principles: What Is Taught in a PBL Approach?

The PBL approach can theoretically be implemented in any subject area. As a result, PBL design principles do not communicate specific disciplinary concepts and practices. However, some PBL scholars set guidelines for the types of questions and topics that a student should encounter, as well as the relationship between the PBL approach and other curriculum and pedagogy featured in the course (Darling-Hammond et al., 2008; Krajcik and Shin, 2014; Larmer and Mergendoller, 2015a; Parker et al., 2011, 2013; Thomas, 2000):

- **Driving Questions to Motivate Learning:** Larmer and Mergendoller (2015a), Krajcik and Shin (2014), Parker et al. (2011, 2013), and Thomas (2000) have all emphasized that the PBL unit/curriculum should be motivated by a driving question. Driving questions are at the core of the project-based science design principles[10] (Krajcik and Shin, 2014). Krajcik and Mamlok-Naaman (2006) explained: "a driving question is a well-designed question that students and teachers elaborate, explore, and answer throughout a project" (p. 3). Krajcik and colleagues provided the following five criteria for high-quality driving questions: 1) feasible, 2) worthwhile, 3) contextualized, 4) meaningful, and 5) ethical (Krajcik and Mamlok-Naaman, 2006; Krajcik and Shin, 2014). Some driving questions from project-based middle school science curricula are: "*How do machines help me build big things?*" (p. 5) and *"Why do I need to wear a helmet when I ride my bike?"* (p. 6) (Krajcik and Mamlok-Naaman, 2006).

Krajcik and Shin (2014) and Parker et al. (2011, 2013) described the influence of the driving questions on the design of a unit/curriculum. Krajcik and Shin noted that in a project-based science curriculum, driving questions provide "continuity and coherence to the full range

[10]Blumenfeld and colleagues (1991) laid the groundwork for the project-based science design principles; these have been further developed over the years by teams consisting of Krajcik and colleagues (Krajcik and Blumenfeld, 2006; Krajcik and Shin, 2014; Krajcik, Blumenfeld, Marx, and Soloway, 1994).

of project activities" (p. 281). Project-based science teachers continually revisit the driving question as students learn new material and engage in new activities. Parker and colleagues also emphasized the importance of students continually revisiting the driving question (referred to as a "master question" in their curriculum) for the PBL course and individual PBL units. They explained that "looping" back to driving or "master" questions is critical to achieving the deeper learning goals of the courses. For example, in their PBL curriculum for an Advanced Placement U.S. Government and Politics course, Parker et al. (2011) indicated that the project cycles are united by a "master question" of "what is the proper role of government in a democracy?" (p. 539). As students move through the course, they continually revisit this question and "try again" to answer it, reflecting on what they are learning in each new project cycle.

- **Target Significant Learning Goals:** Some PBL design principles address the issue of the content of a PBL curriculum (Darling-Hammond et al., 2008; Krajcik and Shin, 2014; Larmer and Mergendoller, 2015a; Parker et al., 2013; Thomas, 2000). In their description of "Gold Standard PBL" on the Buck Institute for Education (BIE) website, Larmer and Mergendoller (2015a) stated that a well-designed PBL approach should teach "students the important content standards, concepts, and in-depth understandings that are fundamental to school subject areas and academic disciplines." They also emphasized the importance of PBL focusing on "success skills" such as critical thinking, self-regulation, and collaboration. Darling-Hammond and colleagues (2008) noted that the central problem or project of PBL and other inquiry-based approaches should be designed to maximize the chances that students will be exposed to "big ideas specified in the learning goal" (p. 214). Other researchers have highlighted the fact that the subject matter or the topic of a PBL approach should be authentic and related to important issues in the real world (Parker et al., 2013; Thomas, 2000). Krajcik and Shin (2014) discussed the importance of designing PBL curricula around learning goals that align with national standards. They explained that learning goals are stated as "learning performances" that bring together the "core ideas" from the discipline with key "disciplinary practices" (p. 283).

- **Use Projects to Promote Learning:** The integral role of the project is clear in all the *project*-based learning design principles cited in this review.[11] Parker and colleagues (2011, 2013) and Thomas (2000) directly addressed the issue of how to position the PBL project within the broader curriculum. Thomas explained that projects should be "central, not peripheral to the curriculum" (p. 3). What clearly distinguishes PBL from other instructional approaches is that projects are not the culmination of learning (as they often are in standard classrooms), but instead are the process through which learning takes place. For example, Parker and colleagues (2013) argued that projects must be the

[11] Design principles for *inquiry*-based learning are included in this review of *project*-based learning because the authors are explicit about the fact that PBL is a type of inquiry-based learning and they provide extensive discussion of PBL (Darling-Hammond et al., 2008).

"spine of the course" and should be thought of as the "main course, not dessert" (p. 1432).

- **Dedicate Sufficient Time to PBL:** While the centrality of a project approach within a single PBL unit is clear, the design principles are generally vague about the time spent on PBL versus other instructional strategies in a semester-long or full-year course. What is the ideal balance between PBL and other types of instruction within a course? Could a one- or two-week PBL unit within a traditionally taught course be considered PBL? How long does a PBL unit need to last for it to be considered PBL? The design principles offered by Parker and colleagues (2011, 2013) and Thomas (2000) require that a PBL approach guide the curriculum and instruction of an entire course and not just appear in a single, time-limited unit. With one exception (Grant, 2002), all other design principles reviewed here are related to students conducting in-depth or extended investigations, which clearly require a good deal of time. Ravitz (2010) specified that PBL instruction should "occur over an extended period" (p. 293). Most PBL advocates would likely agree that a relatively short PBL unit as part of a traditionally taught, teacher-directed course is not truly PBL. However, more specificity regarding the time dedicated to a PBL unit and the relationship between PBL and other pedagogical strategies within a course would be useful.

PBL Instructional Approaches: How Do Students Develop New Skills and Knowledge in a PBL Classroom?

Since PBL requires significant shifts from traditional modes of instruction, it is not surprising that the sets of design principles addressed in the literature discuss the issue of *how* students develop new skills and knowledge. It is important to note, however, that the PBL models reviewed here do not offer a uniform vision of how new learning takes place in the PBL classroom environment.

- **Promote Construction of Knowledge:** PBL has its roots in constructivist theories of learning (Pellegrino and Hilton, 2012; Ravitz, 2010). As a result, it is not surprising that these sets of design principles discuss the concept of PBL units involving students in the construction of knowledge, in-depth inquiry, and/or the use of problem-solving and critical thinking skills. Thomas (2000) explicitly stated that a PBL approach must involve students in the "construction of knowledge" (p. 3). Darling-Hammond and colleagues (2008) explained that projects should have "multiple solutions and methods for reaching solutions and should lead students to confront and resolve conflicting ideas" (p. 214). They also argued that students should be encouraged to be "authors and producers of knowledge" (p. 216). For Krajcik and Shin (2014), the process of building scientific artifacts is one of the ways in which students construct their own knowledge. The use of artifacts is described further in the section below.

- **Cultivate Student Engagement:** Grant (2002) and Parker et al. (2011, 2013) discussed the idea that teachers must begin a PBL approach by cultivating students' "need to know" (Larmer and Mergendoller, 2015b).[12] Design principles highlight a number of strategies that teachers can use to cultivate students' engagement from the start of a project. Krajcik and Shin (2014) noted that the driving question of a PBL approach supports students' engagement in project activities. In Parker and colleagues' (2013) PBL units, students take on roles in the project, for example, a congressperson who needs to move his or her legislative agenda forward, before the teacher initiates the "telling." This "telling" refers to the delivery of the background knowledge necessary for students to engage in the work and fulfill their project roles. Parker and colleagues described why fostering a "need to know," by defining a student's role in the project *before* the delivery of pertinent information or content, is essential for student learning:

  > The purpose of this sequencing is to create a readiness (ideally, an eagerness) for telling so that the information students gain from it, whether through textbook reading or listening to a lecture, is needed for making progress on the project and constructing a suitable understanding. (p. 1433)

Parker et al. (2013) noted that this emphasis on creating a "need to know" through project initiation at the *start* of the learning process is a reversal from the sequencing of traditional instruction.

- **Use Scaffolds to Guide Student Learning:** A learning scaffold can be thought of as any method or resource that helps a learner to "accomplish more difficult tasks than they otherwise are capable of completing on their own" (Singer, Marx, Krajcik, and Chambers, 2000, p. 170). Teachers, peers, learning materials, and technology can all serve as scaffolds. The use of scaffolds to support student learning is an approach that has grown in popularity with the spread of project-based and design-based learning environments (Puntambekar and Hubscher, 2005). Darling-Hammond et al. (2008), Grant (2002), and Krajcik and Shin (2014) have all mentioned scaffolding as an essential component of PBL. Grant (2002) explained that scaffolds could include "student-teacher interactions, practice worksheets, peer counseling,

[12]Cultivating a "need to know" was a design principle for the BIE until 2015 when the Institute intentionally removed "need to know" from its design principles list. While the BIE acknowledged that this component is "one of the most powerful arguments for PBL," it also believes that "this term belongs in a 'Why PBL?' argument, not as a thing teachers design in a project the way they would, say, an authentic product or opportunities for student voice and choice" (Larmer and Mergendoller, 2015b, p.3). Clearly, the cultivation of engagement is critical to PBL. However, whether to consider student engagement as a design principle or the result of other design principles like student choice, authenticity, and sustained inquiry is a topic of debate.

guiding questions, job aides, project templates, etc." (p. 2). Krajcik and Shin (2014) specified that scaffolds should include learning technologies. They explained: "While engaged in the practices of science, students are *scaffolded with learning technologies* that help them participate in activities normally beyond their ability" (p. 276).

A key element of scaffolding is that the scaffold needs to be tailored to a student's current level of understanding (not too much assistance and not too little). To tailor a scaffold to a student's skill level or content knowledge, a teacher needs to engage in ongoing assessment of the student (Puntambekar and Hubscher, 2005). Another critical element of scaffolding is that it should be faded over time as students learn to apply their new knowledge or skills on their own (Puntambekar and Hubscher, 2005; Singer et al., 2000). Although some consider providing students with appropriate scaffolds to be an essential element of PBL (Darling-Hammond et al., 2008; Grant, 2002; Krajcik and Shin, 2014), PBL design principles could use greater specificity in the guidance they provide regarding how scaffolds should be determined and faded over time.[13]

- **Encourage Student Choice:** Darling-Hammond et al. (2008), Larmer and Mergendoller (2015a), Ravitz (2010), and Thomas (2000) all noted the importance of student choice, autonomy, and authority. For example, Ravitz argued that a PBL approach "is student self-directed to some extent" (p. 293). Larmer and Mergendoller noted that students can provide input on their team roles, tasks, questions, resources, and final products, with advanced students given more control. Although encouraging student choice and supporting student autonomy in the classroom certainly align with PBL's emphasis on student-directed inquiry, design principles, with some exceptions, are not explicit about what choice looks like in a PBL environment. Krajcik and Shin (2014) discussed the parameters their project-based science approach sets around student choice. They noted that while some PBL methods allow students to design their own driving questions, their project-based science approach involves teachers and curriculum developers in designing the driving question as well as students having the freedom to "explore solutions to their own related questions" throughout the unit. The PBL implementation and outcomes research does not pay significant attention to the issue of student choice. Notably, however, there is a growing interest in the promise and limitations of student choice in the broader education research literature (Katz and Assor, 2007; Patall, Cooper, and Robinson, 2008).

- **Support Collaborative Learning:** Grant (2002) and Krajcik and Shin (2014) saw collaborative work as an essential element of PBL. Krajcik and Shin ex-

[13]McNeill and colleagues (2006) did address this issue directly in their research on Investigating and Questioning our World through Science and Technology (IQWST) by specifying how the scaffold should be faded. The study involved 331 seventh-grade students and six teachers from public schools and one independent school in the Midwest (McNeill, Lizotte, Krajcik, and Marx, 2006). More detail on this study is provided in the implementation section of this review.

plained that the collaborative activities of their project-based science approach "[mirror] the complex social situation of expert problem solving" (p. 276). Essentially, collaboration is a feature of all project stages. Although Darling-Hammond and colleagues (2008) did not list collaborative learning as a design principle for inquiry-based approaches like PBL, the lead author did note that opportunities for collaboration do support students' capacity to "engage in meaningful learning that will allow them to manage the fast-changing, knowledge-based society of the twenty-first century" (Darling-Hammond, 2008b, p. 196). Like the issue of student voice and choice, the issue of collaborative learning in a PBL classroom is understudied in the PBL literature. Design principles do not consistently make clear whether and how collaborative learning might look different in a PBL classroom than in a more traditional setting.

Assessment Design Principles: How Do Students Demonstrate Learning in a PBL Setting?

Assessment is a critical concern for PBL educators given the unique nature of the academic content and learning process in the PBL context. Often, assessments do not measure the array of cognitive and noncognitive (intra- and interpersonal) outcomes that deeper learning approaches intend to produce (National Research Council, 2012).[14] The standardized achievement tests developed to measure learning under No Child Left Behind are widely viewed as inadequate for measuring the kind of learning and "higher-order skills" that PBL is designed to promote (Conley and Darling-Hammond, 2013). However, it is increasingly recognized that assessment plays a critical role in student learning when it is used to promote student reflection and inform instruction. Thus, educators are interested in assessments both *for* learning and *of* learning. The design principles espoused by Darling-Hammond et al. (2008), Grant (2002), Krajcik and Shin (2014), and Ravitz (2010) all address issues of assessment but set somewhat different guidelines in this regard.

- **Create a Product That Answers the Driving Question:** Krajcik and Shin (2014) are the only authors who specified the type of assessment product that students must create. They indicated that the assessment must involve the creation of a tangible product that addresses the driving question of the unit or curriculum and offers a physical representation of student learning (an artifact). In project-based science, tangible products can include physical models, games, plays, and computer programs:

[14]The Program for International Student Assessment (PISA) and new Common Core assessments like the Smarter Balanced Assessment System do accomplish more than previous standardized exams in measuring cognitive outcomes like problem-solving and critical thinking skills.

- **Provide Opportunities for Student Reflection and Teacher Feedback:** Darling-Hammond et al. (2008), Grant (2002), Larmer and Mergendoller (2015a), and Krajcik and Shin (2014) all noted the importance of students having time for self-assessment, reflection, and feedback. For example, Darling-Hammond and colleagues said that time should be provided for "students to reflect deeply on the work they are doing and how it relates to larger concepts specified in the learning goal" (p. 216). Larmer and Mergendoller noted that "throughout a project, students — and the teacher — should reflect on what they're learning, how they're learning, and why they're learning."

- **Present Products to Authentic Public Audiences:** Darling-Hammond et al. (2008), Larmer and Mergendoller (2015a), and Ravitz (2010) all emphasized the importance of students presenting their work to public audiences. Darling-Hammond and colleagues noted that this public audience "can be highly motivating for students" (p. 215). Krajcik and Shin (2014) echoed this sentiment in their principle of tangible artifacts. When artifacts are to be made public, they can motivate students and present opportunities for feedback.

The public audience principle is also related to Parker and colleagues' (2013) and Thomas's (2000) emphasis on project work as authentic and connected to the real world. Thomas explained his authenticity or "realism" criterion: "*Projects are realistic, not school-like*. Projects embody characteristics that give them a feeling of authenticity to students" (p. 4, italics in original). He noted that creating a product for a relevant audience is one way in which a PBL approach can meet his authenticity criterion.

Discussion: Implications of the Design Principles Debate

Thomas (2000) noted that the research literature did not offer a uniform vision of what constitutes PBL. The present review of Thomas's PBL design principles and those developed in recent years demonstrates that there is still debate in the field about what PBL means. The PBL design principles reviewed in this paper implicitly or explicitly state that the project is the central vehicle of instruction in a PBL classroom. However, there is still no agreement on whether PBL design principles should address the content of learning. All PBL design principles reviewed in this paper are concerned with the ways in which PBL instructional practices differ from traditional modes of instruction. In one way or another, all emphasize the importance of students being active participants in the construction of knowledge. However, there remains a lack of agreement or different levels of emphasis on key issues, including the use of scaffolds to support acquisition of higher-level content knowledge and skills, the use of group work in a PBL unit, the extent of choice over what and how students learn, and how learning is assessed in a PBL approach. Although design principles do not necessarily contradict one another, some are silent or lack specificity on issues like assessment, scaffolding, and student collaboration, whereas others place a strong emphasis on those components as essential features of PBL.

Alternatively, some might argue that PBL can thrive as a dynamic concept without a concrete definition. Relatedly, some argue that when instructional reforms become overly prescriptive, they can hold back innovation (Darling-Hammond, 1993) and unintentionally elicit teacher resistance (Achinstein and Ogawa, 2006). Continued debate among PBL researchers and practitioners on the essential elements of PBL could lead to fruitful new theories and applications. It is also important for design principles to be flexible enough so that teachers can adapt a PBL approach to their local context (Anderson and Shattuck, 2012).

However, the lack of consensus on what PBL entails presents clear drawbacks for practitioners and researchers. As noted by Thomas (2000) and confirmed in more recent qualitative research (Tamim and Grant, 2013), it can be difficult for practitioners to know if they are doing an acceptable version of PBL. Without a clear vision for what a PBL approach should look like, it is difficult for teachers to assess the quality of their implementation and know how to improve their approach. Additionally, education policymakers are increasingly demanding evidence to guide decisions about whether to adopt an educational reform or instructional innovation. For the research literature on PBL to create a useful evidentiary base, the PBL research community needs to study PBL models that have at least some clear common thread. Since the model of PBL often drastically differs from study to study, it is very difficult to make research-based generalizations about PBL's effectiveness (Ravitz, 2010; Thomas, 2000).

The next section of this review provides an overview of how PBL is enacted in K-12 educational settings. As will be made clear in this section, some but not all of these PBL approaches explicitly align with the design principles reviewed here. Similarly, the review of the implementation and effectiveness studies demonstrates that studies purporting to investigate PBL are often examining very different instructional approaches. The concluding section of this review offers considerations that the PBL research community might take into account when developing PBL design principles that can be rigorously evaluated and implemented across a variety of contexts.

Section III: A Scan of PBL Approaches in K-12 Educational Settings

K-12 students can be exposed to PBL in a number of ways: Teachers or schools can access externally developed PBL curricula, teachers can develop their own PBL approach, or PBL can be a part of a whole-school reform effort or a critical piece of a school's structure.[15] In recent years, a number of professional development organizations have been established to help educators, schools, and school systems implement or strengthen their use of PBL. This section of the literature review scans approaches or programs that support PBL implementation in K-12 settings in an effort to convey the range and diversity of programs available. Accordingly, this scan does not provide an exhaustive list of such programs, but rather highlights examples that illustrate this diversity. MDRC identified these examples by consulting the research literature, Lucas Education Research, and experts in the PBL community.

Three basic approaches to using PBL in the classroom are presented in Table 1 and described in more detail in the following paragraphs. In presenting this scan, special attention has been paid to whether and how the PBL approach exemplifies the PBL design principles described in Section II of this review. After describing PBL approaches enacted in K-12 settings, we discuss the implications that the scan has for PBL research and practitioner communities.

"Curricularizing" PBL: Externally Developed PBL Curricula

Providing teachers with externally developed PBL curricula or curricular units is one of the ways that PBL is incorporated into classroom practice. The paragraphs below highlight two science curricula: Investigating and Questioning our World through Science and Technology (IQWST) (Krajcik, Reiser, Sutherland, and Fortus, 2012) and Project-Based Inquiry Science (PBIS; Kolodner, Krajcik, Edelson, Reiser, and Starr, 2009-2013), and one social studies curriculum, Knowledge In Action (KIA) (Boss et al., 2011; Parker et al., 2011, 2013). An important facet of all three curricula is that the developers considered professional development and support for teachers to be critical. These curricula are also notable because they apply the PBL design principles reviewed in Section II. The IQWST and PBIS science curricula were inspired by the project-based science design principles of Blumenfeld and colleagues (1991) and Krajcik and Shin (2014), which emphasize driving questions, student-directed inquiry and collaboration, the use of technology to scaffold student learning, and the creation of authentic artifacts to assess student learning. The KIA social studies curriculum is rooted in the design principles of Parker and colleagues (2011, 2013), which, like the PBIS design principles, emphasize the importance of driving questions and student-directed inquiry projects. The design principles of all three curricula also highlight the importance of engaging students by fostering a

[15]It is important to note that students may also experience PBL through out-of-school time programming. A review of these models is beyond the scope of this review but remains an important area for future research on the implementation and effectiveness of PBL.

"need to know." This "need to know" is achieved by helping students make connections between activities within projects and between different projects by continually "looping back" to driving questions.

Table 1. A Scan of PBL Approaches in K-12 Educational Settings	
Ways in Which PBL Enters the Classroom	**Illustrative Examples**
Externally Developed PBL Curricula	● Investigating and Questioning our World through Science and Technology (IQWST) ● Knowledge In Action (KIA) ● Project-Based Inquiry Science (PBIS)
Teacher-Initiated PBL	Examples of organizations or initiatives that support teacher-initiated PBL: ● Edutopia ● The Buck Institute for Education ● PBLU ● Mathalicious ● PBL Institute ● Engage! Learning
PBL as Part of a Whole-School Approach	● Expeditionary Learning Schools ● New Tech Network ● High Tech High ● Envision Schools

Investigating and Questioning our World through Science and Technology (IQWST) is a middle school science curriculum that was developed through an interdisciplinary collaboration and funded by the National Science Foundation (NSF). The collaborative is comprised of curriculum researchers at the University of Michigan, Northwestern University, Michigan State University, Columbia University, and the University of Illinois. IQWST and the curriculum developed for the Center for Learning Technologies and Urban Schools (LeTUS) are both strongly influenced by the project-based science design principles that Krajcik and Shin (2014) described. IQWST aims to bridge the classroom experience and the real world through a series of activities, including debate, data analysis, and presentations. Formative assessments, which allow teachers to review and change instruction, are essential to the IQWST model. Coherence between and within the IQWST curricular units is another distinctive feature of the curriculum.

Curricular coherence refers to the alignment, depth, and sequencing of topics and learning goals within and across curricular units. Shwartz, Weizman, Fortus, Krajcik, and Reiser (2008) described their conceptualization and manifestation of curricular coherence in IQWST: "IQWST can be seen as a series of learning progressions of scientific ideas and practices that are interwoven throughout the entire curriculum" (p. 203). The authors defined a learning progression as: "(a) a model of the target idea appropriate for learners, (b) the starting points based on learners' prior knowledge and experiences, (c) a sequence of successively more sophisticated understandings, and (d) instructional supports that help learners develop the target science concepts and principles or practice" (p. 203).

A number of studies have examined the challenges and lessons learned from the implementation of IQWST units (Berland, 2011; Krajcik and Shin, 2014; Krajcik, McNeill, and Reiser, 2008) and also the influence of the IQWST approach (Fogleman, McNeill, and Krajcik, 2011; Fortus, Sutherland, Krajcik and Reiser, 2015; Shwartz et al., 2008). Because teachers' professional development is central to this approach, Activate Learning (2015) provides professional development to teachers implementing the IQWST curriculum. It allows teachers to experience the curriculum firsthand and teaches them how to adapt the IQWST curriculum to meet the needs of their students. An important feature of the IQWST approach to professional development is that the curriculum materials are "educative" for teachers as well as students (McNeill and Krajcik, 2008). "Educative curriculum materials" intend to equip teachers with the content knowledge and pedagogical knowledge they need to deliver the curriculum as intended and to adapt and adjust instruction as needed (Davis and Krajcik, 2005).

Project-Based Inquiry Science (PBIS) is a middle school science curriculum developed for science classrooms by leading experts in PBL and curriculum design (Janet Kolodner, Joseph Krajcik, Daniel Edelson, Brian Reiser, and Mary Starr) (It's About Time, 2015). The curriculum borrows from the curricula developed for the Center for Learning Technologies and Urban Schools (LeTUS) and Kolodner and colleagues' (2003) design-based research; it also includes new materials designed specifically for the PBIS curriculum. The PBIS curriculum consists of 8- to 10-week units on life, physical, and earth sciences spanning grades 6 through 8. In their study of PBIS, Harris, Penuel, DeBarger, D'Angelo, and Gallagher (2014) described the distinctive features of the curriculum, which align with the project-based science design principles described in Section II (Krajcik and Shin, 2014): PBIS curricular units present challenges in which students investigate phenomena and apply concepts to answer a driving question or to address a design challenge or goal. The driving question or challenge typically targets a core idea in science; the activities within each unit provide students with multiple occasions for investigating as scientists would — through observations, asking questions, designing and carrying out experiments, analyzing data, building and using models, and constructing scientific explanations (Harris et al., 2014). PBIS is sold and distributed by It's About Time, which also supports implementation by offering in-person professional development and educative curriculum materials such as teacher planning guides and demonstration videos. Harris and colleagues conducted a school-level randomized controlled trial that assessed the effects of two of the PBIS units on student achievement in a sample of 42 middle schools in an urban district. The researchers found positive effects on students' integrated science proficiency (core ideas and practices).

Like IQWST and LeTUS, PBIS was inspired by the project-based science design principles (Krajcik and Shin, 2014) reviewed in Section II. The common thread of project-based science design principles that runs through these middle school inquiry-based science curricula demonstrates the importance of connecting concepts, research, and practice.

The Knowledge in Action (KIA) initiative is a partnership between the George Lucas Educational Foundation and the University of Washington. This initiative created and piloted rigorous PBL curricula for use in Advanced Placement (AP) courses (Boss et al., 2011). KIA's approach is guided by the design principles reported by Parker and colleagues (2011, 2013), which are discussed in Section II. Thus far, KIA includes curricula for three AP courses: U.S. Government and Politics, Environmental Science, and Physics. One distinctive feature of the KIA approach is that it includes a PBL-based redesign of a full AP course. This feature is critical to the KIA approach because the model requires quasi-repetitive project cycles that continually loop back to a course's driving question, providing students with the opportunity to "revisit questions, ideas, and problems that arose in previous project cycles" (Boss et al., 2011, p. 15). As discussed in the section below on PBL-related student outcomes, two studies (Parker et al., 2011, 2013) reported promising findings on the relationship between students' participation in KIA's AP U.S. Government and Politics course and student learning outcomes. Another distinctive feature of KIA's curriculum approach is how it partners with teachers to create a project experience that is jointly created and informed by the field. Although other PBL curricula (such as IQWST) acknowledge and provide support for teachers' adaptations of ready-made curricular materials to meet their students' needs more effectively, KIA's approach relies on collaborative partnership, where teachers actively engage with researchers and curriculum developers in the design-based research process course design, implementation, research, and redesign (Parker et al., 2013).

In the broader education reform literature, researchers have raised concerns that there may be unintended consequences to "curricularizing" instructional innovations like PBL by specifying for teachers what and how to teach (Achinstein and Ogawa, 2006; Darling-Hammond, 1993). Any externally developed curriculum runs the risk of being perceived by teachers as overly prescriptive. In an effort to avoid this, the developers of the KIA curriculum (Boss et al., 2011; Parker et al., 2011, 2013) have argued that teacher ownership and adaptation of their curriculum are core components (design principles) of their approach. As will be discussed in the conclusion of this review, more research is needed to understand the most effective means of supporting teachers in the adoption and appropriate adaptation of an externally developed PBL curriculum. Promising strategies may include ensuring robust professional development and support when an externally developed PBL curriculum is introduced (as with PBIS and IQWST) and addressing the issues of teacher adaptation as a design principle (as with KIA).

Teacher-Initiated PBL: Supporting Teachers in Developing Their Own PBL Approach

Most teachers do not have access to an externally developed curriculum. As a result, most teachers likely design and implement PBL on their own. A number of resources are available to support teachers in developing their own PBL curriculum. In this section, we describe: 1) digital resources available to teachers online and 2) organizations that provide professional development services, both digitally and in-person, for teachers, schools, and districts.

Online resources that support teachers who attempt to do PBL on their own include the George Lucas Educational Foundation's Edutopia, Mathalicious, and the Buck Institute for Education's (BIE) PBLU.[16] Online platforms like Edutopia, Mathalicious, and PBLU try to support the spread of PBL by giving more teachers access to ideas and resources for developing PBL curricula on their own. Notably both BIE (Larmer and Mergendoller, 2015a) and Edutopia (Edutopia, 2014) espouse specific design principles or "essential components" that teachers can use to create their own PBL approach.[17]

BIE's approach is grounded in its design elements (Larmer and Mergendoller, 2015a), which are summarized in Section II of this review and listed in Appendix A. These essential components include a challenging problem or question, sustained inquiry, authenticity, student voice and choice, reflection, critique and revision, and public product (Larmer and Mergendoller, 2015a). BIE has created rubrics or checklists tied to its essential components and offers tools to help teachers find resources that are most relevant to their classrooms. These resources help practitioners connect their implementation of PBL to specific design principles. Recently, BIE has made more PBL support available by creating PBLU, which is a free resource that provides teachers and students with project ideas and PBL professional development (PBLU, 2015).

Two other professional development resources that help teachers initiate the use of PBL include the "Project-Based Learning Institute" (PBL Institute) and "Engage! Learning Inc." (Engage!). Both of these resources aim to support teachers' capacity to adapt existing PBL curricula or create their own. Notably, both Engage! and the organizations behind the PBL Institute have developed frameworks or rubrics to make their vision of PBL clear to educators and to support teachers' capacity for assessing their own implementation.[18]

The PBL Institute is a conference for PBL facilitators hosted by the Center of Excellence in Leadership of Learning, Indiana University, Indiana University-Purdue University Indianapolis, and the Metropolitan School District of Wayne Township. This conference is an opportunity for practitioners and administrators to learn PBL by experiencing an authentic PBL

[16]See the following for website links to these online PBL resources — Edutopia: www.edutopia.org/project-based-learning; BIE: www.bie.org; PBLU: www.pblu.org; Mathalicious: www.mathalicious.com.

[17]Although Mathalicious does not clearly lay out specific design principles, they do encourage the use of scaffolds and guiding questions to motivate learning (Mathalicious, 2015).

[18]One of the partners behind the PBL Institute, the Indiana Collaborative for Project-Based Learning, has developed a PBL certification process to recognize teachers and school leaders who are implementing high-quality project-based learning. The certification process is guided by a rubric that espouses many of the same design principles described in the research literature. This rubric serves as a good example of how design principles can be put into practice to drive instructional change.

environment and creating a sample project for their classrooms. The conference also promotes professional development by hosting sessions and workshops on PBL implementation and displaying examples of other instructors' projects. As discussed in the implementation section below, providing teachers with personal experience in a new instructional approach is theorized to be one way of changing teachers' beliefs about teaching and learning and supporting the implementation of instructional innovations (Ertmer, 2005).

Engage! Learning Inc. provides teachers and districts with training, design consulting, and toolkits. One of the services for school teams is the PBL Collaborative Cohort. Similar to the PBL Institute, this service is an effort to train teachers in part through facilitating teacher networks. More than 250 campuses in Texas are implementing various Engage! strategies, including some district-wide adoption efforts to build capacity for PBL. Campuses can be supported by the PBL Collaborative Cohort and, in some cases, provided with more hands-on consulting through customized support known as the Engage! Transformation Model.[19]

The organizations featured in this subsection aim to increase the number of teachers integrating PBL approaches into their classroom practice. Given the number of resources and degree of public accessibility, these organizations may have succeeded in promoting greater awareness and implementation of PBL. However, as Thomas (2000) noted 17 years ago, there continue to be very few systematic investigations of teacher-initiated PBL, even though it is likely the most common way to expose students to a PBL approach. More research is clearly needed to document the quantity and quality of teacher-initiated PBL as well as effective strategies for supporting teachers in their design and implementation of a PBL approach. A first step would be for teachers to be asked in a nationally representative survey whether, how, and why they use PBL in their classrooms. In addition, it is important for organizations interested in spreading PBL practices to articulate the specific vision or design principles of the PBL approach that they support and/or to make clear the different PBL design principles available to practitioners. A clear connection to measurable design principles will help teachers understand the extent to which they are implementing PBL and will enable internal and external researchers to evaluate the effectiveness of those approaches. Finally, it is important that the field learn how best to help teachers overcome some of the challenges in establishing coherence within and across projects while meeting learning goals. Existing research on these challenges, and some strategies for overcoming these challenges, are described in subsequent sections of this review.

PBL as a Whole-School Approach

In some schools, only an individual teacher adopts PBL. In these schools, PBL classrooms are likely to stand out due to the difference between the PBL approach and traditional modes of instruction. In some cases, however, students are exposed to PBL in all of their classes

[19]The Engage! Learning Model is "a model where the teacher leads, designs, and facilitates: asks questions, provides small-group direct instruction, vets resources, provides critique, assesses and evaluates learning" (Engage! Learning Inc., 2016).

because the approach is part of a school's mission. Although there are no data on the number of schools that have adopted PBL as a school-wide instructional approach, the alignment of PBL with the goals of many high-profile education reform strategies (Ravitz, 2010) seems to indicate that the whole-school approach to PBL is being increasingly implemented. Recently, the American Institutes for Research (AIR) conducted a study of schools that participate in the Hewlett Foundation's Deeper Learning Network, which represents 10 school networks (more than 500 schools) that aim to support students' deeper learning. AIR found that PBL was the most commonly reported instructional strategy across the schools participating in the study (Huberman et al., 2014). The following paragraphs describe how PBL is implemented in four of these school networks: Expeditionary Learning Schools (EL), New Tech, High Tech High, and Envision Schools.

EL is a whole-school reform model that operates in more than 160 schools in 33 states, with PBL the cornerstone of EL's learning expeditions. A handbook describing EL's PBL approach explained: "Projects are a primary structure for in-school learning, teaching core skills and content through classroom lessons, discussions, labs, and work sessions, as well as through student research and fieldwork. Projects are used to teach literacy and math skills, critical thinking, collaboration, and problem-solving" (Expeditionary Learning, 2011, p. 21). EL commissioned Mathematica Policy Research to evaluate the impacts on student achievement in five urban middle schools. Overall, Mathematica reported positive impacts on math and reading (Nichols-Barrer and Haimson, 2013). Thomas (2000) also reported on favorable EL evaluations conducted by internal and external evaluators. In addition to being a whole-school approach, EL provides professional development in the implementation of its design principles and core practices to non-EL practitioners (Expeditionary Learning, 2011). While the evidence makes clear that the EL approach is promising, PBL is only one facet of the EL's comprehensive reform model. As a result, existing evidence does not provide a basis to infer that PBL is the driving force behind EL's effectiveness.

The New Tech Network views PBL as the heart of its approach to instruction. New Tech started in Napa, California, and now supports more than 135 schools in both the U.S. and Australia (New Tech Network, 2014). New Tech believes that a PBL environment helps students collaborate and solve problems. A signature PBL instructional tool called "Entry Events" is used in New Tech schools to motivate students to engage in the project. These events also introduce students to the necessary background knowledge and the "Need-to-Know" (NTK) process through which students co-develop concepts that they feel are essential to understanding the project (New Tech Network, 2015).

Like Expeditionary Learning and New Tech, schools in the High Tech High and Envision Schools networks use PBL to work toward their goal of improving college and career readiness. Both organizations also consider dissemination of PBL instructional strategies to be part of their mission. High Tech High operates in San Diego County, running four elementary schools, four middle schools, and five high schools. The design principles of the High Tech model include personalization, adult world connection, common intellectual mission, and teacher as designer. These principles also feature a project-based approach across disciplines and extensive time for teacher planning. In 2005, High Tech High received funds from the California Department of Education to share PBL strategies outside of its charter networks. High Tech High teachers share projects on High Tech High's website to encourage implementation in other settings (High Tech High, 2015a). Envision Schools is another network of schools that uses a project-based approach across the curriculum. Like High Tech High, Envision Education aims to disseminate its PBL practices to a broad audience of teachers. In 2010, it developed a professional development division, Envision Learning Partners, to share best practices used in Envision Schools (Envision Education, 2015).

In each of the reform models described above, PBL is one of multiple principles guiding these models' approaches to school structure, culture, and instruction. One strength of models like High Tech High and the New Tech Network is that they not only list PBL as a core component of their schools but also provide a clear definition of PBL in their schools.[20] This is important for best practices because, unless the design principles of PBL are clearly articulated within a school building, the teachers there could claim to be "doing PBL" when, in fact, they are using different methods. Research and practitioner communities can learn much from PBL's enactment as a whole-school approach. However, in order to apply these schools' lessons to schools outside their networks, it is important to know what PBL means in each school model and how a particular PBL approach interacts with other unique aspects of the culture and structure of individual schools.

Discussion

The PBL approaches described in this section of the review illustrate the many ways in which PBL can enter K-12 educational settings — externally developed PBL curricula adopted or adapted by teachers, teacher-initiated PBL, and PBL adopted as part of a whole-school reform or woven into the school's design. As discussed throughout this section, not all of these approaches are explicitly linked to the PBL design principles espoused in the research literature. As the PBL research community strives to develop a consensus on the defining features of a PBL approach, it will be important to take into account the experiences of PBL practitioners. On that note, organizations seeking to support teacher-initiated PBL practice should clearly define their PBL design principles in a way that clarifies what it means to enact PBL for practitioners.

All of the PBL approaches featured in this review attempt to expand the reach of PBL. For example, Activate Learning supports the implementation of the IQWST curriculum in increasingly more classrooms across the country. Another example is digital PBL resources like PBLU, which attempts to increase educators' awareness of PBL and their capacity to implement

[20]High Tech High adheres to the following design principles, which are all part of their whole-school PBL approach: personalization, adult world connection, common intellectual mission, and teacher as designer (High Tech High, 2015b). At New Tech, PBL is central to the instructional approach. New Tech describes PBL as "learning is contextual, creative, and shared. Students collaborate on meaningful projects that require critical thinking, creativity, and communication in order for them to answer challenging questions or solve complex problems" (New Tech Network, 2015).

it on their own. The whole-school approaches featured in this review are all part of networks that seek to spread their reform model to more places. The next sections of this review synthesize the PBL implementation and effectiveness research conducted since the release of Thomas's (2000) literature review. The concluding section of this review lists recommendations for advancing the PBL research literature in ways that will improve PBL practice.

Section IV: PBL Implementation Research

The effectiveness of innovations in curriculum and instruction like PBL often hinge on the depth and quality of implementation, which can vary significantly within and across schools (Coburn, 2003; Cohen and Ball, 1999). For this reason, the challenges associated with PBL implementation must be addressed if efforts to scale up PBL are to promote positive student outcomes.[21] Thomas's (2000) specific conclusion regarding the sparse literature on PBL implementation was that "PBL is relatively challenging to plan and enact" (p. 34). He recommended that future research consider the implementation challenges of PBL more deeply and in different contexts.[22] PBL requires a major shift in the practices of both teachers and students, because the student-centered and constructivist orientation of a PBL approach challenges the dominant modes of teaching and learning in a classroom.

The preponderance of the implementation literature has focused on teachers. Changing instructional practice often requires teachers to change their pedagogical beliefs as well (Ertmer, 2005; Ertmer and Simons, 2006; Mergendoller and Thomas, 2000; Rogers, Cross, Gresalfi, Trauth-Nare, and Buck, 2011; Thomas, 2000). As a result, the discussion in this section is organized around issues related to changing teachers' beliefs and practice. It also considers how school context can influence a teacher's implementation of PBL. The section ends with a summary of key findings.

Teacher Beliefs

In her review of the literature on how teachers adopt technological innovations, Ertmer (2005) clarified the meaning of teachers' beliefs and why they are critical to consider when understanding how an instructional innovation, like technology or PBL, is implemented. She argued that there is an important distinction between teachers' knowledge and their beliefs.

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[21]Additionally, understanding what an instructional innovation looks like when implemented in classrooms, and how those classrooms differ from comparison classrooms that do not implement the innovation (a concept referred to as "service contrast" in the evaluation literature), is critical to unpacking the reasons behind the instructional innovation's positive or null effects on outcomes. For example, it is possible that an instructional intervention might have positively influenced student outcomes while effects on student outcomes assessed through a rigorous design (such as a randomized controlled trial) were null because many components of the intervention were also being implemented in control classrooms. High-quality implementation research in intervention and comparison classrooms can elucidate these types of issues. MDRC's randomized controlled trial of the Content Literacy Continuum is an example of the ways in which implementation research can explain null impact estimates (Corrin et al., 2012). The implementation research conducted in treatment and control schools has suggested that the nonsignificant findings may have been attributable to low levels of implementation fidelity in some treatment schools and to a lack of service contrast between treatment and control schools.

[22]Thomas (2000) noted that most implementation research has focused on "packaged" science curricula. He recommended that future research pay special attention to teacher-initiated PBL, but the research literature on teacher-initiated PBL continues to be sparse.

Teachers' knowledge relies on factual propositions and understandings, whereas teachers' beliefs are ideologies and suppositions. Teachers can *know* that a particular instructional innovation is related to student learning outcomes, but their successful implementation of that innovation relies on whether they *believe* this proposition to be true. In this way, simply telling teachers about the promise of an instructional innovation like PBL may not significantly change their practice. Adoption of a new instructional strategy is facilitated by a *belief* in the efficacy of that approach.[23] Ertmer's (2005) review suggested that teachers' pedagogical beliefs are strongly influenced by personal experiences, vicarious experience (observing models of other teachers implementing the innovation), and sociocultural influences. Because teacher-directed instruction, assessed through paper-and-pencil tests, has been the dominant mode of instruction for so long, it is likely that many teachers' personal experiences do not support a belief in PBL.

In their review of the research on problem-based learning implementation in K-12 settings, Ertmer and Simons (2006) argued that changing teachers' beliefs about their classroom role from that of director to facilitator is a key implementation hurdle for student-centered pedagogical approaches like problem- and project-based learning. Based on their observations of teachers' attempts to integrate the Learning by Design (LBD) approach into middle school science instruction, Kolodner and colleagues (2003) found that one of the key implementation challenges involved teachers' willingness to change their role in the classroom and alter their conceptions of classroom control. Kolodner et al. found that this was too difficult for some of the teachers who had attempted to implement LBD; these teachers decided to end their participation in the research team's field test during the year or after one year. Grant and Hill (2006) noted that some teachers found implementation of student-centered approaches like PBL to be risky, because, in addition to modifying the teacher's role, they require teachers to tolerate changes to the traditional learning environment (e.g., noise level, student collaboration, and student movement) and feel comfortable with ambiguity and flexibility in classroom management. Given that teachers face accountability pressures, coping with the changes and levels of ambiguity can be difficult (Grant and Hill, 2006).

How do teachers' beliefs influence PBL implementation? Qualitative case studies have demonstrated that teachers' beliefs about education influence whether and how they implement a PBL approach (Rogers et al., 2011; Tamim and Grant, 2013; Toolin, 2004). For example, Rogers and colleagues (2011) investigated how three middle school teachers' beliefs and prior experiences influenced their enactment of a whole-school reform effort that involved the use of PBL in math and science classrooms. They found that these three teachers' orientation toward teaching and learning strongly influenced their feelings about PBL and the extent to which they implemented the reform. The teacher who believed that his job was to support students' development of 21st century learning skills, not simply their achievement on state standardized assessments, was most closely aligned with the goals of the PBL curriculum and had an easier

[23] It is important to note that the relationship between teachers' beliefs and practice is not necessarily causal or one-directional. Although she argued that changing beliefs was critical to changing teachers' practice, Ertmer (2005) acknowledged that a change in pedagogical beliefs *could* follow a change in practice.

time implementing a PBL approach. Toolin's (2004) case study of high school science teachers' instructional strategies demonstrated that teachers who initially resist a PBL approach could change their mind over time, especially if given sufficient resources, support, and training. These qualitative case studies on the relationship between teachers' beliefs and PBL implementation provide useful ground for the development of hypotheses that can be tested empirically. However, readers should be cautious when interpreting these findings, given the very small sample sizes.

In addition to beliefs about the goals of education and a teacher's role in the classroom, teachers' beliefs about their students' potential can also influence PBL implementation. The relationship between teachers' expectations and beliefs about students, teacher practice, and student learning outcomes has long been a topic of debate and inquiry in the broader education research literature (Jussim and Harber, 2005). Since teachers' instructional innovation implementation is influenced by their beliefs about students (Ertmer, 2005), teachers who have low expectations of their students or feel overwhelmed by their students' academic and social needs (low teacher-efficacy) might be reluctant to implement rigorous PBL, because it requires students to develop and apply high-level thinking and social skills.

Two qualitative case studies explored the relationship between teachers' beliefs about students and PBL implementation (Hertzog, 2007; Tal, Krajcik, and Blumenfeld, 2006). Hertzog investigated how two veteran elementary school teachers in a low-income public elementary school implemented the project approach to early childhood education in two first-grade classrooms. She found that full implementation was hindered by the teachers' perception that PBL would be too challenging given student behavior and ability level. Tal and colleagues conducted a study of two teachers who were strong and effective implementers of a project-based science systemic reform (LeTUS) in Detroit, Michigan. Among the two teachers' common characteristics were high expectations of their students, respect for their students' individual needs, and commitment to the PBL reform and their students' success. The authors noted that these attitudes are likely important to the success of PBL implementation in any context, but may be particularly significant in a disadvantaged urban school system. One difference between the teachers featured in Hertzog's and Tal et al.'s analyses was that the teachers in the latter study implemented PBL as part of a district-wide PBL reform effort in science, whereas teachers in the former study implemented the approach on their own. As will be discussed in the concluding section, future research should consider whether and *how* a teacher's implementation of PBL as part of a broader whole-school effort, as opposed to doing so independently, influences the depth and quality of implementation.

Teacher Practice

Although studies have found that teachers who implement PBL or similar student-centered approaches like PBL often reported positive experiences (Finkelstein, Hanson, Huang, Hirschman, and Huang, 2011; Harris et al., 2014; Thomas, 2000), it has also been noted that these approaches pose a number of unique challenges to teachers (Dole, Bloom, and Kowalske, 2016; Ertmer and Simons, 2006; Mergendoller and Thomas, 2000; Thomas, 2000). In fact, Mergendoller and Thomas argued that "teachers in the learner-centered classrooms tend to have a broader set of management responsibilities than do teachers in more traditional classrooms" (p. 34). The following paragraphs present the research literature that discusses implementation challenges and promising approaches related to designing a project-based curriculum, managing classroom interactions, facilitating student inquiry, and assessing student learning.

Planning for project-based learning. Based on his review of the PBL implementation research, Thomas (2000) concluded that the existing evidence suggested that teachers found it challenging to plan for PBL learning experiences and assessments. Although one can speculate that designing a PBL curriculum from scratch would be incredibly challenging for a teacher, we were not able to identify any studies related to the challenges teachers face in planning their own PBL curriculum from the outset. However, a number of teams that have collaborated with teachers to develop PBL curricula have published accounts of the PBL design challenges for developers and teachers, as well as the ways in which teachers have adapted externally developed PBL curricula to their own classrooms (e.g., Fortus and Krajcik, 2012; Kolodner et al., 2003; Krajcik et al., 2008; Parker et al., 2011, 2013; Veletsianos, Beth, Lin, and Russell, 2016).

The literature on the design challenges program developer/teacher teams confront in collaborating on project-based science curricula (LeTUS, PBIS, and IQWST) has noted that the development of a coherent curriculum is one of the most important but difficult aspects of designing a project-based approach. Shwartz and colleagues (2008) argued that coherence has been underemphasized in the design of PBL units, which teachers often adopt as stand-alone units that fit into the existing curricula: "Although project-based units can create a useful context for learning science, they do not necessarily build coherence. Each unit can be studied independently, and units can be taught in any order" (p. 216).

Fortus and colleagues (2015) identified four levels of coherence that should be captured in a curriculum aimed at deeper learning: content-standard coherence, learning goal coherence, inter-unit coherence, and intra-unit coherence. Content goal and learning goal coherence refer to the sequencing and depth of a curriculum and/or unit's content and learning goals. As a student moves through a *coherent* curriculum, the content knowledge and skills the student develops should build on one another and move the student from a novice level of skills and knowledge toward expertise. Inter-unit coherence refers to the relationship between the activities, content, and practices that make up a curriculum. Intra-unit coherence refers to these relationships across units. According to Fortus and colleagues, achieving curriculum coherence has been identified as a predictor of student achievement; it is also an operational challenge to achieve, given the breadth of content and skills that students are expected to master each year, as well as the depth of teacher content and pedagogical knowledge required to enact a coherent curriculum. To plan for and enact an externally developed coherent curriculum, teachers need to have a deep understanding not only of the curriculum content and pedagogy but also the concept of coherence. Fortus and colleagues recommended that curriculum materials include "educative information (Davis and Krajcik, 2005) regarding coherence to support teachers in optimal enactment" (p. 16). More research is clearly needed to identify the challenges PBL curriculum developers face in meeting such rigorous coherence standards.

A critical issue for the implementation of externally developed PBL curricula is whether and how teachers plan for curricular adaptation to meet their students' needs. Teachers can adapt a curriculum to fit their local context in multiple ways. They can adapt the amount of time they devote to a curriculum and/or to the activities of the curriculum, the depth to which they engage students in the curriculum's content, and the extent to which they implement the suggested activities with fidelity (Fogleman et al., 2011). These adaptations are likely to be influenced by the teacher's beliefs, knowledge, and local context (Fogleman et al., 2011). For example, a teacher might see the need to add additional literacy support scaffolds to an externally developed PBL curriculum if she anticipates that her students will struggle with the curriculum's suggested texts. One might also imagine that a teacher could adapt the activities of a student-directed PBL curriculum into more teacher-directed activities.

The research literature on the topic of teachers' curricular adaptations has found that these adaptations can positively or negatively influence students' classroom experiences (Fogleman et al., 2011). As an example of an unintended, negative consequence, adapted innovative instructional practices like PBL may lead to more traditional and familiar classroom practices (Fogleman et al., 2011). In their study, Fogelman and colleagues studied the influence of teachers' adaptations of an IQWST science unit on students' learning. They reported that some teachers transformed the curriculum's student-directed scientific investigations into teacher- directed demonstrations of those investigations. Additionally, they reported that students who completed the investigations themselves tended to learn more (as measured by pre- and post-unit assessments) than those who attended a class in which the teacher demonstrated the investigation, suggesting that the adaptation had a negative influence on students' learning. Fogelman et al. stressed the importance of letting teachers know that certain types of curricular adaptations may have negative consequences for students' learning.

On the other hand, according to Veletsianos, Beth, Lin, and Russell (2016), there are instances within inquiry-based curricula in which teacher-centered instructional approaches (for example, lecture and demonstration) are both effective and efficient. During the pilot implementation of a new PBL-focused computer science curriculum, the developers determined that some of the PBL approaches to learning basic factual material appeared to be extremely time-consuming. They therefore adapted the curriculum, continuing to use inquiry-learning approaches to target higher-order thinking skills, such as analysis, evaluation, and synthesis, but including teacher-centered methods to impart basic knowledge and demonstrate particular skills. Their study did not report whether this adaptation had effects, positive or negative, on students' learning.

More research is needed on how teachers adapt externally developed PBL curricula and the best ways to support adaptations that improve students' learning.

Classroom interactions. PBL often involves students working collaboratively or independently on student-directed activities for extended periods of time. Teachers in student-centered learning environments like PBL often raise classroom management concerns (Thomas, 2000), particularly about student misbehavior and disengagement during extended periods of intended self-regulated learning and group work (Hertzog, 2007; see for review: English and Kitsantas, 2013; Hung, 2011). In his review of the literature on problem-based learning implementation in K-12 and higher education settings, Hung noted that lack of student motivation and unsatisfactory group work were often cited as implementation challenges. Notably, however, Mergendoller and Thomas (2000) reported that experienced PBL teachers rarely saw student misbehavior as a challenge. The direction of the relationship between a teacher's use of PBL and student behavior issues is impossible to determine from existing research.

Whether or not PBL is associated with outright misbehavior, various kinds of intragroup conflicts among students participating in PBL can arise and need to be managed. Lee, Huh, and Reigeluth (2015) describe such conflict among students in two American studies classrooms in a Midwestern high school in which PBL was the dominant mode of instruction. Students completed surveys about their group work experiences related to three PBL units. Of the 53 groups from which surveys were received, 37 reported some type of conflict in completing their projects. While these conflicts could be productive when they led to discussion about how the task could best be accomplished, they could also be counterproductive when they centered on group members' roles or resulted from personality conflicts.

Developing classroom norms and procedures for group and project work seems to be a promising strategy for overcoming this implementation challenge. In their review of the research on the use of collaborative learning in inquiry-based approaches such as PBL, Darling-Hammond et al. (2008) noted that establishing, modeling, and maintaining classroom norms for effective group work is one method teachers use to support students' engagement in group activities. More research is called for on how this can best be accomplished.

Another challenge that teachers face in managing student behavior in the PBL classroom may stem from students' discomfort with the new cognitive and social demands that PBL places on them (Parker et al., 2011, 2013; Thomas, 2000). In their evaluations of the KIA approach to AP U.S. Government and Politics, Parker and colleagues (2011, 2013) found that, although students enjoyed their projects, the disruption of traditional instruction led to anxiety and frustration among their sample of relatively high-achieving students who were likely concerned about passing a high-stakes test at the end of their course. Students expressed frustration that their teachers did not follow a more traditional approach (Parker et al., 2013). Even though Parker and colleagues' outcome analysis suggested that KIA students performed on the AP exam as well as or better than students who were prepared using traditional methods, some student participants believed that PBL was not an efficient process to help them acquire the necessary knowledge to succeed on the test.

A study conducted in Minnesota supplies further evidence that students accustomed to more traditional modes of learning often experience difficulty in adjusting to PBL. Administrators and teachers at the Minnesota New Country School (MNCS), a learner-centered charter school serving a diverse population in Henderson, MN, identified changing students' mindsets about how schools should operate as a prime obstacle in implementing a self-directed, PBL approach to education (Aslan and Reigeluth, 2015; see also Capraro et al., 2016).

A better understanding of why some students experience frustration in the PBL classroom, how this frustration influences interactions with their peers and teacher, and what teachers can do to ease students' concerns is important for PBL implementation researchers and for practitioners looking to improve PBL implementation.

Facilitating student inquiry. Student-directed inquiry is a cornerstone of the PBL approach (see PBL design principles in Section II). In a PBL classroom, a teacher's role is to facilitate rather than direct students' knowledge acquisition and skills development. Teachers have often reported difficulty with a range of complex pedagogical issues that are unique to PBL and other student-centered, inquiry-based approaches. These issues include: initiating the student inquiry process, facilitating dialogic interactions, and finding the time and resources to support in-depth student investigations (Alozie, Moje, and Krajcik, 2009; Ertmer and Simons, 2006; Hertzog, 2007; Kolodner et al., 2003; Marx et al., 2004; Thomas, 2000).

Scaffolding the learning process. A central goal of PBL is to facilitate the deeper learning process and support students' acquisition of 21st century skills, including complex cognitive competencies such as rigorous content knowledge and critical thinking skills. In a PBL classroom, these skills and content are acquired through student-directed investigation and inquiry as opposed to teacher-directed delivery that is typical of a more traditional classroom approach. Multiple researchers have cited providing students with learning scaffolds as a way for teachers to facilitate the inquiry process and maintain student engagement (Brush and Saye, 2000; Ertmer and Simons, 2006; Hug, Krajcik, and Marx, 2005; Jonassen, 2011; Land and Zembal-Saul, 2003; Mergendoller and Thomas, 2000; Tamim and Grant, 2013). As noted in an earlier section of this review, some researchers have featured scaffolding as a PBL design principle (Darling- Hammond et al., 2008; Grant, 2002; Krajcik and Shin, 2014). A teacher can scaffold student learning in multiple ways, including coaching students, modeling cognitive processes, structuring complex tasks, and providing hints (Hmelo-Silver, Duncan, and Chinn, 2007). Edelson and Reiser (2006) described the appropriate design of learning scaffolds as enabling students to engage in "authentic practices" (e.g., developmentally appropriate practices in which experts engage): "learning environments should scaffold students by reducing the complexity of the practices, while retaining their key elements" (p. 336). It has also been noted that technological software offers unique opportunities for scaffolding student learning (Edelson and Reiser, 2006; Kali and Linn, 2008; Krajcik and Mun, 2014; Quintana et al., 2004; Reiser, 2004).[24]

[24]Kali and Linn (2008) have developed a set of principles for the design of scaffolds for technological software in inquiry-based learning environments. Their four meta-principles — make science accessible, make thinking visible, help learners learn from each other, and promote autonomous lifelong learning — align with a series of pragmatic principles that teachers can implement in their classrooms, such as "provide students with templates to organize ideas" and "provide knowledge representation tools" (p. 8). More research is clearly needed on how to design learning scaffolds in technological software for PBL learning environments (continued)

When scaffolds should be introduced and removed in the PBL classroom is a critical question for researchers and practitioners interested in PBL implementation. Fading of supports over time has been cited as a component of scaffolding (Hmelo-Silver et al., 2007; Puntambekar and Hubscher, 2005) and seems particularly important to a PBL approach, which aims to support *student*-directed inquiry. Puntambekar and Hubscher have noted, however, that this fading is often overlooked in practice. McNeill and colleagues (2006) studied the pre- and post-test scores of 331 seventh-grade students of six different teachers who implemented an eight-week project-based chemistry curriculum (IQWST) that included scaffolds to support students' capacity to produce written explanations for the findings of their scientific investigations. This research team sought to understand the relationship between scaffold fading and student achievement. All classes engaged in six investigations over the course of the eight-week unit and all students received written prompts to support them in writing scientific explanations. However, the level of detail in the prompts faded over time for a randomly selected group of classes, while the rest of the classes' prompts stayed at the same level of detail. An analysis of post-test scores — both for students who received faded scaffolds and those who received the same level of scaffolding throughout — suggested that fading scaffolds was more effective in supporting students' capacity to create scientific explanations independently. Clearly, more research is needed to help teachers develop effective scaffolds and teach them when and how to fade the supports.

Promoting rigor in learning. How teachers support their students' learning is related to the rigor of the learning experience. Rigor is enhanced when students have the opportunity to struggle with a problem before teachers provide them with directive hints or solutions. Other indicators of rigor include: requiring students to explain or justify their thinking; giving them opportunities to summarize, synthesize, and generalize; having them compare and contrast different answers, solutions and interpretations; and asking them to apply knowledge to new situations. A study of 10 STEM-oriented North Carolina high schools used data from student surveys, teachers' logs, and classroom observations to explore the relationship between PBL and rigor (Edmunds et al., 2017). It found that higher levels of PBL implementation were associated with higher perceptions of rigor, but also that academic rigor can be present without PBL and that PBL can be implemented with low levels of rigor. The authors concluded that ensuring that rigor is present within PBL implementation is likely to involve engaging teachers in collaborative review of their projects.

Technology. Multiple researchers have noted that integrating technology into the PBL learning environment is important for teachers using a PBL approach (ChanLin, 2008; Grant, 2002; Krajcik and Shin, 2014; Saye and Brush, 2002). For example, Krajcik and Shin argued that learning environments with the support of technological materials "can maximize individualized, independent learning, which can lead to more meaningful learning" (p. 289).

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beyond the sciences, as well as on the effectiveness of different types of learning scaffolds and different modes of scaffold delivery (e.g., technological versus student-teacher interaction).

Implementation studies have found that the integration of technology into PBL can pose unique implementation challenges (Blumenfeld et al., 2000; Krajcik and Shin, 2014). In their studies of project-based science, Krajcik and Blumenfeld (2006) found that a lack of consistent access to computers, extra classroom time spent on technology usage, and some teachers' need for guidance on technology integration were implementation challenges. Blumenfeld and colleagues (2000) reported that meeting technological requirements for a successful inquiry-based curriculum can have its challenges, including lack of both student access to a sufficient number of quality computers and support for instructors who are knowledgeable about teaching with technology. Addressing these challenges will require investments in technological resources, as well as professional development to help teachers weave technological resources into the PBL curriculum in ways that meet their students' needs. For example, the LeTUS project-based science curriculum materials were accompanied by extensive professional development and ongoing support for teachers, which included assisting teachers to set up necessary technology, modeling how to use the technology as part of classroom instruction, and allowing time to reflect on the implementation's progress (Fishman, Marx, Blumenfeld, Krajcik, and Soloway, 2004; Gerard, Varma, Corliss, and Linn, 2011). As Veletsianos, Beth, Lin, and Russell (2016) report in their study of the introduction of a new PBL-focused computer science curriculum, even experienced computer science teachers may need assistance. Some of these teachers lacked experience with social networking sites and wikis, both of which were major components of the new curriculum.

Technology has been cited as a particularly useful tool for students with special needs (Cote, 2007; Ferretti, MacArthur, and Okolo, 2001; Hernández-Ramos and De La Paz, 2009) and for students learning English as a second language (ELLs) (Foulger and Jimenez-Silva, 2007). Foulger and Jimenez-Silva studied the experiences of 14 K-8 teachers of ELL students who worked with professional developers to develop at least one technology-enhanced, project-based unit that aimed to support the students' writing skills. The teachers in the study believed that technology enhanced their capacity to use seven instructional strategies for supporting ELL students' writing skills, including "time and opportunity to write, a real reason for writing, a genuine audience, access to role models, a safe environment, useful feedback, and a sense of community" (p. 111). Although the study could not assess whether technology truly enhanced the impact of PBL and ELL instructional strategies on students' writing skills, the authors concluded: "Knowing that teachers believe that technology enhances their work with ELLs might, however, provide a foundation for further studies related to the impact on student achievement on any of the seven teacher practices" (p. 122). Whether technology-infused PBL has a positive effect on ELL teachers' practices and special education students is an important and timely empirical question that should be explored further.

Assessment. Assessment is a critical consideration for inquiry-based approaches like PBL (Darling-Hammond et al., 2008). One key tension noted in the literature is a perceived disconnect between the type of learning emphasized in a PBL classroom and the learning assessed on standardized tests, which are often used as summative assessments for student and teacher accountability (Grant and Hill, 2006; Hertzog, 2007; Parker et al., 2013). This perception can hinder PBL implementation by creating anxiety and frustration among teachers and students.

Identifying appropriate student summative assessments is complicated by the fact that the PBL approach is designed to produce some outcomes that a traditional summative assessment may not adequately measure (Hertzog, 2007; Mergendoller and Thomas, 2000). A number of alternatives have been discussed in the literature, most prominently performance-based assessments. Performance-based assessments involve students' completing tasks that demonstrate their capacity to apply new knowledge and skills; they also require that students respond to a question or performance task versus selecting a correct answer, as they would on a non-analytical multiple-choice test (Darling-Hammond and Adamson, 2010).[25] Student artifacts, "external representations" of students' "constructed knowledge," are often cited in the PBL literature as an appropriate assessment for a PBL environment (Grant and Branch, 2005; Krajcik and Shin, 2014). Artifacts could include computer or physical models, games, writing samples, plays, or exhibits. While the use of artifacts certainly appears to be a promising strategy, teachers may find it difficult to score artifacts in a valid and reliable way (Aslan and Reigeluth, 2015).

Assessment that facilitates teacher feedback for students is considered critical to student learning (Hattie and Gan, 2011) and is sometimes cited as a design principle for PBL and other inquiry-based approaches (Darling-Hammond et al., 2008). Research on PBL implementation has reported that teachers often do not have the time or capacity to provide quality feedback or help students engage in self-assessment and reflection (Grant and Branch, 2005; Krajcik and Shin, 2014). It is therefore important to provide teachers with guidance on how to give quality feedback. Krajcik and Shin cited a rubric that could address this issue by linking their curricular units with written descriptions of quality student work at different levels.

Context Matters: How School Context Shapes Implementation

Studies have shown that school contextual factors over which individual teachers have little control (e.g., district and national education policy, teacher mobility, and school culture) can influence PBL implementation (Blumenfeld et al., 2000; Hertzog, 2007; Marx et al., 2004; Ravitz, 2010). In their discussion of the factors influencing the effectiveness of the LeTUS curriculum in Detroit, Michigan, Marx and colleagues cited a number of district contextual factors that influenced the implementation of their PBL instructional reform strategy for science: teacher mobility, difficulty with technology maintenance, competing demands of standardized testing, and staff changes at the district level. In another study (Dole, Bloom, and Kowalske, 2016), district mandates and pacing guides were also found to interfere with PBL implementation.

[25]There is debate in the research literature and in the practitioner community about what constitutes a performance-based assessment (for a review, see Darling-Hammond and Adamson, 2010).

Other studies have suggested that PBL and other inquiry-based approaches like problem-based learning are easier to implement when they are supported by school leadership and used by other teachers in the building (Bitter, Taylor, Zeiser, and Rickles, 2014; Ravitz, 2010). Ravitz examined the use of PBL in three different types of public schools: reform model schools, small schools unassociated with specific models, and large or medium comprehensive high schools. Overall, PBL implementation was the strongest in reform model schools, where PBL was often seen as a core instructional component, encouraged or required by school leadership, and viewed as consistent with the school's student-centered culture. These findings suggested that PBL implementation is influenced by a school's culture, structure, and instructional leadership. The research on instructional practices used in schools participating in the Deeper Learning Network also suggested that PBL implementation is easier when it is encouraged by school leadership and aligned with school culture (see also Marx et al., 2004). A student survey found that more opportunities to engage in PBL and other inquiry-based approaches were available to students in Deeper Learning Network schools than students in non-Network schools (Bitter et al., 2014). While it is possible that teachers at the Deeper Learning Network schools would have used PBL even if they taught at another type of school, it seems likely that their implementation was supported by the schools' emphasis on deeper learning.

Discussion

Thomas (2000) was critical of the PBL implementation literature because it was so sparse. Although the volume of PBL implementation studies has certainly increased over the past 17 years, the fact that these studies often assessed very different PBL approaches makes it difficult to draw general conclusions about the challenges associated with PBL implementation. With that limitation in mind, a review of the PBL implementation literature through the lens of teachers' beliefs and teachers' practices underscores a number of reasons why PBL is unusually challenging to implement. This lens is also useful for efforts to identify factors that may facilitate strong implementation.

The case studies described in this section of the review have suggested that PBL implementation is hindered when teachers' beliefs about the process of learning, students' capacity to engage in student-directed inquiry, and educational goals do not align with the deeper learning aspirations of a PBL approach. Teachers' beliefs are strongly influenced by their school context. For example, some studies (Bitter et al., 2014; Ravitz, 2010) found that it was easier to implement PBL when most, if not all, of the teachers in a building tried it at the same time. The literature also found that PBL implementation is particularly challenging because it changes student-teacher interactions, demands a shift from teacher-directed to student-directed inquiry, and requires nontraditional modes of assessment. Instructional strategies like the establishment of norms for collaborative learning, the provision of scaffolds, and the integration of technology into the curriculum have been identified as ways to address these challenges.

PBL implementation research has strongly suggested that it will be difficult for any PBL model to be implemented with fidelity if it does not include professional development.[26] Effective professional development is likely to entail both initial training and ongoing support during implementation. Exposing teachers to authentic PBL learning experiences is one promising strategy to help teachers align their beliefs with a PBL approach. A strategy for supporting the design and implementation changes in teacher practice is giving teachers the tools they need. These tools could include curriculum materials, appropriate technology, "educative" teacher supports to curriculum including video demonstrations (Davis and Krajcik, 2005), and sample performance assessments to ease the shift from a teacher-directed to a student-directed, inquiry-based learning environment. As described in this section of the review, some research on these curricular features and scaffolds (e.g., McNeill et al., 2006) has started to consider whether and how these embedded tools support implementation and influence student learning.

[26]Research involving qualitative case studies of five high school teachers, most of whom had received three years of sustained PD in STEM PBL (10 sessions per year, seven hours per session), nonetheless found substantial gaps between teachers' understanding of PBL and their ability to implement it well in their classrooms. See Han, Yalvac, Capraro, and Capraro (2015). A second study conducted by some of the same authors (Capraro et al., 2016) emphasizes the importance of teachers implementing with fidelity the PBL principles and practices that they learn in the PD sessions. Math and science teachers in three diverse urban high schools received professional development in PBL and the development of professional learning communities over a three-year period. Students at the school where fidelity of PBL implementation was highest registered the greatest gains over time in achievement on state math and science tests. On the other hand, performance of students at the school with the lowest fidelity of implementation remained essentially unchanged.

Section V: PBL and Student Outcomes

Despite the clear challenges associated with PBL implementation, Thomas's (2000) review of the relationship between PBL and student outcomes found evidence that PBL can support student learning and may be more effective than traditional modes of instruction. However, he argued that future research needs to employ more rigorous methodology in order to strengthen existing claims and that researchers should go beyond measures of student academic achievement to consider a broader array of learning outcomes. This section of the literature review synthesizes the quantitative research on the relationship between PBL and student outcomes published since Thomas's review.[27]

In light of Thomas's claim that PBL research should attend to a range of student outcomes, this review considers the evidence of PBL effectiveness in support of the three domains of student learning identified by the National Research Council's (NRC) report on deeper learning: cognitive, intrapersonal, and interpersonal (Pellegrino and Hilton, 2012). The NRC posited that these three domains encompass the critical 21st century learning competencies needed for success in college and career. A definition of the three domains and the types of competencies (knowledge and skills) they encompass are listed in Table 2. More detail on the theoretical underpinnings of the concept of deeper learning and its relationship to PBL is provided in Appendix B.

In their report on deeper learning, the NRC (Pellegrino and Hilton, 2012) stated that the lack of valid and reliable assessments of deeper learning poses a significant challenge to practitioners and researchers interested in examining the relationship between deeper learning instructional strategies like PBL and students' development of 21st century competencies. They explained that measurement of competencies in the intra- and interpersonal domains is particularly underdeveloped, but it has also been noted that traditional assessments such as state standardized tests are typically unable to measure the full range of complex cognitive competencies that deeper learning strategies seek to promote (Conley and Darling-Hammond, 2013).[28] In their discussion of promising strategies, the NRC (Pellegrino and Hilton, 2012) explained that performance-based assessments of the type often used in PBL may be a way to assess difficult-to-measure 21st century competencies like the capacity to engage in problem solving, critical

[27] This section of the review is mostly limited to quantitative studies investigating PBL's effectiveness in improving student outcomes published since Thomas's (2000) review. Studies of problem-based learning and research published before Thomas were included for those subsections in which the quantitative research is extremely thin or the study of problem-based learning is clearly relevant to understanding the effectiveness of PBL.

[28] Pellegrino and Hilton (2012) highlighted a handful of promising large-scale assessment systems that do assess complex cognitive competencies such as the Program for International Student Assessment (PISA). The assessment systems being developed for the Common Core State Standards contain summative performance-based measures (PARCC, 2015); these new systems may improve the field's capacity to assess PBL using performance-based measures.

thinking, and metacognition. Importantly, however, they also noted that very few performance-based assessments have been shown to be valid and reliable measures suitable for high-stakes decision making or rigorous evaluations. The studies highlighted in this section of the literature review have made use of existing measures and, in some cases, designed their own assessments for evaluation purposes. Scalable, valid, and reliable assessments of cognitive, intrapersonal, and interpersonal competencies are clearly needed.

Table 2. 21st Century Domains and Competencies

Domains	Example Competencies (Knowledge and Skills)
Cognitive Domain: Competencies related to thinking skills, such as reasoning, problem solving, and memory. This domain also includes content knowledge and creativity.	• Academic Content Skills • Critical Thinking • Technological Literacy • Active Listening • Problem Solving • Creativity
Intrapersonal Domain: Affective competencies used to "set and achieve one's goals" (Pellegrino and Hilton, 2012).	• Self-Regulation • Metacognition • Grit • Flexibility
Interpersonal Domain: Competencies used to express, interpret, and react to information.	• Communication • Collaboration • Conflict Resolution • Leadership

Note. These definitions and competency examples were developed from a review of Pellegrino and Hilton's (2012) original definitions as well as Huberman and colleagues' (2014) recent application of this framework in their evaluation of the Deeper Learning Network. See Pellegrino and Hilton (2012) for a complete list of competencies.

This section of the literature review is organized into four subsections: 1) studies focusing on the association between PBL and students' cognitive outcomes, 2) studies that investigate the influence of PBL on the intra- and interpersonal domains, 3) studies of PBL's effectiveness for specific student subgroups, and 4) an evaluation of the Deeper Learning Network schools (which used PBL as a primary but not exclusive learning strategy) and their effectiveness in improving cognitive and intra- and interpersonal skills and in boosting high school graduation and college attendance rates.

Cognitive Competencies[29]

A number of quantitative studies have considered the strength of the association between PBL and students' cognitive skills. Consistent with Holm's (2011) recent review of the research literature related to PBL and student outcomes, MDRC's review of the literature published since 2000 found numerous studies reporting positive associations between a PBL approach and students' development of knowledge and cognitive skills (e.g., Fogleman et al., 2011; Geier et al., 2008; Gültekin, 2005; Halvorsen et al., 2012; Harris et al., 2014; Mergendoller, Maxwell, and Bellisimo, 2006; Mioduser and Betzer, 2007; Parker et al., 2011, 2013; Schneider, Krajcik, Marx, and Soloway, 2002; Summers and Dickinson, 2012). In the following paragraphs, we synthesize the research on PBL's association with cognitive outcomes by discipline.[30]

Science. As noted by Thomas (2000) 17 years ago, much of the research on PBL stems from studies of PBL in the science classroom (Fogleman et al., 2011; Geier et al., 2008; Harris et al., 2014; Marx et al., 2004; Rivet and Krajcik, 2004; Schneider et al., 2002; Shwartz et al., 2008). Much of the evaluation literature on PBL in science classrooms relates, at least in part, to the project-based science (Krajcik and Shin, 2014) approach described in the Design Principles section of this review. As a result, the findings from evaluations of PBL science help build evidence for the efficacy of these design principles.

The Center for Learning Technologies in Urban Schools (LeTUS) is one example of a PBL approach rooted in the design principles of project-based science. LeTUS is a collaborative effort among Detroit Public Schools, Chicago Public Schools, the University of Michigan, and Northwestern University. Among other things, LeTUS developed PBL science curricula for middle school students that incorporated inquiry investigations motivated by driving questions, collaboration between students, the creation of student artifacts to demonstrate learning, and embedded technological software that scaffolds learning. The LeTUS approach was implement-

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[29] As discussed in preceding sections of this paper, problem-based learning contains many of the elements of project-based learning. In our review of the PBL effectiveness research, we targeted studies of project-based learning but included studies of problem-based learning in the K-12 context when the problem-based learning model explicitly aligned with a PBL approach. The NRC report on deeper learning referenced problem-based learning as a promising approach, citing two meta-analyses (Gijbels, Dochy, Van den Bossche, and Segers, 2005; Strobel and van Barneveld, 2009) that found that problem-based learning is more effective in promoting students' conceptual knowledge and application/transfer of knowledge than traditional lecture-based instruction. Notably, these meta-analyses, like much of the problem-based learning research literature, primarily focused on higher education settings, particularly the medical field.

[30] While this body of research certainly suggests the promise of PBL, as will be discussed in the concluding section of this paper, most of the current quantitative outcome studies do not provide a basis for concluding that existing PBL approaches have caused observed gains in student achievement. It is also important to recognize the possibility that researchers and publishers are often reluctant to publish null findings. As a result, reviews of published research like this one may be biased toward the reporting of positive findings.

MDRC's decision to organize the studies on outcomes in this way was guided by LER's interest in better understanding evidence of PBL's effectiveness in each discipline. As discussed in the conclusion of this literature review, organizing the research in this way revealed important differences in the strength of existing evidence between disciplines and suggested important areas for future research.

ed in Detroit Public Schools, which adopted a series of 8-10-week curricular units for middle school science classrooms. Detroit included not only the LeTUS science curricular materials but also professional development for teachers.

LeTUS researchers found a positive relationship between the implementation of LeTUS curricular units and student academic achievement (Geier et al., 2008; Marx et al., 2004). Four LeTUS curricular units were implemented in sixth-, seventh-, and eighth-grade classrooms in Detroit middle schools over the course of three years (1998-2001); as a result, some students experienced multiple LeTUS units. Over the course of these three years, Marx and colleagues (2004) collected data on the pre- and post-unit test scores of close to 8,000 participating students. They generally found statistically significant gains on measures of scientific content knowledge and process skills. Furthermore, the effect sizes tended to increase over the course of the three-year study, suggesting that students' learning improved as teachers became more familiar with the approach. Geier and colleagues (2008) compared the state standardized science test scores of two Detroit middle school student cohorts that either participated or did not participate in one or more LeTUS units.[31] They found that the students who participated in the LeTUS units significantly outperformed nonparticipants on the state standardized tests. These evaluations of the LeTUS program suggest the effectiveness of the LeTUS units for a predominantly disadvantaged urban student population. However, it is important to note (as the authors did) that the analyses could not address all concerns about biases associated with the nonrandom selection of schools, teachers, and students for the intervention.

As noted in preceding sections of this review, Project Based-Inquiry Science (PBIS) is a PBL curriculum that includes professional development. The PBIS approach was informed by the implementation and outcomes studies related to "project-based science" (Krajcik and Shin, 2014) such as the LeTUS studies (Geier et al., 2008; Marx et al., 2004) and studies of the Learning by Design science instruction approach (Kolodner et al., 2003). The curriculum aligns with many of the design principles espoused by Krajcik and Shin (2014), including the importance of driving questions, situated inquiry, and the use of technology as a learning tool. The first-year results of a school-level randomized controlled trial funded by the National Science Foundation in 42 schools in one large urban school district showed positive effects on assessments that integrate science content and practices (Harris et al., 2014).[32]

Math. A search of quantitative outcomes studies identified a very limited number of studies on PBL's effectiveness in math classrooms since Thomas's (2000) review. Although few empirical investigations have compared the use of PBL across disciplines, the paucity of empirical research on PBL's effectiveness in math classrooms may reflect a lower level of

[31]The first cohort included 760 participating students and 8,900 nonparticipating students; the second cohort included 1,043 participating students and 8,662 nonparticipating students.

[32]Schools were randomly assigned in this study. Sixth-grade teachers in these schools were invited to participate, with 96 percent of teachers (n = 55) assigned to the treatment schools consenting to participate and 85 percent of teachers (n = 39) assigned and consenting to the control condition. Student-level data were collected from 2,400 students.

implementation among math teachers. PBL advocates recognize that implementing PBL in math classrooms is difficult (Miller, 2011). This anecdotal evidence aligns with the findings of a recent qualitative study on the instructional strategies used by 19 network schools participating in the American Institutes for Research (AIR) Deeper Learning study (Huberman et al., 2014). Huberman and colleagues found that math teachers reported more difficulty integrating PBL into their classroom than teachers in other disciplines.[33]

Thomas (2000) reviewed two studies that considered the relationship between a PBL math instruction approach and students' cognitive outcomes. A three-year study conducted by Boaler (1997) in the United Kingdom compared the outcomes for students taught in a school that used PBL math instruction to the outcomes for students who were similar in demographic characteristics and prior academic achievement but attended a school that used a more traditional approach (300 students total in the sample). Students in the PBL school outperformed those in the traditional school on a number of outcomes. While Boaler's study certainly suggests the promise of PBL mathematics, the students, teachers, and schools were not randomly assigned to the PBL approach or a control condition. Thus, it is possible that students in the school using a PBL approach might have outperformed their peers even if their teachers had used more traditional methods.

Thomas (2000) also reported the results of evaluations of the Cognition and Technology Group at Vanderbilt University's (CTGV) "Jasper series." The Jasper series videos provided necessary material and information for students to engage in autonomous PBL learning activities. One of the three videos evaluated for the study involved the use of statistics. Thomas reported that the evaluation results of Jasper's PBL video series showed a "significant impact on students' problem-solving skills, metacognitive strategies, and attitudes towards learning" (p. 17). However, Thomas questioned whether the positive findings could be generalized to PBL approaches that do not include the CTGV-packaged curriculum.

Aside from differences in the number of studies on PBL in science and math classrooms, another key distinction is that multiple evaluated PBL science curricula are rooted in common project-based design principles (Krajcik and Shin, 2014). This is not the case for the Jasper series and Boaler's curriculum, the two PBL math curricula that Thomas (2000) reviewed. Thomas said that, in the PBL school that Boaler (1997) studied, "students worked on open-ended projects and in heterogeneous groups" throughout the year (p. 14). In the Jasper series (rooted in theories of "situated cognition"), students engaged in brief project-based learning experiences that were primarily motivated and supported by video. Although both

[33]The Minnesota New Country School described in Section IV provides an interesting example of why math can be so hard to incorporate into project-based instruction. The school abandoned the use of PBL for math teaching because some students entered the school with severe math deficits. Students had to move quickly to meet state standards for graduation, and the use of a self-paced online math learning program that did not include PBL offered an accelerated way to fill the gap. Teachers believed that it would be too hard to integrate the many and varied math concepts that students needed to master into projects. (See Aslan and Reigeluth, 2015).

studies evaluated PBL as a vehicle to support students' acquisition of math skills, the versions of PBL being evaluated in these studies were very different from each other.

A study of Turkish seventh-graders who learned about ratios, percentages, and proportions either through PBL or more traditional instruction suggests that use of PBL resulted in significant knowledge gains compared with the traditional instruction (Özdemir, Yildiz, and Yildiz, 2015). While pretests do not point to differences in prior knowledge between students in the PBL and business-as-usual classes, it does not appear that the students were selected for PBL through random assignment, so it is possible that other unmeasured differences between the two groups may help to explain the findings. There is little discussion of how PBL was implemented in the treatment classroom. A second Turkish study, this time involving secondary school students, found that PBL increased students' ability to represent statistical data graphically (Koparan and Güven, 2015). Again, the procedure for determining which students would receive PBL and which would receive more traditional instruction is unclear, as is the nature of the PBL in which they participated. Both studies were small in scale, each involving a total of 70 students across the treatment and comparison groups.

Social science and humanities (Social studies and English/language arts).[34] As described in prior sections, many PBL models stress that the driving question in a PBL unit should be connected to real-world problems. Social studies and English/language arts courses seem to be subject areas in which these connections can be easily made. A handful of studies have reported a positive relationship between the implementation of PBL social studies (including economics) curricula and students' cognitive outcomes (Finkelstein et al., 2011; Gültekin, 2005; Halvorsen et al., 2012; Hernández-Ramos and De La Paz, 2009; Mergendoller et al., 2006; Parker et al., 2011, 2013; Summers and Dickinson, 2012; Wirkala and Kuhn, 2011).

Evaluations of a PBL approach to AP U.S. Government and Politics courses (Parker et al., 2011, 2013) found a positive association between students' participation in a PBL course and their cognitive outcomes. The authors, who are part of the Knowledge In Action (KIA) project, worked with AP U.S. Government and Politics teachers in two suburban high schools in Bellevue, Washington, to develop an AP-PBL curriculum (Boss et al., 2011). After its initial development, the curriculum continued to be refined each year as teachers provided feedback to researchers and made adaptations to support their students' learning. The curriculum has also been expanded to other sites. The AP-PBL curriculum is rooted in the five design principles put forth by Parker and colleagues (2011, 2013), which were described in prior sections of this review and are listed in Appendix A.

The two published evaluations of this intervention (Parker et al., 2011, 2013) compared students who participated in the AP-PBL classes with students who participated in traditional AP courses, which typically involved a good deal of lecture, at comparison schools. Parker and colleagues' (2013) evaluation used the AP U.S. Government and Politics Exam and the "Com-

[34] These two subject areas are grouped together because they are often linked in a K-12 curriculum and both emphasize literacy standards.

plex Scenario Test" (CST), a researcher-developed assessment of students' capacity to transfer their learning to a novel problem. They used hierarchical linear modeling (HLM) to account for the nesting of students with specific teachers and in specific schools and to control for measures of prior achievement.[35] Parker and colleagues' (2011) evaluation of this project's first year (2008-2009) compared students in the two suburban high schools using the AP-PBL approach (n = 208 students) with students in a high school in the same suburban district that did not use this approach (n = 106 students). Their evaluation of the second year compared students who participated in the AP-PBL approach at the same schools featured in the first-year evaluation (n = 175 students) with students who participated in a traditional AP course at two schools located in different districts in a neighboring state (n = 114 students). Evaluations of the first (Parker et al., 2011) and second (Parker et al., 2013) years of these projects reported that across most comparisons of AP test scores, AP-PBL students achieved higher scores than students who took a more traditional AP U.S. Government and Politics course. Evidence of students' scores on the Complex Scenario Test (a measure of problem-solving skills) was less consistent (Parker et al., 2013). The findings from the two studies suggest PBL's promise in the AP environment, but do not allow for causal inferences. This is so because it is impossible to know whether the positive association between AP-PBL class participation and AP scores was attributable to PBL implementation or to unobserved factors related to teacher and student selection in the AP-PBL course.

Finkelstein and colleagues' (2011) randomized controlled trial of the Buck Institute for Education's (BIE) problem-based learning curriculum is noteworthy because the tested learning model was aligned with many of the PBL design principles.[36] The researchers recruited 128 teachers from 106 schools in California and Arizona to participate. Teachers who were randomized into the treatment condition received a problem-based economics curriculum, five days of professional development, and ongoing support throughout the 2007-2008 school year. The study faced significant problems with teacher attrition; the final analytic sample included 64 teachers and 4,350 students. Researchers found positive effects on tests of economic literacy (effect size = 0.32) and problem-solving skills in economics (effect size = 0.27) for the students of teachers who received curricular materials, professional development, and ongoing support.

[35] The authors reported using HLM but did not consistently report the results of the HLM analyses.

[36] Wirkala and Kuhn (2011) also conducted an experiment testing the effects of two problem-based learning curricular topics on middle school students' capacity to comprehend and apply new knowledge. This problem-based curriculum was very short in duration (students engaged in each curricular unit for two hours over the course of one and a half weeks) but contained many of the project-based learning elements: Students were motivated to engage in the learning through a driving question, the content of the lessons was related to real-world problems, learning scaffolds were provided by the adults, and students were required to construct knowledge independently and/or through group work. The researchers found positive effects on students' comprehension of the content and students' capacity to apply their new knowledge in new contexts nine weeks after completion of the unit.

These results are consistent with the positive results from Mergendoller and colleagues' (2006) evaluation of the same curriculum implemented in California classrooms in 1999-2000.[37]

MDRC was not able to find any outcome studies of PBL's effectiveness in English/language arts classrooms.

Intra- and Interpersonal Competencies

As described above, many aspects of PBL models are intended to support students' development of intra- and interpersonal competencies, such as communication and collaboration skills, metacognitive skills, grit, and self-regulation skills. The NRC (Pellegrino and Hilton, 2012) and other scholars in the Learning Sciences (Scardamalia et al., 2012) have noted that the development and application of valid and reliable assessments of these competencies have not kept up with the high level of interest in these domains. Many researchers rely on self-reported data obtained through surveys. In his review of the PBL research, Thomas (2000) raised concerns about using teacher or student self-reported data to evaluate instructional innovations like PBL: "The tendency to report positively about an experience is heightened for teachers when students seem unusually engaged and for students when the activity is provocative and fun" (p. 19). Despite concerns about such measures, Thomas concluded that there is evidence that PBL may improve students' attendance (a possible proxy for student engagement), self-reliance, and attitudes toward learning, which can all be considered intrapersonal competencies. While the evidence is thin, quantitative research over the past 15 or so years suggests that PBL *may* improve students' intra- and interpersonal competencies (Cheng, Lam, and Chan, 2008; Hernández-Ramos and De La Paz, 2009; Kaldi, Filippatou, and Govaris, 2011; Mioduser and Betzer, 2007).

Much of the research relevant to the intra- and interpersonal domains has focused on students' attitudes toward what and how they learn (Hernández-Ramos and De La Paz, 2009; Holmes and Hwang, 2016; Mioduser and Betzer, 2007) and toward their peers (Cheng et al., 2008; Holmes and Hwang, 2016; Kaldi et al., 2011). The Hernández-Ramos and De La Paz, Holmes and Hwang, and Mioduser and Betzer studies all found that students who participated in PBL units reported significantly more positive attitudes toward learning than did comparison groups of students who were taught using more traditional methods. For example, Holmes and Hwang reported that students who attended a new PBL-focused high school scored higher than their counterparts in a comparison high school on all the motivational constructs examined. Hernández-Ramos and De La Paz found that eighth-grade students who participated in a technology-enhanced PBL social studies unit had significantly more positive attitudes toward learning social studies and toward social learning in general.

[37]The Department of Education, What Works Clearinghouse (WWC) (2013) reviewed the rigor and outcomes of the Finkelstein et al. (2011) study. They found that the effects on students' economic knowledge were strong enough for them to say that the curriculum meets "WWC evidence standards with reservations" (p. 2). WWC's reservations were related to teacher attrition from the study.

Parallel results have been found in other countries. Kaldi and colleagues (2011) measured growth in content knowledge and attitudes of 70 students (ages 9-10) who experienced a PBL environmental science unit in public schools in Greece. In student surveys, significant mean differences were found between pre- and post-scores on scales measuring attitudes toward traditional teaching, experiential learning, peers from different ethnic backgrounds, and group work. Similarly, students at an Arab middle school in Israel who learned science using PBL strategies reported higher levels of satisfaction, enjoyment, and teacher supportiveness than their counterparts at a school where traditional methods were used (Hugerat, 2016).

Another study also provides suggestive but far from conclusive evidence that PBL can improve the attendance of economically disadvantaged students (Creghan and Adair-Creghan, 2015). Random samples of economically disadvantaged students were drawn from two high schools in the same school district and serving the same community: a traditional comprehensive high school and a new PBL-focused school in the New Technology Network of schools. Attendance among students at the PBL-focused school was significantly higher than among their counterparts in the traditional school in all three years of the study. The authors acknowledge that school culture, individual teaching practices, and expertise were not controlled for in the study and may have also have affected attendance. So, too, may the very different sizes of the schools: The traditional school enrolled 1,200 students, while the PBL school enrolled 330 students, allowing for a more personalized environment. Moreover, the PBL school accepted its students through a lottery and may, therefore, have attracted students who were more academically motivated from the outset.

PBL and Student Subgroups

As researchers and practitioners consider bringing PBL to scale, it is important to ask whether and how the impact of PBL on student outcomes varies for different types of students. In his review of the literature, Thomas (2000) noted multiple student characteristics that might influence the direction and magnitude of the effect of PBL on student outcomes, including “age, sex, demographic characteristics, ability, and a host of dispositional and motivational variables” (p. 20). Thomas’s review found that the limited research literature on this topic rested largely on practitioners’ anecdotal evidence that some students — such as those who have traditionally not excelled in particular skills or subject areas — experience positive outcomes from this different way of learning and perhaps benefit more from a PBL approach than others. In the following paragraphs, this review considers the evidence of PBL’s effectiveness for several subgroups of students, including girls, students of lower academic achievement levels, special education students, and students learning English as a second language (ELLs).

Gender differences. Thomas identified one study (Boaler, 1997) that examined gender differences in the effectiveness of PBL. Boaler found that girls benefited more than boys from a PBL approach in the math classroom. Geier and colleagues’ (2008) evaluation of the LeTUS science reform in Detroit public schools came to a different conclusion. Geier et al. examined gender differences in the standardized test outcomes of participating and nonparticipating students. Among nonparticipating students, the researchers found that boys significantly lagged behind girls in their eighth-grade science standardized test scores. This gender gap in science achievement was reduced for LeTUS students. Geier et al. and Boaler evaluated different approaches to PBL, and it is difficult to interpret the differences between their findings on who benefits more from PBL.

Erdogan, Navruz, Younes, and Capraro (2016) examined growth in science knowledge among male and female students at three high schools with varied levels of STEM PBL implementation. The study found that in the school with full PBL implementation, the average yearly growth rate across three years for male students was 0.93 points higher on the state science test than for female students, a statistically significant difference. In a school with no STEM PBL implementation, male and female students experienced similar rates of knowledge growth.

More empirical and theoretical work is needed to explain when and why PBL might influence girls and boys differently.

Achievement level. While some have argued that the highly engaging nature of many PBL approaches may make PBL well suited for lower-achieving students (Thomas, 2000), others have highlighted the concern that the challenges of implementing PBL for lower-achieving students may limit the benefits for them (Hertzog, 2007). Four studies published in the last 14 years explicitly compared the effectiveness of PBL for students with different levels of prior achievement (Cheng et al., 2008; Halvorsen et al., 2012; Liu, 2003; Mergendoller et al., 2006). Halvorsen and colleagues designed two PBL social studies units (20 to 21 lessons each) for the second-grade classrooms of four teachers in three school districts serving an economically disadvantaged student population with lower-than-average achievement levels.[38]

After the implementation of their units, they compared achievement on social studies and content area literacy assessments between a sample of the students (n = 43) in these PBL-implementing classrooms and a sample of second-grade students (n = 20) from two high-SES[39] schools that did not implement the PBL projects. They found that, after the PBL units, there were no statistically significant differences between the scores of students in the low-SES and lower-achieving schools and those in the higher-achieving, more privileged schools, suggesting that PBL was a useful tool for students attending low-SES and low-achieving schools. Mergendoller and colleagues (2006) compared the pre- and posttest scores of students exposed to BIE's problem-based economics curriculum (n = 139 students) and those taught using traditional

[38]Halvorsen and colleagues (2012) cited a number of design principles in their discussion of PBL and noted the debate in the field over how to define PBL. Their project description stated that the projects were connected to real-world issues, involved students collecting data, were linked to state standards, and involved assessments through presentations to a public audience. However, they did not clarify to which design principles their social studies units adhered.

[39]SES stands for *socioeconomic status*.

methods (n = 107 students).[40] Although they found that students exposed to the BIE curriculum made significantly greater academic gains than students taught with more traditional approaches, their analysis found no difference in pretest/posttest gains for students of different verbal ability levels, suggesting that the effect of PBL was not moderated by prior achievement.

Holmes and Hwang (2016) did not examine effects for subgroups defined by academic achievement per se. They did, however, consider impacts for subgroups defined by correlates of achievement: socioeconomic status (SES) and race and ethnicity. They found that the gap in scores on the state standardized math test between students from low-SES and middle/upper-middle SES backgrounds in a PBL-focused high school, while statistically significant, was smaller than the gap in the comparison high school, where instruction was more traditional. In the PBL school, too, race and ethnicity were not associated with performance differences; in the traditional school, on the other hand, white students significantly outperformed minority students. While the PBL school succeeded in narrowing achievement gaps, it is notable that white students and students who were not eligible for free or reduced-price lunch in the comparison school registered significantly higher test scores than their peers at the PBL school. The findings should be regarded with caution, however, because both students and teachers at the PBL school were likely to have differed on both measured and unmeasured variables from their comparison-school counterparts. The authors state, for example, that the PBL teachers were recruited from the comparison school because they were highly experienced and reputed to be excellent math teachers.

Cheng and colleagues (2008) examined the discrepancy between collective and self-efficacy (intrapersonal competencies) among 1,921 high school students in Hong Kong who were exposed to PBL instruction that required significant group work. Specifically, this study's PBL instructional approach involved student-centered small groups engaging in research, discussion, and problem solving about multidisciplinary, culturally relevant topics. The student population was diverse in terms of ability level, and students were required to work in heterogeneous groups for their PBL units. If high achievers were negatively affected by heterogeneous grouping, we would expect them to report low levels of collective efficacy because they might have felt negatively about the prospects of their group's capacity to do well on the project. Cheng and colleagues' quantitative analysis demonstrated that when the quality of the group process was high, both high and low achievers reported higher levels of collective efficacy than they did self-efficacy. In summary, a review of the existing research exploring differences in PBL effectiveness for students of higher and lower levels of achievement is inconclusive, suggesting the need for more research.

[40] Students who were not exposed to the curriculum were taught by the same teachers as those exposed to the curriculum. The teachers taught one class with BIE's curriculum and taught the other class using a more traditional approach.

Special education students. In 2012-2013, special education students[41] were 13 percent of the U.S. public school population, which translates to 6.4 million children and youth receiving special education services (National Center for Education Statistics, 2015a). During that same period, 61 percent of special education students under the Individuals with Disabilities Education Act (IDEA) who were enrolled in regular public schools spent most of their school day in a general class (National Center for Education Statistics, 2015a). Given the high percentage of special education students in U.S. public classrooms, the question of whether and how PBL is an effective, inclusive strategy for this student population should be of interest to policymakers and practitioners.

Although Thomas (2000) noted PBL's potential for students who have not succeeded with traditional approaches to instruction, his review of the research literature did not include any studies that considered PBL's effectiveness for special education students. This review discusses a handful of quantitative studies that suggest the effectiveness of PBL for students with special needs (Filippatou and Kaldi, 2010; Guven and Duman, 2007; Liu, 2004[42]).[43] Filippatou and Kaldi compared academic achievement and attitudes toward learning of a group of 24 students with disabilities[44] before and after the implementation of an eight-week project-based learning curriculum about environmental studies that was implemented in six fourth-grade classrooms in schools located in Greece (see also Kaldi et al., 2011, described earlier). They found that students' scores on tests of content knowledge, self-efficacy, and attitudes toward task value, group work, and experiential learning were significantly higher after the unit than they were before.

While the quantitative evidence of PBL's effectiveness for special education students is thin, in recent years, researchers of PBL and problem-based learning have theorized that these student-centered approaches may be effective ways of addressing special education students' individual learning needs in general classrooms (Belland, Ertmer, and Simons, 2006; Belland, Glazewski, and Ertmer, 2009; Cote, 2007; Filippatou and Kaldi, 2010; Guven and Duman, 2007; Liu, 2004). Belland and colleagues (2006) reviewed the research literature of promising problem-based instructional strategies for students with special needs to consider the ways in which problem-based learning (related but not the same as PBL) *could* support the learning of these

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[41]*Special education students* are also referred to as *students with disabilities*, *students with special needs*, *students with learning difficulties*, and *learning disabled students* in the scholarly literature.

[42]Note that Liu (2004) investigated a problem-based learning environment for sixth-grade students. Her study grouped together students with learning disabilities and ELL students, so it is difficult to draw conclusions about the performance of the students with disabilities in her sample.

[43]Other studies such as Hernández-Ramos and De La Paz (2009) included special education students in their sample. However, since these studies did not disaggregate the findings by student subgroup, they were not included in this section.

[44]Filippatou and Kaldi (2010) described the 24 students as having "learning difficulties," but these difficulties were assessed using many different measures and not all students were assessed with the same measure or given an official diagnosis. According to the authors, all of the students were rated by their teachers as having learning difficulties on receptive and expressive oral language, reading, and writing. The majority were also rated as having a high possibility of exhibiting difficulties in mathematics and reasoning.

students. Their review of the research on students with special needs suggested the following features of a problem-based approach that could support the learning of these students: experiential curriculum, cooperative learning, and learning in authentic contexts. Other studies have noted that PBL and problem-based learning provide a less restrictive and more inclusive environment for special education students' learning, compared with more traditional modes of instruction like strict textbook usage (Belland et al., 2009; Ferretti, MacArthur, and Okolo, 2001; Hernández-Ramos and De La Paz, 2009; MacArthur, Ferretti, and Okolo, 2002).

PBL effectiveness research needs to test these theories by comparing the performance of special education students in PBL and non-PBL classes. Additionally, the implementation research literature should consider the experience of special education students and teachers in PBL classrooms, paying particular attention to the possibilities and challenges posed by such design principles as scaffolding and self-directed inquiry.

English Language Learners. As of 2013, 4.4 million students have been classified as English Language Learners (ELLs) in U.S. public schools (National Center for Education Statistics, 2015b). There are well-documented disparities between ELL and non-ELL students in terms of their high school exit exam pass rates (Sullivan et al., 2005) and mathematics and reading performance (National Center for Education Statistics, 2015c, 2015d). As these achievement gaps persist and public school numbers rise, so has the level of interest in the possibilities of PBL to produce positive education outcomes for ELL students. Scholars and practitioners who focus on promising instructional approaches for ELL students have noted the promise of PBL design principles, which align with current thinking on how to support the language development and content knowledge of ELL students (O'Brien, Lavadenz, and Armas, 2014).

As of this writing, only two quantitative studies of PBL's effectiveness for ELL students published in the past 17 years have been identified for this review (Shafaei and Rahim, 2015; Summers and Dickinson, 2012).[45] One of these, a study of English as a Foreign Language (EFL) learners in Iran, is particularly notable because it used a random assignment design (Shafaei and Rahim.[46] The study participants included 40 EFL students aged 16-18 who were attending a private English language institute. Following random assignment, 20 students in the experimental group were assigned to learn vocabulary through PBL, while the 20 students in the control group were taught using the teacher-centered method that was standard at the institute. In the PBL classrooms, students were divided into groups and given a topic that required the use of new vocabulary terms. Students worked with one another to find the best materials and sources and reported on the results orally and in writing, in the form of a journal, magazine or newspaper, PowerPoint presentation, or poster presentation. On three out of five posttests administered

[45] Amaral, Garrison, and Klentschy (2002) investigated the effectiveness of an inquiry-based elementary school science curriculum that shares many features of a PBL approach. However, since the authors did not say whether this curriculum was PBL, we did not include it in this review.

[46] The researchers report that the students first took a pretest and "were then randomly selected and divided into experimental and control groups." (Shafaei and Rahim, 2015, p. 884).

immediately after each unit, students in the PBL group registered a significantly greater degree of vocabulary recall; they also exhibited greater retention of vocabulary on a test administered later. The authors suggest that, to verify the value of the PBL approach, it would be desirable to consider other language elements, such as grammar, reading, and writing, as well as to include students with different levels of English language proficiency.

Summers and Dickinson (2012) compared the social studies achievement and grade retention rates of students in one school district who attended a high school with either a PBL or traditional approach to instruction. Their findings generally supported the efficacy of the PBL approach for the general student population.[47] However, when they disaggregated their comparisons of grade retention rates by student subgroup, their analysis revealed that freshman ELL students at the school with a PBL approach were more likely to be retained. Their qualitative data suggested that ELL students' freshman-year difficulty in the school using a PBL approach may have been attributable to lower levels of language diversity at that school and the ensuing challenges ELL students faced with engagement and social integration. Notably, Summers and Dickinson also reported that, in the upper grades of high school, ELL students in the PBL school generally experienced the same or better retention rates than ELL students in the more traditional high school.

Although PBL scholars and advocates have theorized that PBL could be an effective means of supporting the achievement of ELL students and addressing disparities between ELL and non-ELL students in academic achievement (Eslami and Garver, 2013; Foulger and Jimenez-Silva, 2007; Stoller, 2006), we were not able to locate any rigorous quantitative empirical evidence supporting this claim.[48] Given the growing number of ELL students, it is important to investigate how PBL affects the academic achievement of this subgroup. While it is certainly possible that PBL is an effective means of supporting the academic achievement of ELL students, rigorous PBL without appropriate scaffolding may also pose some unique challenges for this group. ELL students' potential preference for traditional instruction, with its greater emphasis on learning directly from the teacher and texts, is one potential challenge

[47] It is important to note that, since students were not randomly assigned to these two schools, differences in student outcomes between the schools may be related to differences between the types of students who chose to attend the PBL school and those who did not. The authors of this study did not indicate how many students in each school were designated as English Language Learners.

[48] Despite the limited number of quantitative studies investigating the effectiveness of PBL curricula for ELL students, qualitative research has highlighted many ways in which PBL could support the development of ELL students' cognitive, interpersonal, and intrapersonal competencies. A review of qualitative studies suggested that PBL could positively affect the outcome of ELL students by increasing content accessibility (Golden et al., 2014), providing increased speaking time with English-proficient students (Campbell, 2012), integrating content and skills (Beckett, 2002), and increasing motivation (Beneke and Ostrosky, 2009). It is important to note, however, that ELL students have not always reported favorably on their PBL experience (Beckett, 2002; Moje, Collazo, Carrillo, and Marx, 2001). In his review of the literature, Beckett found evidence that even though some ELL teachers felt that project work facilitated language development, ELL students sometimes preferred the more conventional direct-instruction approach for English language acquisition: "These students felt that project-based instruction prevented them from learning from the teacher and textbooks and from focusing on language skills" (p. 52).

(Beckett, 2002). PBL implementation research should explore this issue directly by investigating the means by which teachers scaffold the PBL experience for ELL students.

Effects of Deeper Learning Network Schools on Cognitive Competencies, Intrapersonal and Interpersonal Outcomes, High School Graduation, and College Entry

A series of AIR reports on high schools in the Deeper Learning Network investigated the relationship between attendance in one of these schools and a range of student outcomes (Zeiser, Mills, Wulach, and Garet, 2016; Yang, Zeiser, and Siman, 2016; Zeiser et al., 2014). The researchers compared data for students who attended well-implemented Network schools in California and in New York City with data for students in comparison schools. They found that, on average, students in Network schools achieved higher scores than did the comparison-school students on the Program for International Student Assessment (PISA) Test for Schools, an international assessment conducted by the Organization for Economic Cooperation and Development (OECD). The test measures core content knowledge and complex problem-solving skills in reading, math, and science. Network school students also achieved higher scores on state-mandated English language arts and math tests (Zeiser et al., 2014)

The evaluation compared the self-reported socioemotional skills of Network school students and their counterparts in non-Network schools. Network school students reported higher levels of collaboration skills (a competency in the interpersonal domain). They also reported higher levels of skill in multiple competencies under the intrapersonal domain, including academic engagement, motivation to learn, and self-efficacy (Zeiser et al., 2014).

Students in the Network schools were about 8 percentage points more likely to graduate from high school on time (that is, within four years after entering ninth grade) than were students from comparison schools — on-time graduation rates were 65.4 percent and 57.5 percent, respectively (Zeiser, Mills, Wallach, and Garet, 2016). And students in Network schools were more likely to enroll in postsecondary institutions than students who attended comparison schools (53 percent compared with 50 percent). In particular, the Network school students were more likely to enroll in four-year institutions than their comparison-school counterparts (22 percent vs. 18 percent). (See Yang, Zeiser, and Siman, 2016.)

These findings are relevant to understanding the effectiveness of project-based learning because PBL was found to be a common practice across all but one of the Network schools included in the study (Huberman et al., 2014). However, it is important to note that, as the authors acknowledge, the model and intensity of PBL varied across the schools in the study and that PBL was just one of many features of the Network schools that could have driven these effects. (Internships, for example, are another such feature.) In addition, although the researchers controlled statistically for differences in observed background characteristics, students were not randomly assigned to Deeper Learning schools. As a result, the better outcomes they experienced may be related to unobserved differences between students attending these schools and those attending non-Network schools.

Discussion

Many studies in this review have reported a positive relationship between PBL and student learning (e.g., Fogleman et al., 2011; Geier et al., 2008; Gültekin, 2005; Halvorsen et al., 2012; Harris et al., 2014; Mergendoller et al., 2006; Mioduser and Betzer, 2007; Parker et al., 2011, 2013; Summers and Dickinson, 2012). However, as noted throughout this section, with a few notable exceptions (e.g., Harris et al., 2014; Shafaei and Rahim, 2015), most quantitative studies investigating the relationship between PBL and student outcomes have not used research methodologies that allow for causal inferences. For this reason, positive findings that report students in a PBL classroom learning as much or more than students in a traditional classroom, or suggest that PBL leads to observed gains in student achievement, should be interpreted with caution.

Many more studies on the PBL and student learning relationship are being conducted in science and social studies classrooms than in math and English/language arts classrooms. It is difficult to know whether this imbalance is related to a PBL approach being better suited for science and social studies classrooms or, rather, reflects the fact that many of the PBL social studies and science curricula were developed by, or in partnership with, university researchers. What is clear is that future research should consider the effects of PBL in other subject areas.

The accumulated research on the LeTUS, IQWST, and PBIS curricula has suggested that their shared roots in project-based science design principles (Krajcik and Shin, 2014) support the design of curricula that positively influence student learning. Research on these specific curricula will undoubtedly continue. Future studies should consider whether these design principles lend themselves to PBL curriculum development in other subject areas, as well as the effects of the design principles on learning when they are applied in other subject areas.

In his review of the research, Thomas (2000) recommended that more attention be paid to whether PBL is more or less effective for specific student subgroups. Several strong theories uphold the idea that PBL may support the learning of lower-achieving students, special education students, and English Language Learners. However, the research evidence on the effects of PBL on specific subgroups is too thin to support any conclusions.

As Thomas (2000) noted, research studies on the relationship between PBL and students' academic achievement continue to outnumber research studies examining PBL's effects on other learning outcomes such as intra- and interpersonal competencies. This disparity is likely related to the challenges associated with assessing deeper learning outcomes (Pellegrino and Hilton, 2012). Clearly, the development of valid and reliable measures of intra- and interpersonal competencies should be a top priority for the PBL research community. Although the existing body of research on PBL's effectiveness does not offer clear conclusions about the efficacy of a PBL approach, the review of PBL research on student outcomes has suggested a number of ways to move the research literature forward; these are described in the next and final section of this review.

Section VI: Key Findings and Recommendations for Future Research

The goals of this review were to: describe how PBL has been defined in the research literature and enacted in K-12 settings, assess the PBL implementation and effectiveness research published since Thomas's (2000) comprehensive review, and recommend priorities for advancing the PBL research literature further. This final section summarizes the findings of this review and provides a number of recommendations to advance the research on PBL design principles, PBL implementation research, and PBL effectiveness research

PBL Design Principles

Thomas's (2000) observation published 17 years ago still holds true: There continues to be a lack of consensus on what constitutes PBL. As the PBL community continues to develop and refine design principles, MDRC recommends that attention be paid to the following:

- **Design Principles Should Be Measurable:** For design principles to be useful to practitioners and researchers, it should be possible to translate the principles into observable measures that set a PBL classroom apart from one using a more traditional approach. Development of design principles should include rubrics that can help practitioners to assess their own implementation of PBL and also facilitate researchers' assessments of implementation fidelity. BIE has linked this type of rubric to their Gold Standard PBL model (Larmer and Mergendoller, 2015a). An important step for the research community will be to ensure that rubrics linked to PBL design principles can be used reliably by internal and external assessors.

- **Design Principles Should Address Both Content and Assessment:** The learning goals in a PBL classroom are different from those in a traditional classroom. As a result, assessment of student learning should also be different. The implementation research has made clear that these differences pose challenges for practitioners. While some PBL design principles provide a guide for how to think about the appropriate content of a PBL approach and modes of assessment in a PBL context (e.g., the assessment should be authentic), not all sets of design principles address this issue. Further guidance is needed on what should be assessed in a PBL context and how that assessment should be administered. The widespread adoption of the Common Core State Standards and the development of the Next Generation Science Standards may provide an opportunity to clarify the learning goals of a PBL approach and to adopt new modes of assessment that more closely align with PBL's deeper learning goals.

- **Design Principles Should Be Informed by Practice:** One of Thomas's (2000) major critiques of PBL research was that the research literature was not sufficiently informed by practice or made relevant to practitioners. Although there is certainly room for improvement in this regard, many of the more recent design principles reviewed have stated explicitly that they were informed by practice and/or designed with practitioners (e.g., Grant, 2002; Krajcik and Shin, 2014; Larmer and Mergendoller, 2015a, Parker et al., 2011, 2013). However, practitioners are also implementing PBL design principles that have not yet made their way into the research literature. For the PBL research literature to be of the greatest use to practitioners, it is important that practice continue to inform the research.

- **Research on Design Principles Should Investigate Adaptation:** Some have argued that design principles for innovations like PBL need to be adapted to fit their local context (see Anderson and Shattuck, 2012, for review). Notably, one of the PBL design principles lists and curricula discussed in this literature review (Parker et al., 2013) considered teacher adaptation of the curriculum to be a core design principle. A systematic study of how educators interpret, adopt, and/or adapt PBL design principles would be a fruitful area for future research (e.g., Linn et al., 2003).[49] Future research might consider questions such as: When and why do some teachers' adaptations contradict the original PBL model? What types of professional development support adaptations that strengthen design principles and implementation? How does school context (e.g., PBL use in other classrooms and school leadership support) influence whether and how teachers adapt PBL design principles?

PBL Implementation Research

Thomas (2000) concluded that PBL was a popular approach among teachers and students but difficult to manage. He noted that the implementation research was very thin and then urged more attention be paid to the challenges that teachers face, as well as to the schools' contextual factors that support implementation. Since the publication of Thomas's review, a number of new approaches to support PBL implementation have been adopted, and case studies on the challenges teachers face when adopting a PBL approach have been completed. The following paragraphs recommend ways to advance the implementation research literature:

- **Explain How Context Matters:** The literature pointing to the effectiveness of whole-school reform models that include PBL as a central component (Ravitz, 2010; Zeiser et al., 2014) has suggested the importance of supportive school leadership and a school culture that aligns with a PBL approach. How-

[49]Linn and colleagues (2003) have conducted this type of research in their study of how design teams use the design principles of the Web-based Inquiry Science Environment (WISE) to create inquiry-based science projects that teachers can then customize to fit their local context.

ever, aside from making clear that supportive school leadership facilitates implementation, the research has not yet clarified how PBL implementation is affected by the broader school context. Future PBL implementation research should examine whether and how PBL is influenced by the broader school context (e.g., school structure, pervasiveness of a PBL approach, school climate and policy). Investigating variation in the implementation fidelity of the same PBL design principles being implemented in different settings could highlight the ways in which local context influences PBL implementation.

- **Investigate the Implementation and Effectiveness of Different Models of Professional Development for PBL:** There are many models of PBL professional development, including online supports, on-site coaching, and in-person trainings delivered in support of an externally developed curriculum. The need for effective professional development is often mentioned in the implementation and effectiveness research. However, specific modes of professional development, such as "educative curriculum materials" (as mentioned in Davis and Krajcik, 2005), direct training, virtual support, conferences, and coaching, have not been rigorously evaluated. An important next step for PBL implementation research is to examine the relationship between the professional development offered for a specific PBL model (curriculum or general design principles) and the fidelity with which teachers implement that model. This includes understanding the amount of training and support needed to achieve high-quality implementation and the most effective and efficient modes of delivery. Since teachers will often need to adapt externally developed curricula to fit their local context, more research is also needed to understand when, why, and how teachers adapt curricula and which best approaches support adaptations that improve a curriculum's implementation and effectiveness.

- **Focus on the Interaction of Technology, Content, and PBL Instructional Strategies:** The PBL implementation literature often cited educational technology as an important tool for supporting student-directed inquiry and scaffolding student learning (e.g., Krajcik and Shin, 2014). More research is needed to understand how technology might address challenges that teachers face in a PBL classroom, including concerns about classroom control, the depth of student inquiry, the challenges students face in learning through text, and modes of formative and summative assessment. One way to address this issue would be to compare the implementation of two versions of a specific PBL curriculum — one that includes technology embedded into the curriculum and another that does not. Additionally, targeted implementation research on differences between the use of technology in PBL and non-PBL classrooms would help to elucidate what distinguishes technology use in a PBL classroom.

- **Pay Attention to Teacher-Initiated PBL:** Teacher-initiated PBL is likely the most common way that students are exposed to a PBL approach, but it is the least well understood. Indeed, 17 years ago, Thomas (2000) recommended that more attention be paid to teacher-initiated PBL. Although small-scale case studies have been conducted since Thomas's review (e.g., Hertzog, 2007; Toolin, 2004), more research is needed to understand when, why, and how teachers initiate PBL on their own as well as which challenges they face in designing a coherent PBL approach (Fortus and Krajcik, 2012).
- **Study the Relationship Between Teachers' Beliefs and Implementation:** The review of the implementation research has suggested that teachers' beliefs and experiences shape their openness to a PBL approach and its implementation. Future research with teachers who are attempting to implement the same PBL approach (e.g., an externally developed PBL curriculum) should consider whether teachers' beliefs about teaching explain variation in implementation.

Research on the Effectiveness of PBL

A significant body of research on the relationship between PBL and student outcomes has accumulated since Thomas's (2000) review. However, except for research on PBL science curricula (e.g., LeTUS, PBIS, and IQWST), the studies published in the past 17 years do not share common design principles. Without a common set of PBL design principles, it is difficult to use the existing body of research to draw conclusions about PBL's effectiveness. Therefore, a top priority for the PBL community should be to develop or refine PBL design principles that can be rigorously evaluated in a number of different settings, such as for different grade levels, student populations, and subject areas. Future research on the relationship between PBL and student outcomes should also:

- **Use More Rigorous Evaluation Methodologies:** Future research on outcomes should use rigorous methods such as randomized controlled trials to estimate the impact of PBL on student outcomes.[50] Except for a handful of studies (Finkelstein et al., 2011; Harris et al., 2014; Wirkala and Kuhn, 2011; Shafaei and Rahim, 2015), most of the quantitative outcome studies reviewed in this paper must be considered descriptive because concerns about internal validity preclude causal inferences. Even when a comparison group is used, differences in observed outcomes may have been caused by pre-program differences in student characteristics.

[50] A key need in any reliable impact evaluation is to understand the "service contrast" — that is, the actual difference in the extent to which PBL design principles are implemented in the PBL and business-as-usual classrooms.

This type of selection bias is a particular concern in evaluations of instructional innovations because the same characteristics that may lead a school, teacher, or student to opt into an innovative approach may also be related to the student outcomes being studied (Raudenbush, 2005). These unmeasured factors are referred to as "unobserved confounders"; in the case of a PBL intervention, they might include a teacher's predisposition toward innovation, a student's or teacher's level of motivation, a student's or teacher's feelings of self-efficacy, or a school's policies on how students are assigned to classes. In this way, the positive outcomes found for the students exposed to PBL may have been observed even in the absence of PBL.

- **Develop Reliable Measures of Intra- and Interpersonal Competencies:** Thomas (2000) called for greater attention to be paid to the effects of PBL on a range of outcomes, including collaboration, metacognition, and communication skills. Studies investigating the relationship between PBL and cognitive competencies continue to far outnumber investigations of the relationship between PBL and intra- and interpersonal competencies. This difference is likely related to the greater availability of valid and reliable measures of certain cognitive skills, as well as to the high level of importance that mainstream policymakers place on these skills. The recent interest in improved intra- and interpersonal competencies as benefits of deeper learning, together with calls to develop improved measures in these domains (Pellegrino and Hilton, 2012; Scardamalia et al., 2012), could lead to an increased assessment of these competencies in the future.

- **Study PBL's Effect on Math and Literacy Skills:** It is important to know whether and how PBL's effectiveness differs by subject area, but studies of PBL in science and social studies classrooms far outnumber studies of PBL in math or English/language arts classrooms. At least in the lower grade levels, math and English courses typically require much greater emphasis on skills development than do science and social studies courses. It is certainly possible that PBL could be an effective strategy for supporting skills development and engaging learners who are behind in their skills. However, the research literature needs to address this issue directly.

- **Focus on Underserved Student Populations:** PBL is theorized to be effective for lower-achieving students and students who have typically had fewer opportunities in traditional educational settings, such as students with special needs, low-income students, and students with limited English proficiency. However, few studies consider the efficacy of a PBL approach for different student subgroups. Researchers should develop clear hypotheses about how and why a specific PBL approach would benefit certain subgroups and then conduct reliable studies to test these hypotheses. It will be important to couple these impact studies with rich implementation studies that can uncover any specific challenges of implementing a PBL approach with specific student populations. For example, it might be that design principles for PBL used with certain subgroups like English Language Learners need to be adapted and enhanced to meet the learning needs of that subgroup.

Conclusion

Much has changed in education research, practice, and policy since the publication of Thomas's (2000) widely cited literature review. Thomas argued that PBL research was needed in light of recent emphasis on mandates like standardized testing, which he believed tended to "move schools in the direction of traditional, teacher-directed instruction" (p. 38). Due in part to the backlash against the test prep curricula of the No Child Left Behind era and concern that the emphasis on cognitive competencies assessed through standardized tests has not produced its intended effects, the education reform movement seems to be shifting toward an emphasis on deeper learning and other 21st century competencies considered necessary for success in college and career. This new focus on higher-level thinking skills as well as intra- and interpersonal skills aligns well with the goals of a PBL approach. Additionally, advances in educational technology make information on instructional innovations like PBL more accessible to teachers, opening up new opportunities for implementation.

Although practitioners and education reform advocates are interested in taking PBL to scale, the research evidence has not kept up with the increasing interest in PBL from the field. More rigorous evidence is needed to confirm whether PBL is a better approach to prepare students for college and career than traditional teacher-directed methods. This review has offered some recommendations for advancing the research agenda in a direction that would help build the evidence needed to decide whether specific PBL models are ready to be brought to scale.

Appendix A: PBL Design Principles[51]

The literature review synthesized the information on the PBL design principles listed in this table. As noted in the main text, these design principles were selected because they are frequently encountered in the recent research literature and/or because they help to illustrate the diversity of PBL design principles that are cited in the literature.[52]

Citation	Design Principles
Darling-Hammond et al. (2008)	In their review of the literature on "inquiry-based approaches" to learning, which include project-based, problem-based, and design-based learning, Darling-Hammond and colleagues (2008) articulated the "Design Principles for Supporting Inquiry-Based Approaches." Unless otherwise indicated, the design principles are quoted directly from the text (pp. 214-216). 1. Problem design: Projects and problems should be complex, open-ended, and realistic; have multiple solutions and methods for reaching solutions; and resonate with students' experience. They should be designed to maximize the probability that students will encounter the big ideas specified in the learning goal and should lead students to confront and resolve conflicting ideas to prevent "doing for the sake of doing." 2. Cycles of work with ongoing assessment and feedback: Sustained project work needs to be designed so that there are cycles of work and revision and adequate time to complete them. Processes should be set in place such that students frequently encounter feedback on their work to date; both peer and teacher feedback can be useful. Feedback that includes explicit suggestions for revision and time for students to implement the revision supports learning. 3. Authentic audiences and deadlines: Working toward a deadline that includes sharing with an outside audience can be highly motivating for students. These deadlines can serve as a vehicle to elicit feedback and revise work before finalizing products. 4. Scaffolds and resources: Informational resources, models of good work, exposure to mature thinking about inquiry, and

[51]The concept of design principles is different from a definition of PBL in that design principles are specific criteria intended to help people know when they are observing or doing PBL. What we are calling "PBL design principles" is sometimes referred to as "PBL principle components," "PBL criteria," "essential elements of PBL," or an "exposition" of the PBL model or approach being evaluated by a researcher. We refer to all of these concepts as "PBL design principles" in this paper.

[52]Barron et al. (1998) developed an influential list of design principles that were not included in this review because Barron co-authored a more recent work with Darling-Hammond and colleagues (2008) that listed the design principles for supporting inquiry-based approaches.

Citation	Design Principles
	access to experts can support learning in various ways. Building in redundancy across resources is the key as it keeps the focus on learning concepts and encourages students to connect these concepts with their design work. Time is also an important resource. Students must be given enough time to reason well and pursue a problem in depth. 5. Productive classroom norms and activity structures: Norms established in the larger classroom context such as accountability, intellectual authority, and respect support small group interactions. [See text for more detail on the types of norms that support productive work.] 6. New roles for teachers and students: Teacher helps to facilitate the progress through the cycle of work and asks questions to make thinking visible, giving students authority to define and address problems and encouraging them to be authors and producers of knowledge. 7. Opportunities for ongoing reflection: Time should be built into projects or problems for students to reflect deeply on the work they are doing and how it relates to larger concepts specified in the learning goal, including deep questioning about process and understanding.
Grant (2002)	Grant (2002) reviewed the theoretical underpinnings of PBL and provided three different examples of implementation to discern the common features of a PBL approach. The following seven PBL elements are excerpted verbatim from his text (p. 2). 1. Introduction. Many projects use an introduction “to set the stage” for, or anchor, the project. This often contributes to motivating learners. Occupational skills, such as graphic arts or webpage design, typically use the domain as the anchor, since the skills are authentic to the profession. 2. Task. The task, guiding question, or driving question explicates what will be accomplished and embeds the content to be studied. The tasks should be engaging, challenging, and doable. 3. Resources. Resources provide data to be used and can include hypertext links, computers, scientific probes, compasses, CD-ROMs, eyewitnesses, etc. 4. Process. The process and investigation include the steps necessary to complete the task or answer the guiding or driving question. The process should include activities that require higher-level and critical thinking skills, such as analysis, synthesis, and evaluation of information. 5. Guidance and scaffolding. As learners need help, guidance and scaffolding will be needed. These can include student-teacher interactions, practice worksheets, peer counseling, guiding questions, job aides, project templates, etc. 6. Cooperative/Collaborative learning. Many projects include groups or teams, especially where resources are limited.

Citation	Design Principles
	But, cooperative learning may also employ rounds of peer reviews or group brainstorming sessions. 7. Reflection. The superior examples of project-based learning offer an opportunity for closure, debriefing, or reflection. These may include relevant in-class discussions, journal entries, or even follow-up questions about what students have learned.
Krajcik and Shin (2014)	In their chapter in *The Cambridge Handbook of the Learning Sciences*, Krajcik and Shin (2014) described the six "key features" of PBL environments, excerpted below (p. 276). The chapter then explains how they have applied and learned from these features in their work on PBL use in science classrooms (IQWST and LeTUS).[53] 1. Driving Questions: "They start with a driving question, a problem to be solved." 2. Focus on Learning Goals: "They focus on learning goals that students are required to demonstrate mastery on key science standards and assessments." 3. Scientific Practices: "Students explore the driving questions by participating in scientific practices — processes of problem solving that are central to expert performance in the discipline. As students explore the driving question, they learn and apply important ideas in the discipline." 4. Collaborative Activities: "Students, teachers, and community members engage in collaborative activities to find solutions to the driving question. This mirrors the complex social situation of expert problem solving." 5. Learning Technology Scaffolds: "While engaged in the practices of science, students are scaffolded with learning technologies that help them participate in activities normally beyond their ability." 6. Creation of Artifacts: "Students create a set of tangible products that address the driving question. These are shared artifacts, publicly accessible external representations of the class's learning."
Larmer and Mergendoller (2015a)	The Buck Institute for Education (BIE) recently revamped its original eight essential elements of PBL (see Larmer and Mergendoller, 2015b). BIE explained that the project design needs these elements in order to be considered the "gold standard" of PBL (Larmer and Mergendoller, 2015a). The verbatim excerpt below appears on the BIE (2015) website in its design elements checklist. Larmer and Mergendoller reported that it was also adapted from their recently published book (see Larmer, Mergendoller, and Boss, 2015). 1. Key Knowledge, Understanding, and Success Skills: The

[53] The IQWST webpage lists slightly different design principles than those listed here (IQWST, 2015).

Citation	Design Principles
	project is focused on teaching students key knowledge and understanding derived from standards, and success skills including critical thinking/problem solving, collaboration, and self-management. 2. Challenging Problem or Question: The project is based on a meaningful problem to solve or a question to answer, at the appropriate level of challenge for students, which is operationalized by an open-ended, engaging driving question. 3. Sustained Inquiry: The project involves an active, in-depth process over time, in which students generate questions, find and use resources, ask further questions, and develop their own answers. 4. Authenticity: The project has a real-world context, uses real-world processes, tools, and quality standards, makes a real impact, and/or is connected to students' own concerns, interests, and identities. 5. Student Voice and Choice: The project allows students to make some choices about the products they create, how they work, and how they use their time, guided by the teacher and depending on their age and PBL experience. 6. Reflection: The project provides opportunities for students to reflect on what and how they are learning, and on the project's design and implementation. 7. Critique and Revision: The project includes processes for students to give and receive feedback on their work, in order to revise their ideas and products or conduct further inquiry. 8. Public Product: The project requires students to demonstrate what they learn by creating a product that is presented or offered to people beyond the classroom.
Parker et al. (2011, 2013)	The following are the design principles that shaped the Knowledge In Action (KIA) approach to designing a U.S. Government and Politics AP-PBL course. Parker and colleagues explained that the first three design principles are related to the learning theory of their PBL approach and the final two principles are related to the design-based research approach they engaged in for their study. The literature review focused on the first three principles, but all five design principles (Parker et al., 2013, pp. 1432-1435) are listed here. 1. Rigorous projects as the spine of the course: Challenging projects are the "main course, not dessert" (Parker et al., 2013, pp. 1432-1435). 2. Quasi-repetitive project cycles: "Central to this design principle is that the projects are united by a course 'master question.' As students move through the different projects, they revisit (loop back on) the master question and 'try again' to generate a response, reflecting on what they have gleaned from the prior project cycles and the project cycle

Citation	Design Principles
	at hand" (Parker et al., 2013, p. 1433). 3. Engagement that creates a need to know: Readiness for learning new content is developed before students are exposed to that content. Students first take on the role they will play in the project before they are exposed to new content during the "telling" (i.e., lecture or reading). This sequencing intends to enhance student engagement during the "telling." 4. Teachers as co-designers: Teachers are course "designers and curriculum makers" (Parker et al., 2013, p. 1434). 5. A course that can scale (migrate): The course is designed in such a way that it could be adopted and adapted in other settings.
Ravitz (2010)	For the purposes of his study, Ravitz (2010) operationalized and defined his project-based learning approach broadly in order to be inclusive of teachers' participation levels, while acknowledging that a more rigorous version exists. Below are excerpted titles for each of his principles (p. 293): 1. In-depth inquiry 2. Over an extended period 3. Student self-directed to some extent 4. Formal presentation of results
Thomas (2000)	Thomas (2000) lists five criteria that can answer the question: "What must a project have in order to be considered PBL?" The following descriptions of Thomas's five criteria were excerpted directly from Thomas's text (pp. 3-4): 1. Centrality: PBL projects are central, not peripheral to the curriculum. 2. Driving Question: PBL projects are focused on questions or problems that "drive" students to encounter (and struggle with) the central concepts and principles of a discipline. 3. Constructive Investigations: Projects involve students in a constructive investigation. An investigation is a goal-directed process that involves inquiry, knowledge building, and resolution. 4. Autonomy: Projects are student-driven to some significant degree. 5. Realism: Projects are realistic, not school-like.

Appendix B: Overview of Learning Science Research and Its Implications for PBL

Theoretical Basis of PBL: How and Why Could PBL Support Student Learning?

PBL has its roots in numerous educational theories that support hypotheses on the positive relationship between PBL and student learning outcomes. John Dewey's philosophy of experiential education and William Kilpatrick's "Project Method" (Ravitch, 2000)[54] laid the theoretical groundwork for PBL. More recently, research on how students develop 21st century learning competencies (Pellegrino and Hilton, 2012) and the "science of learning" (Bransford, Brown, and Cocking, 1999) have suggested ways in which PBL *could* influence a broad range of student outcomes.

A recent publication from the National Research Council (NRC) (Pellegrino and Hilton, 2012) sought to define the set of student competencies that support important adult outcomes such as employment, health, and educational attainment. In the education research literature and education reform discourse, these competencies are often labeled as "21st century skills," "deeper learning," or "college and career readiness skills." The NRC committee clarified these concepts by defining "21st century learning competencies" as the "transferable knowledge" and "skills" that are produced through deeper learning processes (Pellegrino and Hilton, 2012, p. 23). Drawing on the "science of learning" (Bransford et al., 1999), the committee defined deeper learning as "the process through which an individual becomes capable of taking what was learned in one situation and applying it to new situations (i.e., transfer)" (Pellegrino and Hilton, 2012, p. 5). Other scholars are also in agreement that 21st century competencies are the results of deeper learning (Huberman et al., 2014). Pellegrino and Hilton (2012) noted that through this process, the individual moves from being a novice in a particular skill or subject area to becoming an expert.

The core design principles of many PBL models intend to support the transition of students from novices to experts and the development of students' capacity to transfer knowledge (see: Pellegrino and Hilton, 2012). As a result, schools and other entities invested in deeper learning often cite PBL as a core instructional strategy (Huberman et al., 2014; Pellegrino and Hilton, 2012). The paragraphs below provide a brief overview of research on these defining features of deeper learning and the ways in which PBL can support their development in: 1) moving from novice to expert and 2) learning for transfer.

[54] We note that recent historical analyses have demonstrated that the theories of Kilpatrick and Dewey were not necessarily compatible (Sutinen, 2013).

Novices and Experts

In his brief review of the literature on experts and novices and the relevance of this research for PBL, Thomas (2000) noted this body of research has suggested that one way to support student learning is to "simulate the conditions under which experts master subject matter and become proficient at conducting investigations" (p. 7). As described in prior sections of this paper, many PBL design principles seemingly set the stage for the conditions under which novices become experts. Particularly relevant to the research on experts and novices are the design principles related to anchoring the curriculum in driving questions or big ideas. These questions and ideas should support the development of students' self-regulation skills, conceptual knowledge, and sense of autonomy (Darling-Hammond et al., 2008).

Learning for Transfer

Learning for transfer refers to the concept that students should be able to "extend what has been learned in one context to new contexts" (Bransford et al., 1999, p. 39). Based on their review of the literature on the science of learning, Bransford and colleagues noted specific considerations that educators should make when designing learning environments for transfer (for a complete review, see Bransford et al., 1999, pp. 39-66). The following considerations align with the aspirations of many PBL models:

- **A Strong Foundation of Initial Knowledge Is Essential:** Bransford and colleagues (1999) noted that achievement of initial knowledge or mastery of a particular subject or skill is supported when:
    - *Educators teach for conceptual understanding as opposed to memorization.* Teaching for conceptual understanding (Darling-Hammond, 2008a) requires that students be given sufficient time to engage in inquiry and that teachers assess the progress of students in order to adjust instruction and students' work. Teaching for conceptual understanding as opposed to rote memorization was implicitly or explicitly communicated in all design principles reviewed for this paper.
    - *Educators support the development of students' intrinsic motivation to learn.* Bransford and colleagues (1999) noted that this goal can be achieved by providing students with developmentally appropriate challenges, levels of learning support, and social opportunities for learning. PBL design principles that mention learning scaffolds, collaborative learning, and assessments involving a public audience clearly align.
- **Connections to Prior Knowledge and Real-Life Experience:** Transfer is promoted when teachers acknowledge and build upon students' prior knowledge and experiences, including cultural practices. Transfer is also promoted when connections are made to everyday life. The emphasis on the authenticity of the project's content in a PBL classroom, or the driving ques-

tions anchoring a PBL unit, can support students' capacity to make connections to prior knowledge and real-life experiences.

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Over the years, MDRC has brought its unique approach to an ever-growing range of policy areas and target populations. Once known primarily for evaluations of state welfare-to-work programs, today MDRC is also studying public school reforms, employment programs for ex-prisoners, and programs to help low-income students succeed in college. MDRC's projects are organized into five areas:

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- Improving Public Education
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