Learning Progressions as Tools for Supporting Teacher Content Knowledge and Pedagogical Content Knowledge about Water in Environmental Systems

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Abstract

Research on learning progressions has led to advances in understanding student learning about big ideas in science, but teachers struggle to leverage the full potential of learning progressions for classroom instruction. Because learning progressions lay out how students' ideas change over a long period of time, learning progressions could help teachers build better understanding of student thinking, appropriate learning goals, and instructional moves for supporting students in developing more sophisticated ideas. In this study we explored the potential of learning progression-based curriculum materials to support teachers in developing more sophisticated content knowledge (CK) and pedagogical content knowledge (PCK) for teaching about water in environmental systems. Teachers participated in professional development that introduced them to a learning progression for water in environmental systems and curriculum materials based on this learning progression. Teachers completed written assessments of their CK and PCK prior to the workshops and a year later. Analyses showed that teachers who taught lessons using the learning progression-based curriculum materials showed modest increases in content knowledge, knowledge of learning goals, and knowledge of student thinking. These increases were greater than analogous changes evident for teachers who did not use the curriculum materials. However, even among those who implemented the curriculum materials, teachers' post-assessment performance did not yet reflect knowledge for supporting students in developing model-based reasoning about water. These results show that learning progressions have potential for supporting teacher learning, but that the ubiquity of traditional school science discourse may limit their potential for both student and teacher progress towards model-based reasoning.

Key Words: Learning Progressions, Content Knowledge, Pedagogical Content Knowledge

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Learning progressions have been hailed as tools for building coherence among curriculum, assessment, and instruction (Alonzo & Gotwals, 2012; Corcoran, Mosher, & Rogat, 2009; Duncan & Hmelo-Silver, 2009; Fortus & Krajcik, 2012; National Research Council, 2007). Until recently, however, most of the work related to learning progressions has been on understanding how students' ideas change over time (e.g., Gunckel, Covitt, Salinas, & Anderson, 2012; Mohan, Chen, & Anderson, 2009; Plummer & Maynard, 2014; Stevens, Delgado, & Krajcik, 2010). Developing research on how teachers use learning progressions in the classroom suggests that teachers sometimes struggle to leverage the full potential of learning progressions to inform instruction that is both rigorous and responsive to students' ways of thinking. Work by Furtak and Heredia (2014), for example, showed that learning progressions supported some teachers in finding coherence among disparate aspects of their curriculum, but only when teachers actively collaborated on the development of learning progression-based resources such as formative assessments or when teachers were not overly constrained by school mandates and accountability requirements. Furtak (2012) also found that teachers often viewed learning progressions as lists of misconceptions that should be corrected during instruction. Jin, Shin, Johnson, Kim and Anderson (2015) argued that teacher content knowledge (CK) and pedagogical content knowledge (PCK) can limit teachers' abilities to use learning progressions in the classroom. These findings cast doubt on the potential for learning progressions to impact classroom instruction.

Yet learning progressions are not just tools for supporting student learning; they could also be tools for supporting teacher learning and teacher practice (Sztajn, Confrey, Wilson, &

Edgington, 2012). Rather than viewing learning progressions as constructs that require CK and PCK to use, learning progressions could be seen as tools for developing teacher CK and PCK for teaching about specific topics. In our project, we designed educative curriculum materials based on a learning progression for student ideas about water in environmental systems and provided professional development for teachers on the curriculum materials and the learning progression underlying them. In this article we explore the potential for the learning progression and associated resources to support teachers in developing more sophisticated CK and PCK for teaching about water in environmental systems.

Background

As research-based innovations, learning progressions are new to most teachers. Two important factors in teachers learning to use innovations are teachers' CK, defined as knowledge of the subject matter, and PCK, the specialized knowledge of curriculum, students, teaching, and assessment used by teachers to transform content knowledge into knowledge for teaching subject matter (Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Shulman, 1987). Both CK and PCK affect teachers' practice (Abell, 2007; Childs & McNicholl, 2007; Falk, 2012; Kind, 2009; Park & Chen, 2012; Roehrig & Luft, 2004). When new research-based innovations, such as learning progression-based standards (i.e., Next Generation Science Standards) and learning progression-based curriculum materials, are introduced into the classroom, teachers' CK and PCK influence how they understand the purpose and use of those innovations (Cohen & Yarden, 2009; van Driel, Beijaard, & Verloop, 2001).

Research in this area provides some indications that teachers' CK and PCK may be limiting factors in teachers' use of learning progressions. Jin et al. (2015) developed measures of teacher knowledge for using learning progressions for tracing energy and matter through ecological systems. Their work pointed out that teachers struggle to apply scientific principles to tracing matter and energy (CK component) and that they have difficulty understanding students' intuitive ideas about matter and energy (PCK component). Jin et al. are also some of the few researchers who have shown that teachers with higher CK and PCK have a greater effect on student learning gains. These findings suggest that increasing teacher CK and PCK is important for supporting teachers in using learning progressions to teach model-based science.

Teachers' PCK for particular topics can deepen over time. Teachers' experiences with students help them notice patterns in student thinking and develop instructional strategies that respond to student learning challenges (Lee & Luft, 2008; Mulholland & Wallace, 2005; van Driel, Jong, & Verloop, 2002). Efforts to support teachers in developing their PCK for specific topics beyond what they may gain from classroom experience have included professional development to help teachers widen their repertoire of instructional strategies (Clermont, Krajcik, & Borko, 1993; Justi & van Driel, 2005); workshops on formative assessment (Falk, 2012; Nilsson, 2013); study groups analyzing vignettes or case studies of instruction about a topic (Daehler & Shinohara, 2001); and mentoring of inexperienced teachers by more experienced teachers or teacher educators (Nilsson & van Driel, 2010).

In our work, we explored a different approach to supporting the development of teacher CK and PCK for teaching model-based science, as represented by the *Framework for K-12 Science Education* (NRC, 2012). We reasoned that rather than thinking about how teachers' CK and PCK limit their use of learning progressions to teach science, learning progressions could support teachers in developing their CK and PCK for teaching science that grounds explanations and predictions in theoretical models (Windschitl & Thompson, 2006). As frameworks for organizing teaching, learning progressions provide tools for coordinating different aspects of

PCK (Sztajn et al., 2012). Educative curriculum materials (Davis & Krajcik, 2004) based on learning progressions and professional development on the learning progressions underlying those materials could support teachers in developing the CK and PCK necessary to elicit and interpret student thinking and provide rigorous and responsive instruction. This conjecture raises two important questions for our research.

1. How do teachers' CK and PCK for teaching about water change after learning about and using learning progression-based curriculum materials?
2. How do teachers' CK and PCK for teaching about water affect student learning about water in environmental systems?

Conceptual Frameworks

We take a sociocultural perspective on knowledge as embedded in practice and mediated by discourse (Vygtosky, 1978; Wertsch, 1991). Teachers' talk about scientific phenomena and teaching reflects the knowledge they use to engage in scientific and teaching practices. This knowledge is embedded in discourse patterns shaped by the practices and perspectives of various communities in which teachers have contact and participate (Gee, 1991; Wenger, 1998). For example, scientific discourse and school science discourse reflect two different ways of using knowledge to engage in the practices of creating explanations and making predictions. We refer to explanations and predictions as accounts of phenomena. Scientific accounts incorporate model-based explanations that include mechanisms for how and why an event happens. In contrast, school science accounts emphasize phenomenological narratives that describe rather than explain events. As such, patterns are summarized and conclusions are reached, but models are not tested or revised (Windshitl & Thompson, 2008). Similarly, when engaging in setting learning goals, responding to student ideas, or making decisions about instructional moves, all core practices of teaching, teachers use different knowledge, depending on the discourse that is shaping their talk. A discourse that emphasizes rigorous and responsive teaching emphasizes the use of different knowledge about learning goals, students, and instruction to build student understanding than a discourse that emphasizes a more traditional approach to teaching that focuses on vocabulary, misconceptions, and transmitting information. To examine teacher content knowledge and pedagogical content knowledge related to teaching about water in environmental systems, we looked at the discourses they used to account for water moving through connected systems and how they talked about learning goals, student thinking, and instructional decisions. We provide more detail below.

Accounts of Water Moving through Environmental Systems

To assess content knowledge, we used the Water Systems Learning Progression (Gunckel et al., 2012) to examine teachers' and students' accounts of water moving through environmental systems. In this framework, environmental systems include both natural (i.e., surface water, soil and groundwater, atmospheric, and biotic systems) and human-engineered dimensions (i.e., wells, water treatment plants, and human-altered landscapes including roads, buildings, canals, agricultural fields, etc.). The learning progression describes four levels of accounts that span from ideas common among upper elementary students through goal knowledge and practice expected for high school students. Level 1 and level 2 force-dynamic accounts frame events as resulting from natural tendencies of water to move by itself or from agents acting to move water (e.g., clouds sucking up water). These accounts focus mostly on water in visible locations. Level 3 phenomenological accounts, also called school science accounts because of their prevalence in school-based discourse, trace water along potential pathways by putting events in order, naming processes that move water, and tracing water through hidden (e.g., underground) and invisible (e.g., water vapor) parts of systems. Level 4 model-based accounts explain how and why water moves through systems. They identify driving forces that move water (e.g., gravity, pressure) and constraining factors (e.g., permeability, topography) that govern the pathways of water. These accounts trace water along multiple pathways and at multiple scales (i.e., atomic-molecular through landscape). Level 4 aligns with performance expectations for high school as described in the *Framework for K-12 Science Education* (National Research Council, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013). Table 1 provides an overview of accounts at each level.

Pedagogical Content Knowledge for Teaching about Water

A common model for PCK includes five dimensions: orientations to science teaching, knowledge of curriculum, knowledge of students' understanding of science, knowledge of assessment, and knowledge of instructional strategies (Magnusson et al., 1999; Park & Oliver, 2008). These dimensions are interrelated, with each shaping, constraining, and building the others (Park & Chen, 2012). In our framework, we focused on three of these dimensions: teachers' knowledge of curriculum, knowledge of students, and knowledge of instruction. We did not include orientations to science teaching because of the difficulty operationalizing and measuring orientations (Friedrichsen, van Driel, & Abell, 2010). We did not include knowledge of assessment because we feel this broad and important area deserved separate attention (Covitt, Gunckel, Caplan, & Syswerda, 2017). Our focus on curriculum, students, and instruction allowed us to highlight the central work of supporting students in achieving model-based understanding.

Pedagogical content knowledge is the specialized knowledge that teachers use in practice (Brown, Friedrichsen, & Abell, 2013; Falk, 2012; Park & Chen, 2012). For example, Falk (2012) showed how teachers use their knowledge of student understanding about a topic, their knowledge of curriculum, and their knowledge of instruction when engaging in formative assessment. In defining the relationship between PCK and teacher practice, Alonzo and Kim (2015) recognized two types of PCK: declarative and dynamic. Declarative PCK is the knowledge about students, curriculum, and instruction that teachers apply to their practice, such as when making planning decisions. Dynamic PCK is the knowledge that teachers use "on the fly" or in the moment of teaching. Alonzo and Kim's work suggested that declarative and dynamic PCK are related. Teachers' dynamic PCK is based on their declarative PCK, although having strong declarative PCK does not necessarily translate into strong dynamic PCK.

Alonzo and Kim (2015) also described the range of teacher PCK, categorizing both declarative and dynamic PCK as weak, intermediate, or strong. They characterized weak declarative PCK as having inadequate content knowledge that interfered with interpretations of student thinking, or as having little awareness of student thinking. Teachers with weak dynamic PCK enacted instructional moves that were not responsive to student thinking or not strongly related to learning goals. Teachers with intermediate declarative PCK had some ideas of common student ideas for a specific content area and some instructional representations they could use in teaching, but the links between the two were not strong. Indicators of intermediate dynamic PCK included a focus on student misconceptions rather than student ideas. Strong declarative PCK included tight links between knowledge of student ideas and instruction. Similarily, strong dynamic PCK included following students' logic and responding to students in ways that addressed their learning needs in order to reach rigorous learning goals.

As tools for organizing knowledge for teaching, learning progressions have the potential to bring more coherence to teachers' declarative knowledge of curriculum, students, and instruction that teachers use for teaching. Such knowledge could then be leveraged to strengthen teachers' dynamic PCK for teaching and support teachers in engaging in more sophisticated teaching practices (Furtak, Thompson, Braaten, & Windschitl, 2012). Learning progression-based curriculum materials with educative features (Davis & Krajcik, 2004) could translate learning progressions for specific topics into tools for teacher learning by making explicit how the learning progressions inform the establishment of coherent and rigorous learning goals, providing resources for interpreting student thinking, and offering guidance in selecting instructional activities that are both responsive to student thinking and tied to rigorous learning goals. In essence, learning progressions could support teachers in learning to access knowledge embedded in more rigorous and responsive discourses about teaching science.

Figure 1 shows how we conceptualize learning progressions and learning progression-based curriculum materials bringing coherence to teacher PCK for a given topic. Within the outer area of the figure are indicators of less coherent PCK for each of the three dimensions. Moving inward are indicators of PCK typical of school science instruction, such as an emphasis on vocabulary, a focus on misconceptions, and a propensity to transmit information (Covitt, et. al, 2017; Magnusson et al., 1999). Where the three dimensions come together in the center are indicators of focused PCK for model-based reasoning. The dark circle shows where knowledge of the Water Systems Learning Progression could bring coherence to teachers' PCK for teaching about water in environmental systems.

- *Knowledge for establishing learning goals (KLG)* describes curricular knowledge for selecting learning goals for teaching about water. The Water Systems Learning Progression defines the concepts and practices necessary to provide model-based accounts of water moving through environmental systems. Curriculum materials based on the learning progression could be a tool for using the knowledge necessary to identify challenging goals for model-based reasoning about water in environmental systems.

- *Knowledge of student thinking (KS)* describes knowledge of student thinking about water in environmental systems. The Water Systems Learning Progression describes characteristics of student accounts at each level of performance and how their thinking changes as their ideas become more sophisticated. These descriptions could be tools for interpreting student thinking with respect to developing more sophisticated ideas.
- *Knowledge for instruction (KI)* describes knowledge of appropriate instructional strategies and activities. The Water Systems Learning Progression provides principles for responding to students at various levels of performance on the learning progression. Learning progression-based curriculum materials could be a tool for using knowledge necessary to engage students in learning experiences that are both responsive (i.e., build on students' current ideas and ways of thinking) and rigorous (i.e., scaffold students in moving toward sophisticated model-based knowledge and practice).

While the area inside the circle represents both declarative PCK (knowledge applied to teaching) and dynamic PCK (knowledge used during teaching), because we did not observe teachers in their classrooms, our study attends only to how teachers use knowledge to talk about their thinking related to these teaching practices.

Methods

Study Context

Data from this study came from teachers who participated in two related projects focused on the development and use of curriculum materials based on the Water Systems Learning Progression. Table 3 summarizes these two projects as described below. The Tools Project focused on middle school students and teachers in two states (Arizona and Montana) and involved the use of curriculum materials that teachers could incorporate into their existing instruction on water. The Water Budget Project was a larger project that included middle school and high school students and teachers in four states (California, Colorado, Maryland, and Michigan). The Water Budget Project involved students calculating a water budget for their schoolyard. Teachers in both projects were introduced to the learning progression and curriculum materials during a professional development and then asked to use the curriculum materials in their classroom instruction. The main difference between the two projects was that the Water Budget Project curriculum materials included an instructional sequence while the Tools Project teachers used their own instructional sequences.

Curriculum materials. Both projects included two types of educative curriculum materials designed to support teachers in aligning their instruction with the Water Systems Learning Progression.

Formative assessments. Four formative assessments were provided that teachers could use to assess students' accounts of water. Each formative assessment focused on a different aspect of model-based reasoning about water (i.e., interpreting land surface from maps, structure of groundwater systems, transpiration, runoff). Each formative assessment included a prompt for students and guidance to teachers on how to interpret student responses based on the Water Systems Learning Progression. Educative features also provided suggested instructional foci for students performing at different levels on the learning progression. For an example of a formative assessment, please see Supplementary Materials (S1).

Tools for Reasoning. Both projects introduced teachers to two graphic tools for reasoning designed to support students in developing model-based accounts of water. The Pathways Tool guided students in tracing water along multiple pathways through a system. The Drivers and

Constraints Tool guided students in thinking about the driving forces (i.e., gravity, pressure) and constraining factors (e.g., permeability, elevation, topography) that govern the pathways of water within a system. Educative features for teachers included descriptions of how the tools could be incorporated into an instructional sequence and suggestions for supporting students at each level of the learning progression. An example of these tools is in the Supplementary Materials (S2).

Professional Development. Teachers in both projects participated in week-long summer professional development workshops. All teachers in both projects were introduced to the Water Systems Learning Progression. A major focus of the workshops was on how to use the formative assessments. Teachers practiced using the guides to interpret examples of student responses to the formative assessment prompts and discussed alternative instructional moves they could make based on student progress. Teachers also learned how to incorporate the graphic reasoning tools into their instructional sequences (either the Water Budget instructional sequence or their own instructional sequence), with an emhasis on how to use the tools to best support students performing at each level on the learning progression. There was no formal follow-up on the learning progressions or use of the curriculum materials during the academic year.

In both projects, teachers took online assessments prior to their participation in the professional development and again one year later. Teachers were also asked to teach their students using the learning progression-based curriculum materials (e.g., formative assessments and graphic tools for reasoning). Teachers who taught using the materials were asked to administer assessments eliciting accounts of water moving through environmental systems to their students before and after instruction.

Participants and Sampling

Across both projects, 50 teachers completed both the pre- and post- teacher assessments.

These teachers taught in a variety of school contexts, including urban schools with minority-majority student populations (48%), small town/rural schools with majority white populations (40%), and suburban schools with majority white populations (12%). Of these teachers, 18 taught high school, 31 taught middle school, and one teacher taught both. Thirty-seven teachers participated in the Water Budget Project and 13 participated in the Tools Project. Teachers were predominately white (85%) and women (72%). The teachers also had a range of teaching experience: 14% had one to six years experience, 24% had seven to fifteen years of experience, 32% had greater than 15 years of experience, and 30% did not provide this information.

Of the 50 teachers, 29 reported that they had used the curriculum materials. Of these teachers, 16 were from the Water Budget Project and 13 were from the Tools Project. Twenty of the teachers who used the curriculum materials also administered pre and post assessments to their students. Seven of these teachers participated in the Water Budget Project and 13 came from the Tools Project. Together, these teachers produced a pool of 1569 students, of which 89% were middle school students and 11% were high school students. Forty-two percent of these students came from urban minority-majority schools, 46% were from small town/rural majority white schools, and 12% were from suburban majority white schools.

Assessments

Teacher assessments included a total of 12 items. These items were grouped into three content clusters focusing on dimensions of the Water Systems Learning Progression: (a) surface water runoff, (b) surface-atmospheric-groundwater connections, and (c) evapotranspiration from living systems. Each cluster included CK and PCK items related to the content of that cluster. PCK items elicited teacher responses related to the three dimensions of the PCK framework: Knowledge for establishing learning goals (KLG), knowledge of student thinking (KS), and knowledge for instruction (KI). Table 2 shows the organization of CK and PCK items in clusters. All assessment items are provided in the supplementary materials (S3).

Content Knowledge Assessment Items: Accounts of Water. Content knowledge items asked for written accounts of water moving through environmental systems. These items met learning progression-based criteria for content validity by eliciting a range of possible responses (not just correct or incorrect answers) across the levels of the learning progession, being accessible to students and teachers who perform at lower levels of the learning progression, and at the same time signalling to students and teachers through item wording that their most scientific explanations were preferred (Doherty, Draney, & Anderson, 2012; Jin & Anderson, 2012). Both teachers and students responded to content items. The student version of the assessment included nine or ten items (depending on the project). The teacher version of the assessment included a subset of three content knowledge items from the student assessment. This overlap allowed us to use Item Response Theory (IRT) analysis to calibrate the assessments across all students and teachers (Wilson, 2005). Pre-test and post-test items were the same for both students and teachers.

Pedagogical Content Knowledge Assessment Items. An assumption guiding the development and analysis of these items was that written responses to items would provide indicators to how teachers used their pedagogical knowledge in practice (e.g., writing learning goals, responding to students, or planning instruction). There were three types of PCK items, each related to one of the dimensions of our PCK framework from Figure 1. These PCK items assessed only the use of declarative PCK; we did not assess teachers' dynamic PCK in the classroom. To assess knowledge for establishing learning goals (KLG), we were interested in both what learning goals teachers set for their instruction on water in environmental systems and how teachers considered learning goals based on their interpretation of student thinking. The assessment included two KLG items that asked teachers to write learning goals for teaching about water in environmental systems and one KLG item that asked teachers to write a learning goal for a particular student based on that student's response to a question about evapotranspiration. Knowledge of student thinking (KS) items provided teachers with a student response to an item on the student version of the assessment, then asked teachers to interpret the student's response. Knowledge for instruction (KI) items asked teachers to describe their next instructional move for the student based on the example student's response to the related KS item. Some versions of the KS and KI items were multiple-choice and explain items in which teachers selected their response from a set of possible options and explained their choice (Chen, Gotwals, Anderson, & Reckase, 2016). One of each type of item was open-ended with no choice options given. We discuss validity evidence for these items below in the analysis section. Pre- and post-test items were the same.

Implementation Interviews and Surveys. All teachers from the Tools Project were interviewed about their use of the formative assessments and graphic reasoning tools and Water Budget teachers were asked to complete an online survey about their use of the curriculum materials. Five Water Budget Project teachers who reported teaching with the curriculum materials also completed the survey. All of the teachers who participated in the interviews or survey reported that they used both the Pathways and Drivers and Constraints reasoning tools and at least three of the four formative assessment prompts and related guiding materials.

Analysis

Analysis of both the CK and PCK items focused on indicators of how teachers' (and students') language signalled their use of knowledge to either trace water through environmental systems (CK) or engage in pedagogical thinking for teaching about water (PCK). Development of these indicators followed a grounded approach described below.

Content Knowledge Analysis. To analyze CK items, we used exemplar workbooks created during development of the Water Systems Learning Progression (Doherty et al., 2012; Gunckel et al., 2012). Exemplar workbooks included indicators of accounts that aligned with each level on the learning progression. Coders used these indicators to assign a level of account (1 through 4) to each assessment response.

To code the large number of responses, seven coders were used. Two coders were lead researchers (and co-authors of this article) and served as the lead coders, three coders were post-doctoral researchers, and two coders were graduate research assistants. The lead coders, who developed the original exemplar workbooks (Gunckel et al., 2012), provided coder training which involved successive rounds of coding to achieve satisfactory interrater reliability. During each round, a pair of coders were assigned to each cluster, along with one lead coder. All three coders independently coded 30 responses, discussed differences, revised the exemplar workbooks to clarify ambiguities, and repeated the process until all coders reached a high agreement, defined as a weighted Cohen's Kappa of at least 0.85. Then, pairs of coders completed the coding for the entire data set for their assigned cluster of items. Within pairs, a 10% overlap of responses was coded, facilitating ongoing interrater reliability checks. Interrater reliability remained above 0.85 (weighted Cohen's Kappa). As the final step in coding, differences between coders were discussed by the two coders involved and an agreed-upon code was assigned.

To model the learning progression in each of the content clusters, we conducted an IRT analysis with *ConstructMap* software (Kennedy, Wilson, Draney, & Tutunciyan, 2007) using a partial credit model. To estimate the difficulty and variations of student and teacher performance across the items, we calibrated the items using all responses from all teachers and students (n=2,892). Weighted item fit was 0.91 to 1.08 across all items, indicating acceptable random variation in responses (Doherty et al., 2012; Wilson, 2005). In order to visualize the distribution of performances across clusters, items, and by pre and post conditions, we produced Wright Maps showing person proficiency plotted against item difficulty for both pre and post assessments. Wright Maps showed no overlap in steps, providing evidence that the assessment was able to distinguish between levels of accounts on the learning progression (Doherty et al., 2012; Wilson, 2005).

To estimate the change of teacher performance on CK items, we used the expected a posteriori (EAP) proficiency estimate for each person, measured in logits, which was provided by the IRT analysis. We averaged these values across teachers included in the sample for all three CK items for the pre-assessment and the post-assessment. The IRT analysis also produced an item difficulty for each item, also measured in logits. To estimate the step values between levels of the learning progression, we used the Thurstonian threshold produced by the *ConstructMap* software for each item. We averaged these values to produce a mean item difficulty and mean step values across all CK items. We then compared the average of teachers' pre- and post-assessment performances on the CK assessment items to examine change in performance on the Water Systems Learning Progression.

Pedagogical Content Knowledge Analysis. To analyze the PCK items, we developed new coding exemplar books for PCK, using the same proccess used to develop the Water Systems Learning Progression (Doherty et al., 2012; Gunckel et al., 2012). These exemplars had three categories based on our framework for PCK (Table 4). Category A represented responses that indicated less-coherent PCK. We called this category general PCK. Responses in this category included learning goals that were statements of fact or were about ideas that were outside the scope of the learning progression, such as a statement about the importance of water. Category A responses also included responses with indicators that suggested teachers' use of CK was interfering with their interpretations of student thinking and that their instructional decisions were not connected to the learning goals or their students' thinking. Category B represented responses that indicated PCK used in traditional school science instruction about water. The content in this category, which we called school science PCK, was more aligned with the scope of the Water Systems Learning Progression. Teachers' learning goals emphasized vocabulary, their interpretions of students' ideas identified misconceptions to be fixed, and their instructional moves focused on transmitting information about the water cycle. Category C responses included indicators of more coherent PCK for supporting model-based reasoning. We called this category rigorous and responsive PCK. Learning goals in this category were challenging and focused on models of water moving through systems; interpretations of student ideas referenced the Water Systems Learning Progression; and instructional moves were both responsive to students' ideas and focused on rigorous, learning progression-aligned learning goals.

Once the categories were developed, three coders (the two lead researchers and one graduate research assistant) independently coded all responses to all PCK items. Weighted Cohen's Kappa for interrater reliability was 0.87 across all coders. All coders discussed differences and came to consensus on all response codes. Categories were then assigned a numerical value (A = 1, B = 2, C = 3). We used the same IRT analysis procedures that we used for the CK scores. Weighted item fit was 0.85 to 1.00 across all items, indicating acceptable random variation in responses. Wright Maps showed no overlap in steps. We also averaged teachers' EAP scores for the three items for each dimension (i.e., KLG, KS, KI) and ran Pearson's correlations. All of the correlations between dimensions were negligible, providing evidence that the three types of items were different from each other.

Student Learning Effect Size Analysis. We calculated a Cohen's *d* effect size for each teacher based on the EAP means and standard deviations of their students' pre- and post-assessments. We used these values in multiple regressions to examine the relationship between teacher CK and PCK and pre-post change in student assessment scores.

Results

Teachers' Accounts of Water in Environmental Systems

On average, teachers' pre-assessment accounts of water in environmental systems aligned with level 3 on the Water Systems Learning Progression (Figure 2). Level 3 phenomenological accounts represent typical school science narratives that name processes that move water through the water cycle. For example, the Soccer Field item (in the Soil/Groundwater Cluster) asked why a puddle might form during a rainstorm on a grassy soccer field but not on a sand-covered playground. Typical teacher responses included, "Sand allows for quicker and more efficient infiltration," and "The sand has better drainage than the grassy areas." These accounts focused on naming processes (e.g., infiltration), but did not include driving forces (e.g., gravity) or constraining factors (e.g., permeability) to explain why the water infiltrates faster in the sand. In contrast, an example level 4 model-based account said, "The grass and soil structure below it is less permeable than the sand. This limits the ability of the water to move by gravity through the grass layers, resulting in pooling." This response acknowledged the effects of gravity in pulling the water downwards and permeability in constraining water movement. While some teachers provided this type of account, the majority provided level 3 school science accounts. This result indicates that while most teachers probably understand that gravity pulls water downwards, they did not access this knowledge to write their accounts and instead used knowledge in ways more typical of level 3 school science accounts.

On the post-assessment, teachers' accounts showed some improvement. Teachers who taught using the learning progression-based curriculum materials had a moderate pre-post effect size ($d = 0.71$) while teachers who only attended the professional development workshops and did not use the curriculum materials had no effect ($d = 0.05$) (Table 5). There was not a significant difference in the post-assessment means of teachers from the Tools Project (M=1.23, SD = 0.54) and Water Budget Project (M=1.09, SD=.56) who used the curriculum materials to teach about water (t(27)=0.68, p=0.50), meaning we were able to assume that differences between teachers who taught using the curriculum materials and those who did not were the result of using the curriculum materials and not the project in which they participated (i.e., Tools Project or Water Budget Project). However, even though the teachers who used the curriculum materials showed a moderate effect size in their pre-post growth, their post-assessments accounts remained within the level 3 school science range (Figure 2). These results suggest that when providing accounts on an assessment, the teachers relied largely on school science narratives. Despite the emphasis in the workshops and curriculum materials on level 4 model-based reasoning, the teachers' responses did not tend to include model-based principles for tracing water through environmental systems.

Teachers' Pedagogical Content Knowledge (PCK) for Teaching about Water

Figure 2 shows that teachers' PCK scores on both the pre-assessment and post-assessment were between steps 1 and 2, which aligned with category B school science PCK. However, these teachers did show increases in PCK on the post-assessment from their pre-assessment scores. Teachers who taught using the curriculum materials had a large pre-post assessment effect size (*d* = 0.93); teachers who did not teach using the curriculum materials had a small pre-post assessment effect size (*d* = 0.30). There was not a significant difference in mean post-assessment EAP scores between teachers from the Tools Projects (M=-0.12, SD 0.69) and the Water Budget Project (M=-0.24, SD=0.45) who used the curriculum materials to teach about water (t(27)=0.54, *p*=0.59), meaning that we could assume the groups' PCK scores were similar.

Knowledge for Establishing Learning Goals (KLG). The KLG items assessed teachers' learning goals about water in environmental systems. On the pre-assessment, all teachers' mean KLG scores were just above the step 1 threshold, indicating teachers' learning goals were a mix of disconnected facts about water (category A general PCK) and goals for naming and defining water processes (category B school science PCK). Typical category A general learning goals included, "The atomic structure of water as a compound," and "All living things need water." These goals were stated as topics or facts and were outside the scope of the Water Systems Learning Progression. Category B school science learning goals included statements such as, "I would like my students to be able to explain the various pathways that water can take" and "Students demonstrate understanding of the urban water cycle." These statements were more focused than category A goals and aligned with the domain of the Water Systems Learning Progression. They emphasized tracing water, but did not include the drivers or constraints that explain water movements.

On the post-assessment, teachers' KLG scores became more focused. A few teachers provided category C rigorous and responsive learning goals. One teacher stated,

> I hoped that students would realize that the movement of water isn't arbitrary, but rather that water moves in predictable ways based upon dynamic forces and

> variables (whether small or large scale). For example, if water doesn't travel uphill on a small scale, rivers should not be able to defy gravity and flow uphill just because they are on a larger scale.

This statement showed that the teacher recognized the implications of students' common accounts about water movement and framed a goal for learning based on model-based principles for driving forces and constraining factors.

Teachers who used the curriculum materials to teach had a large pre-post assessment effect ($d = 0.96$) while teachers who only attended the professional development showed no pre-post assessment effect ($d = 0.00$) (Table 5). Nevertheless, the mean post-assessment KLG scores remained between steps 1 and 2 (Category B school science), even for teachers who used the curriculum materials to teach about water (Figure 2). The use of the learning progression curriculum materials may have supported some teachers in focusing their learning goals on content relevant to tracing water in environmental systems, but it was not enough for most teachers to write category C rigorous learning goals.

Knowledge of Student Thinking (KS). Knowledge of student thinking (KS) items assessed teachers' interpretations of student ideas about water. Teachers' mean KS scores on the pre-assessment were between step 1 and step 2, suggesting that most teachers interpreted student ideas as misconceptions that need fixing or as evidence of what students do not know (category B school science PCK), rather than considering student ideas as resources for learning or teaching (category C rigorous and responsive PCK). For example, one KS item asked teachers about the direction of river flow based on a map. The map showed a river with two tributaries. There was also a large lake to the west, but in a different watershed from the river in question. The student account given in the PCK item traced water downstream along one tributary and then upstream along the other tributary rather than downstream along the main stem of the river. This response was typical for students who provide level 2 accounts because they often read maps as representations of flat surfaces (two dimensional) only and did not interpret three-dimensional topography from the map. Example category B school science teacher responses were, “This student doesn't understand that rivers only flow from upstream (highest) to downstream (lowest),” and “The student could have the misconception that all water in rivers and streams flows towards larger bodies of water, e.g. lakes.” Both of these responses focused on what the student got wrong or student misconceptions.

Post-assessment scores showed that teachers who used the curriculum materials provided more category C rigorous and responsive replies to the KS items. These teachers showed a large pre-post effect size of (1.11). For example, a typical response to the river flow map item was

> I would think that the student is using their knowledge of local river flow direction to answer this question or they could be seeing the lake and thinking that all rivers must flow into the lake. They are not thinking about mountain ranges and there [sic] roles in a watershed.

Rather than framing the student response as evidence of incorrect knowledge to be fixed, this teacher focused on interpreting how the student was thinking (i.e., using knowledge of local river flow direction) and identified what the student was not thinking about (i.e., mountain ranges and watersheds). This response shows a more interpretative stance of how students think and typical errors students make as opposed to identifying misconceptions. Teachers who did not use the curriculum materials had a small pre-post assessment effect ($d = 0.33$) (Table 5).

The larger effect size for teachers who did use the curriculum materials indicates that the educative features of the formative assessments that provided guidance on how to use the Water

Systems Learning Progression to interpret student ideas may have been useful for helping teachers begin to reframe their thinking about student ideas. However, as with the KLG scores, even teachers who used the curriculum materials, as a whole, did not move above step 2 into more rigorous and responsive KS (Figure 2). Teachers have long been conditioned to correct misconceptions and taking a different approach to identify where on a learning progression student ideas align may require a considerable shift in thinking.

Knowledge for Instruction (KI). KI items assessed teachers' next instructional moves based on student accounts of water in environmental systems. As with the KLG and KS dimensions, teachers' mean scores on the KI pre-assessment items were between steps 1 and 2. These scores indicate teachers' answers tended to represent instruction as telling students how water moves through the water cycle (category B school science PCK). For example, in a KI item related to the KS item described above about the flow of rivers shown on a map, teachers were asked what their next instructional move would be based on the student answer. An example teacher response was that the teacher should explain that water moves from smaller bodies of water to larger bodies of water because, "I think that the student is confused about the direction of water flow." This response focused only on what was wrong about the student's answer and suggested that the student's ideas could be corrected by providing information. It did not identify that the student's account indicated that the student might need practice connecting a two-dimensional map representation of a watershed to a three-dimensional conceptual model of how water would flow in that watershed. Furthermore, the instructional move chosen relied on a typical school science heuristic that does not explain how or why water moves in a particular direction governed by elevation and topography.

On the post-assessment, neither the teachers who only attended the professional development workshop nor the teachers who taught with the curriculum materials showed a significant change in their mean EAP scores (Figure 2 and Table 5). The pre-post assessment effect size for teachers who taught with the curriculum materials was 0.21 (small) and the effect size for teachers who did not teach with the curriculum materials was 0.05 (negligible). These changes were not statistically significant for either group (Table 5). While the learning progression workshops, curriculum materials and instructional experience had a small to moderate effect on the KLG and KS dimensions of PCK, they had little influence moving teachers towards more rigorous and responsive instructional moves.

Relationship between Teacher PCK and Student Accounts

Twenty of the 50 teachers in the study also submitted student pre and post-assessments. From these data we calculated an effect size for each teacher based on average change in student pre-post score, as described in the methods section. Teacher effect sizes on student scores ranged from 0.13 (negligible effect) to 0.97 (strong). We first ran a multiple regression to find out if teacher effect size on student scores correlated with CK or any of the dimensions of PCK. However, none of the regressions showed a significant relationship.

Nevertheless, further examination of the data revealed some intriguing patterns that offer evidence for conjecture and direction for future investigation. Reasoning that differences in teacher knowledge may be more prominent at the extremes rather than in the middle, we compared teachers who had the least effect and the greatest effect on student learning. We ranked and grouped the teachers by effect size and found that six teachers had negligible effects on student learning ($d < 0.25$) and five teachers had large effect sizes ($d > 0.75$). We compared the difference in means for these two groups for CK and the dimensions of PCK (KLG, KS, and KI) (Table 6). We found that the only significant difference between teachers who had no effect on student learning and teachers who had a large effect on student learning was in the KI dimension (teacher effect size 1.93). Although the effect of this difference for KI appears to be large, the difference in means between the groups was significant only at an alpha of 0.1 (p=0.09). A multiple regression for these teachers produced the same result, showing that only KI had any relationship to effect size ($b = 1.16$, $t(6) = 2.25$, $p = 0.06$). Because the number of teachers in each group was small, with caution we suggest that these results indicate that teachers who had a higher KI also had a larger effect on student learning.

Summary of Results

The teachers who used the learning progression-based educative curriculum materials produced more sophisticated accounts of water in environmental systems, developed learning goals more aligned with the Water Systems Learning Progression, and made more informed interpretations of student responses. All changes were modest in size and most teacher performances remained within the range of category B school science PCK. Teachers showed no significant change in the knowledge for instruction dimension, which evidence suggests may be a dimension that is particularly important for impacting student learning in the classroom.

Discussion

The changes in teachers' accounts of water in environmental systems, their learning goals, and their interpretations of student thinking offer empirical support to Sztajn et al.'s (2012) argument that learning progressions can be organizing tools that bring coherence to PCK. The formative assessments and the tools for reasoning were both grounded in the Water Systems Learning Progression and were designed to make elements of the learning progression explicit to teachers. Likely, the use of these educative curriculum materials to teach about water helped the teachers focus their learning goals from broad statements of fact to content more aligned with the learning progression (KLG), and may have provided teachers with a stronger basis for interpreting student ideas (KS). This finding shows that learning progressions are not just tools for supporting student learning (e.g., Gunckel, et al., 2012; Mohan, et al., 2009; Plummer & Maynard, 2014; Stevens et al., 2010); they are also tools that can support teacher learning.

Recognizing learning progressions as tools for teacher learning is important because the usual argument is that learning progressions can bring coherence among curriculum, instruction, and assessment (Alonzo & Gotwals, 2012; Corcoran, Mosher, & Rogat, 2009; Duncan & Hmelo-Silver, 2009; Fortus & Krajcik, 2012; National Research Council, 2007), but most of the work related to the utility of learning progressions in classrooms has focused on challenges that teachers experience when using learning progressions (Covitt et al, 2017; Furtak, 2012; Furtak & Herida, 2014; Jin et al., 2015). Yet, when viewed not as tools that are difficult for teachers to use but instead as supports for building teachers' CK and PCK, the potential for learning progressions to have a positive impact on instruction expands greatly. As foundations for educative materials for teachers, learning progressions could support teachers in building the PCK that Jin et al. found is necessary for teachers to use learning progressions to support student achievement. Our results add to Jin et al.'s findings that teachers with more coherent PCK have larger effect sizes by suggesting that the KI dimension of PCK may be of particular importance in enacting instruction that leads to significant learning among students.

Nevertheless, all of the gains in this study were modest and the KI dimension of teacher PCK (compared with KLG and KS dimensions) was affected the least by teachers' participation and instructional experience. Although the Water Systems Learning Progression and associated curriculum materials were designed to support students and teachers in providing level 4 model-based accounts, teachers' accounts of water and PCK for teaching about water remained grounded within traditional school science discourse. We argue that this result points to two realities.

First, developing PCK for more rigorous and responsive teaching takes time and may require additional resources. Our research looked at teachers' changes in PCK over one year. Yet there is ample evidence that PCK develops over extended periods of time as teachers gain more experience with students and curriculum (Lee & Luft, 2008; Mulholland & Wallace, 2005; van Driel et al., 2002). Evidence from one of our projects suggests that teachers who use learning progression-based curriculum resources for two years have a greater impact on student learning in their second year of learning progression-based instruction (Covitt, Gunckel, & Salinas, 2015; Gunckel, Covitt, & Salinas, 2014). Furthermore, the lack of growth along the KI dimension suggests that the educative materials did not make explicit how the Water Systems Learning Progression could inform instructional moves. Curriculum materials that make explicit how the instructional sequence was designed to respond to student ideas may be necessary. For example, students moving from level 3 to level 4 learn to use understandings about how water moves in three-dimensional landscapes to interpret two-dimensional representations, such as maps (Gunckel et al., 2012). Supporting students making this move requires identifying when students are having trouble making this connection and then providing instruction that supports this transition, such as making two-dimensional maps from three-dimensional physical models of watersheds, and vice versa. Developing the PCK for more responsive and rigorous instruction may require multiple years of experiences using curriculum materials that make this type of pedagogical reasoning more explicit.

The second reality that our results expose is the dominance of traditional school science discourse and the associated instructional inertia that limits teachers' development of PCK for more rigorous and responsive practices. While the Water Systems Learning Progression, like the Next Generation Science Standards, is aimed at supporting students in reaching model-based understandings of big ideas, the culture and discourse of schools is firmly grounded in a traditional emphasis on facts, fixing misconceptions, and teaching as explaining (Banilower et al., 2013; Capps & Crawford, 2013; Lyons, 2006). Teachers' thinking about content, curriculum, students, and instruction is shaped by this discourse, which pervades every aspect of school science teaching (Lotter, Harwood, & Bonner, 2007). This discourse can have a strong influence on teacher beliefs, knowledge, and practice, as it has long been known that teachers can easily fall back on the traditional ways of teaching they may have experienced as students or that are prevalent in schools (Lortie, 1975; Zeichner & Tabichnik, 1981; Brouwer & Korthagen, 2005). Furtak (2012) and Furtak & Herida's (2014) work, which showed how teachers' uses of learning progressions are limited by their views of teaching and the constraints of school and district mandates, speaks directly to this situation.

The influence of the traditional discourse of school science teaching is evident in our results and explains the limited gains that the teachers demonstrated. For example, on average, teachers' accounts of water in environmental systems remained embedded in level 3 phenomenological accounts. While the teachers may have been able to access more sophisticated understandings of water than their assessment results showed, the strong influence of traditional phenomenological descriptions of water moving through the water cycle in middle and high school curricula may have constrained the shift from phenomenological to model-based accounts in their responses to the assessment items. Teachers' gains in KLG and KS may have been similarly constrained. Setting challenging, model-based learning goals for water in environmental systems requires knowledge and ways of thinking that have not typically been part of school science instruction. Likewise, shifting from identifying misconceptions to interpreting student sense-making is a major departure from common ways teachers read student responses. Teachers may also feel limited by the instructional sequences they have available or are most comfortable using. We argue that it is the pervasiveness of the discourse of traditional school science that limits teachers' accounts and use of learning progressions to inform their instruction (Jin et al., 2015), constrains their opportunities to learn from using learning progression-based curriculum materials, and ultimately caps students' understanding of water in environmental systems at level 3 phenomenological understanding on the Water Systems Learning Progression (Gunckel et al., 2012).

Changing the discourse of schools from one stuck in traditional school science to one that supports model-based science will require systemic changes in expectations and support for teacher practice and student performance. Structural elements such as administrative expectations and mandates (Furtak & Heredia, 2014) will need to reflect and support more rigorous and responsive teaching. Negotiated classroom norms for performance and activity (Doyle, 1983; Jin, Johnson, Shin, & Anderson, 2017) will need to shift so that both teachers and students can develop more model-based discourse and practices in the classroom. Professional development and learning progression-based curriculum materials may play a role in the effort to improve teachers' CK and PCK for using learning progressions and teaching model-based reasoning, but ultimately, changes beyond teacher knowledge may be necessary for learning progressions to have a significant influence on classroom teaching and learning.

Limitations and Future Research

The results are limited to teachers' declarative PCK. We did not observe teachers' classroom practice to study their use of PCK while teaching. Future studies that assess teachers' dynamic PCK may shed more light on how learning progressions can influence specialized knowledge for teaching. The reliance on a relatively small sample of teachers' assessment scores limited analysis of teachers' PCK performances. Studies that include more teachers and in-depth interviews with teachers may provide additional insight into how teachers use learning progressions to teach and how learning progression-based educative curriculum materials can support teachers in developing their CK and PCK. The results related to teachers' knowledge of instruction may be limited by the fact that relatively few of the Water Budget Project teachers submitted student assessment scores, thus constraining our ability to tease apart the influence of having a learning progression-based instructional sequence on teachers' PCK. Future studies that examine this influence using experimental or quasi-experimental approaches are warranted. Finally, studies that incorporate teachers' experiences implementing learning progressions may provide more clues to explain how learning progression-based curriculum materials can be tools for developing teachers' CK and PCK for rigorous and responsive model-based teaching.

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Table 1

Water Systems Learning Progression Framework

Levels of accounts	Characteristics of accounts
4: Model based accounts	Use causal mechanisms to explain how and why events occur. • Identify driving forces that move water (e.g., gravity, pressure) • Identify constraining factors (e.g., permeability, topography, etc.) • Connect multiple scales from atomic-molecular to landscape
3: Phenomenological (school science) accounts	Tell school science stories that trace water along potential pathways but do not attend to model-based principles. • Trace water through multiple connected steps and processes • Span microscopic through landscape scales • Recognize hidden and invisible parts of systems
2: Force dynamic accounts with mechanisms	Frames events as resulting from natural tendencies of water or agents acting on water. • Identify informal mechanisms that move water • Limited to visible and macroscopic parts of systems
1: Human-centered force dynamic accounts	Provides human-centric accounts of events. • Identifies humans as movers or changers of water • Describes water as fulfilling the needs of humans • Describes water in isolated, visible locations only (e.g., puddles, bathtubs)

Table 2

Organization and Number of CK and PCK Items

Type of Item	Surface runoff cluster	Soil/ground-water cluster	Evapotranspiration cluster	General learning goals (not embedded in a content cluster)
CK	1	1	1	
PCK-KLG			1	2
PCK-KI	1	1	1	
PCK-KS	1	1	1	
Total items	3	3	4	2

Table 3

Comparison of Water Budget Project and Tools Project

	Water Budget Project	Tools Project
Grade level	Middle school and high school	Middle school
States	CA, CO, MD, MI	AZ, MT
Type of instructional materials	Instructional sequence for calculating a water budget of the schoolyard	Graphic tools for reasoning and formative assessments for integrating into teachers' existing instructional sequences about the water cycle.
Educative features of curriculum materials	Graphic tools for reasoning, formative assessments	Graphic tools for reasoning, formative assessments
Professional development (PD)	Week-long summer PD on water budget instructional activities, Water Systems Learning Progression, tools for reasoning, and formative assessments	Week-long summer PD on Water Systems Learning Progression and integrating tools for reasoning and formative assessments into existing instructional sequences.
Teacher Assessments	Prior to first PD (pre) and one year later (post)	Prior to first PD (pre) and one year later (post)
Student Assessments	Pre and post instruction	Pre and post instruction
Number of teachers who took pre and post assessments	37	13
Subset of teachers who took assessments and used the curriculum materials.	16	13
Subset of teachers who used curriculum materials and administered assessments to students	7	13

Table 4

Coding Categories for Each PCK Item Type

PCK Dimension	Category A General PCK	Category B PCK for traditional school science instruction	Category C PCK for model-based reasoning
KLG	Disconnected facts about water	Emphasis on naming processes and events and defining vocabulary	Challenging learning goals for model-based understanding
KS	Teacher's content knowledge interferes with assessing student ideas	Emphasis on fixing misconceptions	Interprets student ideas and reasoning with reference to learning progression
KI	Chooses activities that are fun to do or because they are hands-on	Emphasis on transmitting facts or explanations about water	Plans responsive and rigorous instruction

Table 5

Mean Comparisons Pre and Post Assessments

	Pre-Assessment EAP Mean, SD	Post-Assessment EAP Mean, SD	Difference in EAP means (post-pre)	*t*	*p*	95% Confidence Interval	Cohen's *d*
CK							
Used CM	0.70, 0.71	1.15, 0.54	0.45	3.23	.003	[-0.74,-0.16]	0.71 (moderate)
Did not use CM	0.62, 0.68	0.65, 0.55	0.03	0.21	.83	[-0.33,0.27]	0.05 (negligible)
Overall PCK							
Used CM	-0.61, 0.33	-0.18, 0.56	0.43	4.07	.0004	[-0.65,0.21]	0.93 (large)
Did not use CM	-0.52, 0.50	-0.65, 0.35	-0.13	1.25	.22	[-0.09,0.34]	0.30 (small)
KLG							
Used CM	-0.56, 0.35	-0.21, 0.37	0.35	3.71	.0009	[-0.54,-0.16]	0.96 (large)
Did not use CM	-0.61, 0.26	-0.61, 0.31	0.00	0.02	.98	[-0.13,0.13]	0.00 (negligible)
KS							
Used CM	-0.69, 0.27	-0.36, 0.32	0.32	4.70	.0001	[-0.45,-0.18]	1.11 (large)
Did not use CM	-0.43, 0.35	-0.54, 0.25	-.11	1.06	.30	[0.10,1.30]	0.33(small)
KI							
Used CM	-0.46, 0.32	-0.54, 0.39	-0.08	0.79	.43	[0.12,0.27]	0.21 (small)
Did not use CM	-0.52, 0.43	-0.50, 0.43	0.02	0.18	0.85	[-0.24,0.20]	0.05 (negligible)

Educative, Learning Progression-based Curriculum Materials (CM)

Table 6

Differences in EAP Means for Teacher Effect Size

	Strong Effect Group		Negligible Effect Group		Difference in Means	*t*	*p*	95% Confidence Interval	Cohen's *d*
	M	SD	M	SD					
CK	1.32	0.51	1.06	0.50	0.26	-0.85	.414	[-0.06,0.59]	0.52
KLG	-0.06	0.33	-0.06	0.50	0.00	0.00	.999	[-0.27,0.27]	0.00
KS	-0.26	0.57	-0.46	0.26	0.20	-0.76	.466	[-0.09,0.48]	0.44
KI	-0.45	0.16	-0.78	0.35	0.33	-1.90	.089	[0.15-0.50]	1.93