ELEMENTARY TEACHERS’ LEARNING TO CONSTRUCT HIGH-QUALITY MATHEMATICS LESSON PLANS

A Use of the IES Recommendations

ABSTRACT
This study explored a group of elementary teachers’ (n = 35) learning to construct high-quality lesson plans that foster student understanding of fundamental mathematical ideas. The conceptual framework for this study was gleaned from the recently released Institute of Education Sciences (IES) recommendations, including (a) interweaving worked examples and practice problems, (b) connecting concrete and abstract representations, and (c) asking deep questions to elicit student self-explanations. Comparisons between teachers’ pre- and post-surveys, and among teachers’ initial, revised, and end-of-course lesson plans, indicated teachers’ growth in using worked examples, representations, and deep questions during their lesson planning. Issues related to teachers’ learning as they constructed lesson plans that aligned with the IES recommendations were also revealed.

LESSON plans are "intended curricula" reflecting teachers’ thinking about how a lesson should be taught (Clark & Yinger, 1987; Remillard, 1999; Stein, Remillard, & Smith, 2007). Lesson planning closely relates to classroom instruction (Burns & Lash, 1988; Stein et al., 2007) and students’ learning outcomes (Peterson, Marx, & Clark, 1978). Yet, the quality and style of many U.S. teachers’ mathematics plans are discouraging, especially when compared with those of their counterparts from high-achieving countries (Cai, 2005; Fernandez & Cannon, 2005). These findings call for greater effort to deliberately support teachers’ lesson-planning skills. This study documents such an instructional effort, reporting how teachers learn to construct high-quality mathematics lesson plans guided by the recently released Institute of Education Science (IES) recommendations (Pashler et al., 2007).

Prior Research on Lesson Planning

Many studies have explored teachers’ conceptions of lesson planning (e.g., Sardo-Brown, 1990, Yinger, 1986). Experienced teachers, compared with novice teachers, more strongly believed that they did not need to devote much time to lesson planning (Sardo-Brown, 1990). Elementary teachers held this belief more firmly than their secondary counterparts because elementary teachers felt that detailed plans would hinder their ability to make connections across subjects and prohibit their teaching flexibility (Kagan & Tippins, 1992). The tendency to spend relatively little time developing lessons and to produce outlines (e.g., Brown, 1988; Peterson et al., 1978) appears to be a cultural style specific to U.S. teachers (e.g., Cai, 2005; Fernandez & Cannon, 2005). For example, Cai (2005) studied the difference between Chinese and U.S. teachers’ representations of mathematics lessons. Nine Chinese and eleven U.S. distinguished mathematics teachers created introductory lesson plans for the topic of “average.” It was found that Chinese plans were more detailed and longer (4–9 pages) than the U.S. plans, which were mainly in “outline and worksheet” formats (3–5 pages). Although the length of a lesson plan does not necessarily reflect its quality, a brief outline cannot adequately prepare teachers to “unfold tasks” during classroom instruction (Chastainbous, 2000). Effective teaching entails deciding “what to teach, how to represent it, how to question students about it and how to deal with problems or misunderstanding” (Shulman, 1986, p. 8). However, U.S. teachers studied in Cai (2005) did not agree on what tasks to use for teaching the same topic, even when teachers were from the same school and used the same textbooks. In addition, U.S. teachers who viewed using manipulatives as indicators of good lesson plans actually meant “collecting and copying materials” rather than how the materials would be used to teach the targeted mathematical concept (Cai, 2005; Fernandez & Cannon, 2005). Failing to carefully consider key teaching components in lesson plans might be due to teachers’ beliefs. For example, some teachers believe that students should not be shown how to solve problems and should instead figure out how to solve problems themselves (Burns & Lash, 1988). Beliefs like this were more popular in classrooms where teachers misunderstood constructivism as a theory for teaching rather than a theory of learning (Anderson, Reder, & Simon, 2000). Such beliefs make detailed lesson planning or teacher guidance seem unnecessary. However, minimal guidance during students’ problem solving did not work because, in some cases, students searched for irrelevant information that taxed their limited working memory (Kirschner, Sweller, & Clark, 2006). In fact, advocates of problems-based approaches to learning also suggested that teachers carefully structure classroom activities to allow students access to “expert guidance” (Hmelo-Silver, Duncan, & Chinn, 2007).

It is clear that, to improve the effectiveness of teaching and learning, teachers should first consider...
the “design” of classroom instruction, which begins with careful lesson planning (Brown, 2009).

Prior research on lesson planning focused mainly on teachers’ natural styles and thinking. Very few studies have explored how teachers can be deliberately supported to construct high-quality mathematics lesson plans. Since lesson planning is a complex process (Fernandez & Cannon, 2005), it might be unreasonable to expect teachers to effectively develop lesson-planning skills by themselves. As such, there is a need to guide and support teachers’ lesson-planning practices (Fernandez & Cannon, 2005). This study addresses such a need, exploring how the recently released Institute of Education Science (IES) recommendations for instructional principles can be used as scaffolds to support elementary teachers’ lesson planning.

Conceptual Framework for Improving Quality of Lesson Plans

The IES recommendations (Pashler et al., 2007), drawn from numerous evidence-based studies in the fields of cognitive science, experimental psychology, and classroom research, were intended to help teachers organize instruction to improve student learning. Since lesson planning is a critical first step to instruction, it is meaningful to use relevant IES recommendations to support teachers as they craft lesson plans. Among the seven recommendations (simply “R’s”), we recognized R1 (spacing learning over time) as an important element in long-range lesson planning, but chose not to include it because our focus was on developing a single plan. We thought R3 (combine graphics with verbal descriptions) was related to R4 (connect concrete and abstract representations) because R3, the use of graphics, could be considered a concrete representation. For simplicity, we focused on R4. In addition, we excluded R5 (use quizzing to promote learning) and R6 (help students allocate study time efficiently) because these principles are relatively far from the planning and teaching process, and their levels of evidence were low (except R1, post-quizzing). As such, the recommendations that form a conceptual framework for this study included (a) interweaving worked examples with practice problems (R2), (b) connecting concrete and abstract representations (R4), and (c) asking deep questions to elicit student self-explanations (R7).

Worked examples. Worked examples are problems with solutions given. Effective examples can serve as instantiations of general principles. The use of worked examples may facilitate students’ schema acquisition, which enables students to retrieve relevant information to solve new problems, resulting in effective learning (Kirschner et al., 2006; Sweller, 1988, 2000). As such, it is necessary for teachers to know that there are times when worked examples are applicable and should be included in their lesson plans. However, effective teaching through worked examples involves more than showing procedures and telling solutions. This is because worked examples typically contain unexplained actions (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). When students explain why particular actions are taken, their understanding of an example and the underlying general principles can be enhanced (Atkinson, Renkl, & Merrill, 2003; Chi et al., 1989; Chi, de Leeuw, Chiu, & VanLehn, 1994). Other researchers (e.g., Carpenter, Fennema, Franke, Levi, & Empson, 1999) also found that children construct important mathematical ideas when they participate in activities that allow for meaning making. Therefore, when teaching a worked example, teachers should consider how to engage students’ thinking and facilitate their explanations. In addition, gradually “fading” examples into practice problems (Renkl, Atkinson, & Große, 2004) and interweaving examples with problem solving (Sweller & Cooper, 1987) benefited student learning. In this study, the textbook materials used for teachers’ lesson planning included worked examples. We expected teachers to carefully unpack an example and plan corresponding practice problems to improve the effect of example on learning.

Representations. Concrete representations support initial learning because they provide familiar situations that students can draw on to construct meanings for abstract ideas (Rosnick, Cuisinier-Marmoche, & Mathieu, 1987). However, an over-reliance on concrete situations may hinder students’ transfer of learned knowledge to new contexts (Koedinger, Aihali, & Nathan, 2008). Thus, concrete representations should be linked to abstract ideas in order to prompt students’ deep learning of key concepts (Pashler et al., 2007). Recently, cognitive psychologists (Goldstone & Son, 2005) have recommended “concreteness fading” as an effective method for linking concrete to abstract. In Goldstone and Son’s study, the concreteness-fading method was used to gradually change the appearance of ants and food from vivid pictures to dots, lines, and patches during students’ learning of a scientific principle—competitive specialization. It was found that students who learned through concreteness fading outperformed their counterparts in both initial learning and transfer tasks. Concreteness fading was also reported to be effective in supporting students’ learning and transfer of mathematical concepts such as equivalence (Fyfe & McNeil, 2009). In this study, we expected teachers to incorporate the concreteness-fading method in lesson planning to effectively link concrete situations to abstract ideas. For example, a teacher may first present a concrete situation (e.g., story problems with vivid illustrations), then model it using semiconcrete representations (e.g., dots, cubes, number line or tape diagrams), and eventually transform the situation into abstract symbols. In particular, the number line and tape diagrams (drawings that look like tapes, strips, or bars, used to illustrate quantitative relationships), commonly used in Asian curricula (Ding & Li, 2000; Murata, 2008), were powerful tools to connect concrete and abstract (Pashler et al., 2007).

Deep questions. Deep questions target underlying principles, structure, and causal relationships (Craig, Sullivan, Whientspoon, & Ghoshal, 2006). When students are prompted to explain underlying structures or relationships, their “germane cognitive load” is increased, which contributes to schema acquisition and automation (Sweller, 2006) and results in effective learning (Chi et al., 1994). In fact, both the National Council of Teachers of Mathematics (NCTM, 2000) and the American Association for the Advancement of Science (AAAS, 1993) have strongly recommended that students communicate, explain, and justify their mathematical thinking. Thus, teachers should ask deep questions to elicit students’ self-explanations (Pashler et al., 2007). Bouler and Staples (2008) found that when teachers wrote questions before teaching a lesson they had specific strategies for drawing students’ attention to key mathematical ideas. Indeed, Cai (2005) reported that, unlike U.S. teachers, Chinese teachers uniformly included questions in their lesson plans. In addition, teachers should anticipate deep explanations for their proposed questions. Otherwise, guidance may remain superficial and may stop prompting students’ thinking too quickly.
Supporting Teacher Changes through Textbook Experiences

We used existing textbook materials as a basis for discussing how to incorporate the IES recommendations when planning lessons. A large body of research has suggested that curriculum materials play a central role in teachers’ curriculum planning and instructional practices (Ball & Cohen, 1996; Nathan, Long, & Alibali, 2002; Remillard, 2005). A variety of factors, including teacher knowledge and beliefs, orientations, personal identities, and local contexts, influence the ways in which teachers read, interpret, and eventually implement curricula (Drake & Sherin, 2006; Forbes & Davis, 2010; Lloyd, 1999, Pintó, 2005; Remillard, 1999, 2005; Valencia, Place, Martin, & Grossman, 2006). Prior studies have suggested that teachers may off-load, adapt, or improvise with curriculum materials. These actions indicate a literal use of curriculum, a combination of using curriculum materials and personal resources, or a minimal reliance on curriculum materials, respectively (Brown, 2009; Remillard, 1999).

Understanding the ways in which teachers interpret and use textbooks may allow teacher educators to better use textbook materials to support teacher learning and change (Remillard, 1999). Left to their own devices, teachers may rely on what is consistent with their experiences as learners and misinterpret the intention of curricular structures and student activities (Lloyd & Behm, 2005). However, recent work in science education has revealed the benefits of supporting preservice teachers’ interpretation and adaptation of existing curriculum materials (Beyer & Davis, 2012; Forbes, 2016). Forbes found that preservice teachers were able to adjust curriculum used in elementary school classrooms to provide opportunities for students to formulate questions, gather and interpret data, and communicate and evaluate “evidence-based explanations” (p. 941). As such, our integration of textbook materials in this study may enhance teachers’ pedagogical design capacity, that is, their ability to “perceive and mobilize existing resources in order to craft instructional episodes” (Brown, 2009, p. 29). The integration of textbook materials and the IES recommendations through lesson planning may also enable textbooks to function as educative curriculum materials that support teachers’ learning and changes (Ball, 1998; Davis & Krajick, 2005; Drake & Sherin, 2006). Indeed, teachers in mathematically high-achieving countries such as China consistently reported that intensive study of textbooks was a necessary part of producing quality lesson plans and teaching (Cai & Wang, 2010; Ding, Li, Li, & Gu, in press).

This Study

This study explores how the IES recommendations can be used to support elementary teachers as they learn to construct high-quality mathematics lesson plans based on existing textbook materials. To the best of our knowledge, our study is among the very first to document such an effort. In particular, we ask two questions: (a) To what extent can elementary teachers be supported to learn to use worked examples, representations, and deep questions in lesson planning based with existing textbooks? (b) If worked examples, representations, and deep questions are learnable, what challenges might teachers face in learning these components during lesson plan development?

Method

Participants

A group of K–3 in-service teachers (n = 35) who participated in a National Science Foundation–funded project at the University of Nebraska–Lincoln took a 2-week intensive summer graduate course. The first author was the lead instructor for the course, and the second author was a teaching assistant. This course was part of a larger professional development program that aimed to increase K–3 teachers’ capacity to be intentional, planful, observant, and reflective practitioners. All the participants were female and came from 13 cities statewide. At the time of the course, 28 of the participants were preparing to return to their districts as classroom teachers, and 7 were preparing to be building- or district-level coaches. All of the participants had previous teaching experience ranging from 3 to 40 years.

The Summer Course

One of the goals of the summer course was to improve teachers’ lesson-planning skills based on the IES recommendations. Teachers were asked to read the IES document (Parshall et al., 2007) before the summer course. During the first class, we discussed the IES recommendations focusing on the use of worked examples, representations, and deep questions in a general sense. Throughout the 2 weeks, we situated our discussion of these recommendations in three fundamental mathematical topics: (1) the concept of equivalence denoted by the equal sign (=), (2) the inverse relations between addition and subtraction and between multiplication and division, and (3) the basic laws of arithmetic including commutative, associative, and distributive properties. Table 1 illustrates a timeline of the professional development (PD) activities.

As indicated by Table 1, during the first week, we discussed the equal sign, the additive inverses, and the properties of addition (commutative and associative). During the second week, we addressed multiplicative inverses and properties of multiplication (commutative, associative, and distributive). For each topic, we discussed the relevant literature and related the readings to the IES recommendations. For example, for the concept of equivalence, we discussed Li, Ding, Capraro, and Capraro (2005) and investigated students’ misinterpretation of the equal sign as an operational rather than relational sign.

Table 1. Timeline and Data Collected for This Study

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<thead>
<tr>
<th>PD Activity/ Data Collected</th>
<th>Week 1</th>
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</table>

*Indicates the data collected for this study.
We discussed how the Chinese first-grade textbook introduced the equal sign in a comparison context and used the concreteness-fading method (e.g., fading from vivid animal illustrations to circles, and then to abstract number sentences). We also discussed literature (e.g., Murata, 2008; Resnick et al., 1987) that supported the IES recommendations. We then examined textbook pages selected from K–5 Houghton Mifflin (Greenes et al., 2005), a textbook series that was used by most of our participants at the time they participated in this study. We prompted teachers to think about how they could maximize the use of the existing examples and representations and ask deep questions to support students’ learning.

Over the 2 weeks, we discussed two sample plans written by Chinese expert teachers (e.g., Cai, 2005; see Table 1). Both plans addressed the topic of “average.” We asked teachers to evaluate the plans using a rubric aligned with the IES recommendations (elaborated below). The purpose of these activities was twofold. First, the activities familiarized teachers with the rubric we would use to evaluate their plans. Second, examining exemplary plans that aligned with the selected IES recommendations offered teachers concrete images of thorough lesson plans that could act as models for their own work.

During the course, teachers were asked to construct their own lesson plans. Initially, teachers were given a textbook page to use as the basis for their plans. These plans were then revised based on instructor feedback (elaborated below). Writing and revising a lesson plan laid a foundation for the teachers’ final project, the end-of-course (EOC) lesson plan, which was independent work. The three lesson plans (initial, revised, and EOC), along with pre- and postsurveys, were collected as sources of data for this study (see Table 1).

Data Sources

Three lesson plans. At the end of the first class, we asked teachers to design a plan using a first-grade lesson from the Houghton Mifflin series (see Fig. 1). This lesson targeted the inverse relationship between addition and subtraction. The textbook pages clearly included a worked example around the equations 6 + 3 = 9 and 9 − 3 = 6 and suggested different types of representations with varied levels of concreteness. For instance, there was a kitten illustration with six kittens on the left side of the page and three on the right, a part-part-whole mat with yellow and blue cubes on it, and the number sentences 6 + 3 = 9 and 9 − 3 = 6. However, the representations were not arranged from concrete to abstract (see Fig. 1). We expected teachers to incorporate the concreteness-fading method—first by using the kitten illustration to situate the example in a concrete context, then to model the problem with cubes and a part-part-whole mat, and eventually fade into abstract number sentences. We also expected teachers to ask deep questions to prompt students to see the inverse relations (e.g., how 6 + 3 = 9 and 9 − 3 = 6 are related in terms of the story situation, the part-part-whole model, or the paired number sentences).

Because this was teachers’ initial lesson plan, we did not discuss the textbook page with teachers until after it was completed. We simply encouraged teachers to write plans based on their current understanding of planning and the aforementioned rubric. The rubric included six subcategories (see Table 2). Under “worked examples,” we expected teachers to (a) sufficiently discuss at least one worked example, and (b) fade examples into carefully designed practice problems. Under “representations,” we expected teachers to (a) meaningfully use concrete representations, and (b) connect concrete to abstract repre-
Table 2. An Example of Feedback to Teachers' Initial Plan

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worked examples</td>
<td>(a) Sufficiently discuss at least one worked example</td>
<td>The time allotted to worked example (20 minutes) is appropriate. Yet, your current plan may not take into account other factors during actual classroom discussions. Feedback: “You may lack evidence of sufficient discussion of a worked example with students.”</td>
</tr>
<tr>
<td></td>
<td>(b) Provide examples to carefully designed practice problems</td>
<td>The logic of your discussion is very clear. It is great to ask students to change an addition situation into a subtraction situation. However, you should compare the two number sentences and ask students how they are related to each other. “Your explanations lack evidence of sufficient discussion of a worked example with students.”</td>
</tr>
<tr>
<td>Representations</td>
<td>(a) Meaningfully use concrete representations</td>
<td>You still can use the cubes to represent the problem. “You can use the cubes to help students visualize the problem.”</td>
</tr>
<tr>
<td></td>
<td>(b) Connect concrete to abstract representations</td>
<td>It will be better if you can ask your students to refer back to the concrete contexts (e.g., What does 6 + 2 mean? Why do we add? How does it make sense? How are the numbers related?)</td>
</tr>
<tr>
<td>Deep questions</td>
<td>(a) Propose deep questions to elicit key ideas</td>
<td>You need to ask deep questions to elicit the relationships between addition and subtraction when appropriate. “You can ask deep questions to elicit the relationships between addition and subtraction when appropriate.”</td>
</tr>
<tr>
<td></td>
<td>(b) Anticipate student explanations to deep questions</td>
<td>It is a good idea to provide “anticipated answers” to some questions. For example, under “deep practice,” you have provided anticipated student explanations for “8 + 7 = 15.” “You can provide anticipated student explanations regarding how addition and subtraction are related.”</td>
</tr>
<tr>
<td>Other comments (e.g., revision, summary)</td>
<td></td>
<td>What will your review problems be? Please write them down. How many of these problems will be modeled and explained? All of them or only the selected ones? How will you guide students to review them? Please write down your questions.</td>
</tr>
</tbody>
</table>
Table 3: The Coding Rubric for Three Lesson Plans

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<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
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<tbody>
<tr>
<td>Worked examples</td>
<td>Example</td>
<td>No example is visible. Example as guided practice cannot be differentiated.</td>
<td>There are 2-3 well-documented worked examples before student practice or exploration. However, the example is illustrated in a relatively brief manner, or planned to discuss &quot;many&quot; examples.</td>
<td>There are 3-5 well-documented worked examples before student practice or exploration. Example clearly shows teacher's attention on the worked-example effect.</td>
</tr>
<tr>
<td>Practice</td>
<td>No practice problem is listed</td>
<td>Practice problems are listed. However, there is little consideration of how to discuss typical problems with students.</td>
<td>Practice problems are listed. There is clear consideration of how to discuss typical problems with students.</td>
<td></td>
</tr>
<tr>
<td>Representations</td>
<td>Concrete</td>
<td>Discussions, especially of worked examples, are not limited to the abstract. No manipulatives, pictures, or story situations are used.</td>
<td>Concrete materials/situations are involved but not utilized sufficiently for teaching the worked example.</td>
<td>Semi-abstract representations such as dots or cubes are used, but a context for teaching the worked example is lacking.</td>
</tr>
<tr>
<td></td>
<td>Abstract</td>
<td>Discussions are limited to the concrete and abstract representation of the target concept.</td>
<td>Both concrete and abstract representations are involved, but the link between both is lacking.</td>
<td>Semi-abstract representations such as dots or cubes are used, but the link between concrete and abstract is visible.</td>
</tr>
<tr>
<td>Deep questions</td>
<td>Question</td>
<td>No questions are visible when discussing a worked example or guided practice.</td>
<td>Some questions are written down, but there are obvious missing opportunities to ask deep questions to elicit deep explanations.</td>
<td>A set of questions is listed with no clear indication of when and how they will be asked.</td>
</tr>
<tr>
<td>Explanation</td>
<td>No student responses are anticipated.</td>
<td>Some responses are provided. However, explanations related to the target concepts are not anticipated.</td>
<td>Student responses are provided. Explanations related to the target concepts are anticipated.</td>
<td></td>
</tr>
</tbody>
</table>

In this section, we report an overall picture, including teachers' conceptions and actual details of lesson planning based on the survey and the lesson plan data. Successive categories and subcategories provide detailed descriptions of teachers' successes and challenges in using worked examples, representations, and deep questions in lesson planning at the beginning and end of this course.

### Results

**An Overall Picture**

In this section, we report an overall picture, including teachers' conceptions and actual details of lesson planning based on the survey and the lesson plan data. Successive categories and subcategories provide detailed descriptions of teachers' successes and challenges in using worked examples, representations, and deep questions in lesson planning at the beginning and end of this course.

**Pre-and Postworkshop**

Analyzing teachers' conceptions and deep questions in lesson planning at the beginning and end of this course and their concerns about transferring knowledge into classrooms.

**Conclusion**

Analyzing teachers' conceptions and deep questions in lesson planning at the beginning and end of this course and their concerns about transferring knowledge into classrooms.

The second author, co-instructor, who was familiar with the EOC rubric, independently scored teachers' initial, revised, and EOC plans in this study. Cohen’s k was used to assess the interrater reliability of the scores.

### Comparison of Pre- and Postsurveys

A paired t-test was used to assess the difference in teachers' conceptions and actual details of lesson planning at the beginning and end of this course.

**Appendix**

A detailed description of the rubric used for coding the lesson plans. The coding of the postsurveys was relatively straightforward (average kappa = 0.70). The coding of the postsurveys was relatively straightforward (average kappa = 0.70). The resulting average kappa of 0.70 indicated high agreement between the two authors in independent coding of the lesson plans. The reliability of the coding was further improved by averaging the scores from both authors, resulting in an improved interrater reliability (average kappa = 0.80). The interrater reliability for the coding of the lesson plans was calculated using Cohen’s kappa, which measures the agreement between two raters beyond what would be expected by chance. The reliability of the coding was further improved by averaging the scores from both authors, resulting in an improved interrater reliability (average kappa = 0.80). The interrater reliability for the coding of the lesson plans was calculated using Cohen’s kappa, which measures the agreement between two raters beyond what would be expected by chance.
The survey results indicated that over time, teachers’ (n = 32) awareness of incorporating the IES recommendations into their lesson plans increased. In the presurvey, fewer than half of the teachers discussed the use of examples (28.8%), representations (42.9%), and questions (25.7%). In the postsurveys, most teachers explicitly mentioned the use of examples (74.7%), representations (82.9%), and questions (88.9%). A paired t-test indicated that the above changes from pre- to postsurveys were significant, t(31)example = 5.35, p < .001; t(31)representation = 3.46, p < .001; t(31)question = 7.59, p < .001.

Results from teachers’ (n = 34) lesson plans indicated an overall improvement in lesson-planning abilities, although six teachers did not carefully follow the assignment instructions for EOC plans and created plans around topics that were not covered in our course. Figure 2 illustrates the means for each of the six subcategories from initial to revised, and to EOC plans. Repeated-measures ANOVA tests, with Greenhouse-Geisser correction, indicated significant changes in teachers’ lesson-planning skills, F(1, 63)example = 21.02, F(1, 30)representation = 10.45, F(1, 63)question = 17, F(1, 63)example = 24.03, F(1, 63)representation = 11.76, F(1, 63)question = 48.22, p < .001 for each category (the assumption of sphericity was met for testing each category except practice, which was corrected with Greenhouse-Geisser). Examination of these means (see Fig. 2) suggested that teachers’ lesson-planning skills increased linearly over time. Polynomial contrasts indicated that, in support of this, there was a significant linear trend for each category, F(1, 33)example = 29.60, F(1, 33)representation = 17, F(1, 33)question = 22.44, F(1, 33)representation = 42.68, F(1, 33)question = 20.43, F(1, 33)representation = 90.81, p < .001 for each category. However, except for the category of practice, these findings were qualified by the significant quadratic trends, reflecting the fact that the increases leveled off, and even fell, from revised to EOC plans. F(1, 33)example = 10.15, p = .001; F(1, 33)representation = 3.34, p = .06; F(1, 33)question = 9.64, p = .004; F(1, 33)representation = 12.48, p = .001; F(1, 33)representation = 8.36, p = .007; F(1, 33)question = 23.74, p = .001. Below, we present teachers’ use of worked examples, representations, and deep questions across three lesson plans. When appropriate, we triangulate these results with the survey data.

Teachers’ Use of Worked Examples in Lesson Planning

Figure 3 indicates that across initial, revised, and EOC plans, an increasing number of teachers paid full attention to planning worked examples (12, 28, and 32, respectively) and practice problems (20, 28, and 33, respectively). Sufficiently discussing a worked example. In the initial plan, more than half of the teachers (n = 16) did not sufficiently discuss the worked examples. This finding aligned with the presurvey, where only three teachers mentioned the word example. Teachers’ plans revealed three issues. First, some teachers provided broad descriptions rather than attempting to unpack an example. For instance, T13 planned to ask students to study an example by themselves and then figure out how the part-part-whole mat, the cubes, and the number sentences are related to each other. T4 said that she would teach an example and use cubes to model it. However, it was not clear what example she might discuss, or when and how the cubes would be used to model the example. Second, some teachers overlooked the underlying idea (inverse relations) and thus missed opportunities to further unpack an example. Most of the lesson plans discussed addition and subtraction in a separate manner, and some

placed more emphasis on the former than the latter. For instance, T13 used only one sentence to discuss subtraction. Teachers’ overlooking of the lesson’s underlying idea might be due to their own incomplete comprehension of the important idea.
gram, which led to a number sentence, $7 - 3 = 4$. The teacher then planned a particular section titled “exploring relationships,” during which addition and subtraction problems were explicitly compared and the term related facts was revealed.

In the EOC plans, the majority of teachers ($n = 29$) discussed a worked example in great detail. This is consistent with the postsurvey, on which typical responses were similar to “be more intentional and purposeful about 3 or 2 good worked examples versus presenting students multiple procedural problems” (T20). For instance, in order to teach the equal sign to kindergartners, T10 created a worked example about “$4 = 4$,” using an activity of “sorting classmates” (four boys and four girls). After students obtained a sense of “equal groups,” she continued to unpack this example using the concreteness-fading method. It should be noted that, even though in this study we encouraged teachers to use existing textbooks as a basis for lesson planning, most teachers’ worked examples were self-created and were not found in the corresponding textbook pages.

**Fading examples to practice problems.** We expected teachers to fade instruction as they transitioned from examples to guided practice in their plans. We also expected teachers to plan a discussion around a few typical practice problems. In their initial plans, four teachers (10.8%) did not plan any practice problems. Ten teachers (26.3%) provided a list of practice problems without any plans. The remaining 20 teachers (53.8%) met our expectations in this category (see Fig. 3). We discussed fading instruction to practice problems in our Friday class. In both the revised and EOC plans, teachers’ attention to practice problems improved considerably. Almost all of the plans ($N_{initial} = 28$, $N_{revised} = 33$) planned discussions around typical practice problems. Interestingly, although many teachers tended to create their own worked examples, they used textbook materials to plan practice problems. For example, T10’s EOC plan used a “tea party” activity (an optional activity in the textbook) to reinforce students’ understanding of the equal sign. T20 used the textbook’s worked example as a guided practice problem.

**Teachers’ Use of Representations in Lesson Planning**

Figure 4 shows teachers’ use of representations. Across the initial, revised, and EOC plans, the number of teachers who effectively used concrete representations increased from 4 to 50 (for both the revised and EOC stages), while the number of teachers who successfully connected concrete to abstract improved from 4 to 24 (revised), but fell to 21 (EOC). It appeared that teachers were more skillful in using concrete representations than connecting concrete to abstract.

**Using concrete representations.** A prevalent issue in teachers’ ($n = 29$) initial plans was the limited use of concrete situations in the worked examples, that is, starting from the cubes but not the rich story situations. This finding was consistent with teachers’ comments on the presurvey in that many mentioned the use of manipulatives, but not story contexts. In fact, all but four teachers completely ignored the kitten situation suggested in the textbook (see Fig. 1). In our feedback to individuals, we suggested, “Could you start from a more concrete situation such as a story problem?” (see Table 2 for an example). Our Friday class discussed the kitten illustration. We asked, “Why does the textbook include this picture? Can we utilize it as an example for teaching? How?” It was not until our class discussion that many teachers realized that the kitten illustration actually matched the pair of number sentences, $7 - 3 = 4$. The teacher then planned a particular section titled “exploring relationships,” during which addition and subtraction problems were explicitly compared and the term related facts was revealed.

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stress the additive inverses. For example, T24 started her lesson by reading a story about addition called “Elevator Magic.” She asked students to generate addition number sentences for each page. Although the concrete situation may have piqued children’s interest or supported their understanding of addition, these stories were not modified further to teach subtraction and the additive inverses. A second issue was that some teachers directly introduced the abstract vocabulary related facts at the beginning of the lesson plan as the textbook suggested, rather than situating this abstract term in a concrete situation. In our feedback to teachers, we stressed the connection between concrete and abstract and emphasized that the use of concrete situations should be gradually faded out to serve the purpose of teaching underlying concepts.

In the revised plans, teachers progressed in connecting concrete to abstract, as indicated by their use of concreteness-fading methods (see Fig. 4). T32 explained that she decided to revamp her plan using what she had learned from this course. This teacher modeled her worked example using schematic representations, tape diagrams, which were not suggested in the textbook. In the EOC plans, six more teachers used tape diagrams, and 21 teachers demonstrated full attention to connecting concrete to abstract. Among those 21 teachers, T29’s lesson plan about the equal sign was a typical example of concreteness fading. This teacher faded the actual four boys and four girls into stick figures and eventually into 4 = 4. In her lesson plan analysis, T29 explained, “Students are now shown how they can count and match the stick figures on the grid, just as they could count and match the ‘real’ boys and girls.”

Although teachers made progress in connecting concrete to abstract, difficulties remained (10 revised and 13 EOC plans receive partial/no credit; see Fig. 4). For example, although T24 improved her revised plan by adapting the events (elevator up and down) to teach both addition and subtraction, she still did not use the situations to stress the inverse relations between addition and subtraction. We suspect that she overlooked the underlying ideas. In her EOC plan, T24 planned a lesson about place value—a topic that was not discussed in the course. Although this plan incorporated various representations such as money and tiles, as well as the number sentence 10 + 2 = 12, the planned teaching appeared to be rapid and lacked careful connections between concrete and abstract representations.

**Teachers’ Use of Deep Questions in Lesson Planning**

As Figure 5 indicates, the number of teachers who successfully proposed deep questions increased from initial to revised plans but fell on the EOC plan (9, 26, and 24, respectively). The same pattern was observed with anticipating deep explanations (3, 24, and 20, respectively). This finding was in contrast to the survey data, in which teachers’ awareness of questioning improved most.

**Proposing deep questions.** Twenty-five teachers’ initial plans (75.3%) revealed issues that needed attention. One plan did not include any questions, and others provided a question list titled “deep questions” either at the beginning or at the end. It was not clear when or under what contexts these questions would be asked. A third issue was that some plans did not include “deep” questions to address the inverse relation. For example, the teachers who noticed the kitten picture (T4, T8, T15) simply asked, “Why is the kitten here?” without further prompts. This again might be related to teachers overlooking the underlying ideas embodied by the example.
fifth issue was revealed by teachers who captured the underlying idea but whose questions in the lesson plans were not likely to elicit students’ deep explanations of the concept. T1 planned to teach students a “part-part-whole” song (“Part, part, whole, that means addition” and “Whole, part, part, that means subtraction”) and then ask, “Is 5 + 2 = 7 an example of part, part, whole or whole, part, part?” 7 − 2 = 5 an example of part, part, whole or whole, part, part?” In our feedback to such lesson plans, we suggested that teachers utilize their worked example situation (e.g., orange and blue cubes) and raise questions that prompt a comparison between the corresponding number sentences. Finally, a few teachers (e.g., T3, T10) planned to ask the deep question, “How are 5 + 2 = 7 and 7 − 2 = 5 related?” which was suggested in the textbook’s “guided practice” section (see Fig. 1). However, these teachers did not raise a similar question during the teaching of worked examples, perhaps because that part of the textbook did not provide a similar deep question. In our feedback, we acknowledged teachers’ deep questions and suggested that they ask such questions earlier during their teaching of the worked example.

In the revised lesson plan, most of the teachers addressed our feedback by asking questions about the inverse relations (e.g., How are the addition and subtraction sentences related?). In the EOC plan, more than half of the teachers employed this instructional principle, asking questions to stress the key ideas, such as the commutative property of addition (e.g., How are 3 + 2 and 2 + 3 the same and different?) and the multiplicative inverses (e.g., What are the similarities and differences between 20 ÷ 4 = 5 and 4 × ______ = 20?). These questions shared the same feature, targeting the “relationships” among quantities. These lesson plans were consistent with teachers’ postsurvey comments, such as, “I will use deep questioning throughout the lesson to guide student thinking” (T2).

Although teachers made progress in the revised and EOC plans, we noted ongoing challenges in asking deep questions. Teachers who planned a topic that was not covered in this course (e.g., place value) had the most difficulty. Even among those teachers who designed a plan around topics covered in this course, some did not recognize the opportunity to ask deep questions. T13 planned a lesson that involved the commutative property. However, most of this teacher’s questions in the lesson plan required only single-word answers. When she asked a “why” question, she planned to explain it herself. In addition, the teacher herself implicitly stated the property and did not ask a deep question to elicit students’ understanding. In her reflections, this teacher expressed unreserved satisfaction with her plan: “I asked questions throughout the lesson to enhance their thinking. I asked ‘why’ whenever I felt like I would need more of an answer.” T3’s case indicated the challenging nature of helping teachers understand what is meant by deep questions during lesson planning.

Anticipating student explanations. Compared with the other five subcategories we assessed, anticipating deep explanations was weakest on teachers’ initial plans. First, some teachers (n = 18) did not provide any anticipated responses to any questions. Second, teachers who provided anticipated responses (n = 34) did not stress the main mathematical point. For example, a few teachers who asked how 5 + 2 = 7 and 7 − 2 = 5 were related suggested that “both sentences have the same numbers so they are related.” In our feedback, we suggested that teachers guide students to see the relationships among quantities, rather than seeing the quantities only. For example, they could develop prompts to help students understand that when you combine two parts, you will obtain the whole, and when you take away one part from the whole, you will obtain the other part. We also used two Chinese sample plans that included possible teacher-student dialogue to discuss this issue.

Adding anticipated responses to teacher questions helped improve revised and EOC plans. A few teachers’ anticipated explanations were even more thorough than what the textbooks suggested. For example, T20 in her EOC plan asked the question suggested by the textbook, “Why does the array model only include two number sentences in this fact family, (4 × 4 = 16 and 16 ÷ 4 = 4)?” The textbook explained that there were “same” numbers (4 and 4) in the multiplication sentence (4 × 4 = 16). T20 went beyond this explanation. She planned to first guide students to compare this array (4 groups of 4 dots, thus 4 × 4) to a second array (3 groups of 4 squirrels, thus 3 × 4). She then expected students to see that if they rotated the arrays, they would obtain 4 groups of 3 squirrels (4 × 3), but the arrangement of dots would stay the same (4 groups of 4 dots or 4 × 4).

However, difficulties anticipating deep explanations increased from 19 teachers in the revised plan to 14 teachers in the EOC plan (see Fig. 5). Predictably, teachers who did not ask a deep question did not anticipate deep explanations. Yet, even teachers who asked good questions did not necessarily predict deep explanations. In addition,
some teachers moved to the opposite extreme. A few teachers tried to write down every possible student reaction—including nonmathematical responses such as “students are laughing” on their EOC lesson plans. It is likely that our teacher participants tried to mimic the detailed Chinese plans but did so at a superficial level. We would have preferred that our teacher participants spend time and energy anticipating deep and appropriate explanations to their questions, and considering follow-up prompts if students could not provide the explanations they were looking for.

Discussion

This study reports an attempt to use IES-recommended instructional principles (Patashnik et al., 2007) to support elementary teachers’ learning as they construct high-quality mathematics lesson plans. Our summer course experience with teachers revealed both successes and challenges related to teacher learning, as well as factors that may support or hinder teacher learning. It also offers insights for future professional development.

The Successes and Challenges Related to Teachers’ Learning

Teachers’ lesson plans in this study demonstrate successes in unpacking worked examples and practice problems, and using concrete representations. Most teachers’ initial plans were insufficient because the examples were brief and relied only on abstract or semiconcrete representations. However, with the guidance of the IES recommendations, many teachers situated worked examples in rich story situations. Some teachers also tried to incorporate the concreteness-fading method (Goldstone & Son, 2005) to unfold tasks (Charalambous, 2010). As such, our teachers’ lesson plans, resulting from deliberate learning experiences, seem to be different from those of their peers in prior studies (Kagan & Tippins, 1992; Sardo-Brown, 1990) but similar to their international counterparts (Gai, 2005; Fernandez & Cannon, 2005). However, we caution against overgeneralizing our findings because teachers’ successes in planning were due, at least in part, to their attempts to follow the detailed feedback made by the course instructors. In fact, the decrease in teachers’ performance on several categories in the EOC plans that were independent work calls this to attention.

Teachers’ challenges were mainly related to connecting concrete to abstract, asking deep questions, and anticipating deep explanations, which are key factors in supporting students’ mathematical learning (Cai, 2005). In this study, we expected teachers to conduct lesson planning based on textbook materials. Teachers’ transformation of textbook resources into lesson plans revealed the affordance and limitations of textbooks (Remillard, 1999). As reported, teachers in this study tended to discard the textbook example or the key illustration. For example, many teachers ignored the mathematical and pedagogical potential of the kitten illustration. This may reflect teachers’ limited pedagogical design capacity (Brown, 2009; Brown & Edelson, 2003). However, our teachers’ omission of the kitten illustration was also likely due to its location at the bottom of the worked example. Such arrangement of the illustration could have emphasized its decorative and organizational function (Mayer, Sims, & Taïjka, 1995)—separating the worked example from the guided practice, similar to the bunny illustration on the right-hand page (see Fig. 1). We suggest that textbook designers place key illustrations on the first half of the textbook page so that they are clearly a component of the worked example. Such a rearrangement may draw teachers’ attention to the textbook’s existing rich, concrete situations and facilitate their pedagogical design capacity during lesson planning (Brown, 2009). In addition, the sequences of teachers’ representation uses in their lesson plans were directly aligned with the textbook presentation starting with the definition of the “related facts.” This sequence may reflect a symbol-precedence view that is common in textbooks but ineffective in supporting student learning (Nathan et al., 2002). Thus, we suggest that textbook designers present abstract statements or definitions after a worked example, thus facilitating teachers’ use of the concreteness-fading method (Goldstone & Son, 2005) to teach abstract ideas meaningfully.

In this study, some teachers planned to ask deep questions during guided practice as suggested in the textbook, such as, “How are the number sentences 5 + 2 = 7 and 7 – 2 = 5 related?” However, questions like this were not asked within the plans for teaching a worked example. We noticed that when textbooks suggested deep questions, teachers were likely to recognize and use them in lesson plans. When such questions were absent from the textbooks, teachers did not necessarily develop them on their own. We suggest that textbook designers arrange a few deep questions early in a worked example to assist teachers’ unpacking of the example. Such an arrangement offers choices but not full guidance for teachers, and thus may serve as a possible solution to the tension in designing educative curriculum materials (Davis & Krajcik, 2005).

The above challenges also indicate that there is indeed room to improve teachers’ capacity to incorporate worked examples in planning. In this study, the coding of worked examples was separated from the coding of representations and questions in order to avoid redundancy. However, these components cannot be separated in the act of teaching. Thus, if teachers’ ability to connect concrete to abstract, ask deep questions, and anticipate deep explanations can be improved, so too might the quality and depth of their worked-example design. In addition, we acknowledge that the 0–2 scale on our rubric may not have adequately captured the connections among worked examples, representations, and questions in a teacher’s lesson plan.

Textbook Potential in Supporting Teachers’ Lesson Planning

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Factors that May Hinder Teachers’ Lesson Planning

During the summer course, we heard teachers voice concerns about implementing what they learned. One concern was related to the requirement of fidelity to district-selected curriculums. For example, teachers who used Saxon textbooks shared that they were required to follow lesson scripts and had little flexibility when it came to modifying the scripts to incorporate the IES recommendations. Promisingly, one teacher who used Saxon shared how she resolved this conflict in her reflection. Her textbook directly introduced “1 + 4 and 4 + 1” and called it the commutative property. This teacher felt that this presentation emphasized memorization rather than understanding. She designed a story problem that could be solved using same-number sentences, which led to the revealing of the property. The teacher said that this was a way to keep the integrity of the textbook and also use what she learned from the summer course. This teacher’s strategy aligns with our course expectations—that teachers design high-quality plans based on the IES recommendations by adapting rather than improvising or off-loading (Brown, 2019; Davis, Beyer, Forbes, & Stevens, 2011) the textbook materials.

Another concern expressed by many teachers was that they do not have time to design detailed lesson plans because mathematics is only one of the many subjects they teach. This again cautions against overgeneralizing teachers’ successes in this study because teachers’ high-quality lesson plans may be partially due to their commitment to the course work. Thus, it is reasonable to question how teachers’ learned planning skills might be applied during their busy daily schedules. During our class conversations and teachers’ overall reflections on the summer course, some teachers suggested promising solutions. For example, they planned to focus on a few key lessons in detail, thus starting the long journey of building their professional library of lesson plans. Other teachers planned to focus on the worked example of each lesson and design that part in detail. Regardless of the potential challenges our teachers faced, they acknowledged the great impact the IES recommendations had on their planning, teaching, and learning. A few teachers expressed excitement, saying that they could not wait until the fall semester to implement all their new knowledge.

Implications for Professional Development

Our summer course is designed to deliberately support teachers’ lesson-planning skills. This approach is different from previous research on natural processes of teachers’ lesson planning (e.g., Brown, 1988; Cai, 2005; Fernandez & Cannon, 2005; Kagan & Tippins, 1992; Peterson, Marx, & Clark, 1978; Sardo-Brown, 1990) in that our focus is on specific interventions intended to improve teachers’ planning skills. Our findings suggest that professional support plays a critical role. As seen in teachers’ pre- and post-tests, and their initial lesson plans, many teachers who had read the IES recommendations did not understand how these principles could be incorporated into their plans. In contrast, after they received our timely and targeted feedback based on the IES recommendations, most of the teachers improved their understanding of the guidelines and consequently generated high-quality revised plans. We also observed some degree of transfer into teachers’ EOC plans. Our teachers’ growth shows the importance and promise of carefully supported lesson planning in future professional development.

Throughout the course, we worked with teachers on only one lesson plan and required them to go through a revision process. We consider teachers’ experience planning one lesson as a “worked example” in and of itself, which may build their schema (Sweller, 2006) for understanding how to incorporate the IES recommendations in their future planning and teaching. Teachers’ EOC plans confirm the “worked-example effect.” Our findings suggest that, instead of asking teachers to practice writing many lesson plans, teacher educators and professional developers may first focus on one plan and ask teachers to make revisions rather than beginning again with a new topic. Through intensive work on developing, evaluating, and revising lesson plans, teachers will likely improve their knowledge of and for teaching (Breyer & Davis, 2012).

Of course, learning takes time (Pashler et al., 2007), and promoting teacher learning is even more complex than promoting student learning (Davis & Krajcik, 2005). The challenges revealed by the EOC lesson plans demonstrate a need to enhance teachers’ domain-specific knowledge so they can recognize underlying ideas and plan appropriate representations and questions. This calls for more than a 2-week summer course. The challenges in EOC plans also call for more “guided practice” in the form of ongoing support for teachers in lesson planning. At our university, we are working with teachers who recently graduated from this project through study groups, during which teachers discuss lesson plans and enact teaching from perspectives of worked examples, representations, and deep questions. To obtain a sense of how teachers may transform their lesson plans into classrooms and gather information to better support teachers, we also have observed six teachers’ implementation of their EOC plans in their fall classrooms and documented their accomplishments and unexpected challenges. Our effort is a step toward supporting elementary teachers’ success. Further studies into the identified difficulties in lesson planning, the continuous support, and the transformation processes from textbook resources to lesson plans and classroom teaching can lead to necessary changes in teaching and learning of elementary mathematics.

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