New Elementary Teachers' Knowledge and Beliefs about Instructional Representations: A Longitudinal Study

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Elementary teachers face an enormous challenge in the classroom, as they are usually responsible for teaching most if not all subjects to their students. These subjects range from science and math to language arts, spelling and social studies and sometimes even art, music and physical education. Teaching expertise in all of these areas requires content knowledge as well as the ability to communicate that knowledge in a manner that promotes student learning. However, it is impossible for elementary teachers to have extensive content knowledge in all of those areas, and science content knowledge is often at the bottom of the list (Anderson & Mitchener, 1994; Zembal-Saul, Blumenfeld & Krajcik, 2000). The amount of science content alone is that is required of the teachers is extensive. As described in the NSES (NRC, 1996) and Benchmarks (AAAS, 1993), elementary science teachers are expected to help students build an understanding of a broad scope of content in the context of authentic scientific practice, or inquiry (Davis, Petish & Smithey, 2006).

Elementary science teachers

New elementary teachers often are reluctant to teach science due to their lack of content knowledge (Ginns & Watters, 1999). Inquiry-based instruction places an even higher demand on teachers as they must integrate their content knowledge into the context of authentic scientific practice for their students (Crawford, 2000). However, elementary pre-service teachers tend to have a limited understanding of the nature of science (Smith, 2000), and as a result a lack of understanding of inquiry and other related skills (Davis, Petish & Smithey, 2006).

Teachers exhibit different strategies to deal with their lack of comfort with teaching science. Appleton (2003) has shown that teachers tend to employ either strategies to avoid teaching science, or come to rely on a collection of “activities that work” to survive their science teaching experience. These “activities that work” allow teachers to develop some pedagogical content knowledge (Shulman, 1986) in a piecemeal fashion that supports some student learning (Appleton, 2003). For those that do not employ those tactics and willingly teach science, little is known about how they develop and enhance their skills as teachers.

Pedagogical Content Knowledge

Pedagogical content knowledge (PCK) is a complex combination of knowledge, beliefs and skills that are required for teaching a given discipline successfully (Shulman, 1986). PCK includes combining knowledge of content, pedagogical knowledge and beliefs and curricular knowledge to support student learning of the desired learning goal in a given setting (Van Driel, De Jong & Verloop, 2002). Content knowledge is at the core of PCK (Shulman, 1986). It provides a foundation that for the PCK that helps teachers make decisions about how to represent content for students. More importantly, strong content knowledge provides teachers with more flexibility in the classroom, as they are better able to deal with student ideas (Ball & Bass, 2000; Yerrick, Doster, Nugent, Parke & Crawley, 2003).

Content knowledge feeds into curricular knowledge, which focuses on the discipline as a whole, and involves an understanding of the goals and objectives of the discipline (Magnusson, Krajcik & Borko, 1999; Shulman, 1986). Curricular knowledge extends beyond the teacher’s classroom and requires understanding about how an individual concept or learning goal fits within the overall curriculum (Carlsen, 1992). This awareness of the overall curriculum provides teachers with knowledge pertaining to students’ academic experiences and helps them evaluate whether their students have the proper prerequisite knowledge.

Pedagogical knowledge and beliefs include the general principles and strategies used to manage and organize classroom (Shulman, 1986, 1987). It includes the procedures and strategies learned in teacher educational programs as well as from experience (Van Driel, De Jong & Verloop, 2002). A teacher's PCK is influenced by the teacher's orientation toward science teaching (Magnusson, Borko, & Krajcik, 1999). One teacher might have an orientation toward inquiry-oriented science teaching whereas a different teacher might have an orientation toward activity-based science teaching; a third teacher might have a more didactic orientation. These different orientations will affect the instructional strategies they choose to use in their classroom. Thus teachers' development of PCK involves combining and integrating a broad range of knowledge and skills to make decisions that create a productive learning environment.

The study

An important aspect of PCK to which content knowledge contributes greatly is the representations that teachers choose to use as instructional aids, in other words *instructional representations* (Zembal-Saul, Blumenfeld & Krajcik, 2000). These representations can take the form of analogies, where the teacher relates the content to students' real life experiences; charts or graphs to organize collected data; models and modeling; pictorial representation; and activities (Davis & Petish, 2005). Lack of content knowledge has been shown to limit the variety and accuracy of instructional representations that teachers use in the classroom (Davis & Petish, 2005; Yerrick, Doster, Nugent, Parke, & Crawley, 2003). In addition, strong content knowledge is generally connected with the ability to better cope with the dynamic nature of the classroom and generate multiple representations to support student learning in every unique environment (Ball & Bass, 2000; Carlsen, 1992). However, since elementary teachers usually have limited content knowledge in most science topics, how do they develop their skills at representing science content?

Little is known about the way that teachers choose to represent content in the classroom

(Hogan, Rabinowitz & Craven, III, 2003). A few studies have compared novice and expert teachers and their knowledge and beliefs about representing content (Clermont, Borko & Krajcik, 1994; Borko & Livingston, 1989; Livingston & Borko, 1990). In each of these studies, the researchers found that the experts possessed more knowledge about content and learners. In addition, they were better able to integrate that knowledge in their evaluations and decision-making regarding content. However, little is known about how novice teachers develop the ability to integrate the complex set of knowledge required to make decisions about content representation.

In this study, we focus on the knowledge and beliefs that new elementary science teachers hold about instructional representations. In particular we investigated *what criteria* new elementary teachers use to evaluate instructional representations and *what types of representations* the teachers believe to be valuable. Because we are interested in teachers' trajectories (Anderson, Smith, & Peasley, 2000), we follow these teachers and observe how their knowledge regarding instructional representations changes over time.

Research Design, Methodology and Data Analysis

This study is part of an ongoing longitudinal study that follows a set of elementary teachers through their first several years of science teaching. The teachers work in a range of contexts from a private, Catholic school in a highly affluent suburban setting to a public, urban setting where a large portion of the student body is of low SES and speaks English as a second language. In this study, we focus primarily on their evaluation and adaptation of instructional representations embedded in curriculum materials and how these change over time.

Data Sources: Three structured interviews per year were performed with each of the teachers individually for three years. The interview protocols were developed in order to probe the new teachers' knowledge and beliefs about effective science teaching. Discussion also surrounded their enactment of science curriculum with innovative educative curriculum materials designed to support new teachers in teaching science as well as their normal science curriculum. Each of the interviews also included critiques of a lesson plan that focuses on an instructional representation and a fictional classroom scenario that depicted the enactment of a science lesson (Table 1). Transcripts of these interviews serve as a primary data source; complementary data sources include the teachers' written reflective journal entries (numbering in the hundreds for some of the teachers), daily logs describing their science teaching practice, and log files cataloging their use of an online learning environment.

Table 1.

	Lesson Plan incorporating instructional representation	**Classroom Scenario incorporating instructional representation or activity**
Interview 1	Natural selection is modeled by having students use a variety of implements that represented mouths or beaks to "eat" a quantity of beans within a given amount of time.	Students learn about electric circuits as they work to make a light bulb light up.
Interview 2	A peanut butter and jelly sandwich is used as a model for the layers of the earth. By bending and cutting, students are able to model various landforms.	Students learn about chemical reactions my mixing different white powders and liquids.
Interview 3	A "cloud" is created when smoke nucleates cloud formation from water when sealed inside a plastic bottle. Students then investigate the effect of changing temperature and pressure on "cloud" formation.	Students worked to design the best coverings for preserving water in a sponge as a model of a cactus plant.

Table 1. During the interviews, the teachers were asked to evaluate lesson plans that were built around three different instructional representations. In addition, they were also asked to evaluate scenarios depicting a lesson enactment.

Population: Three new elementary teachers were followed through their first years of teaching experience as part of an ongoing longitudinal study. All three teachers graduated from a small teacher education program at the same major Midwest public university. In addition, all three teachers willingly teach science and work to increase the science content in their classrooms. Catie spent her first year teaching sixth grade at a suburban Catholic school and has been teaching second grade at a different school with similar characteristics since then. Lisa and Whitney both taught fourth grade through their first three years teaching. Lisa taught in a small public elementary school with approximately 50% low SES students. Whitney taught in a public school with a diverse student population that was transient due to a high number of military personnel in the community.

Data Analysis: The data were analyzed qualitatively using a coding scheme that centered around the criteria the new teachers used to evaluate instructional representations including: resources, context, standards, accessibility, comprehensibility, content representation, engagement, management issues, student ideas, scientific accuracy and support of student learning. Additional codes were added when new themes emerged then the data were reduced to focus on the most relevant points.

Coding schemes

Tables 2, 3, and 4 provide the coding schemes for teachers' evaluation criteria, alternative representations, and types of instructional representations, respectively.

Table 2. Coding scheme for teachers’ evaluation criteria

Content	*The teacher generally agrees that the instructional representation (IR) represents the content well. She does not mention scientific accuracy.*
	The teacher specifically relates the IR to how well it relates to the content it is supposed to represent and its scientific accuracy.
	The teacher also integrates students’ difficulties and ideas, or prior knowledge, etc. into the discussion
Accessibility	*The teacher comments generally about the accessibility and comprehensibility of the representation.*

	The teacher relates the appropriateness of the representation to something in her knowledge or experience (e.g. students' or her own academic and life experience, prior knowledge, misconceptions, etc.)
Management Issues	*The teacher is focused on more superficial management issues (e.g. safety, messiness, resources, time)*
	The teacher discusses the students in her thinking about classroom management
	The teacher specifically discusses how management issues will support student learning.
Context	*Does the school context affect the teacher's choices?*
Engagement	*Will children enjoy the enactment?*
Learning Goals/Objectives/ Standards	*Does the lesson/rep help achieve the desired learning objectives? Does the objective of the representation connect to the standards?*

Table 3. Coding scheme for alternative representations

Alternative representations	*Teacher cannot make any suggestions for alternative ways of representing content. OR The suggestions that the teacher has for changing the representation result in an equivalent representation (e.g. different, but comparable materials)*
	The teacher suggests ways to improve the representation or provides a completely different representation that can either replace the representation or be used to supplement or further support student learning of content.
	The teacher compares and evaluates the different representations; compares how they support student learning

Table 4. Coding scheme for types of instructional representations

Type of Representation	
Analogy or example	*examples taken from real world that relate to scientific concepts*
Data Organization	*visual display of data (chart, graph, table, etc.)*
Pictorial representation	*Pictures, diagrams, video*
Games & Simulations	*games, role-playing, computer simulation*
Symbols	*symbols, figures employing symbols (circuit drawings, etc.)*
Model	*a simplified representation of a target , which shares similar characteristics with the target, but also differs from the target.*
Other	*misc. (KWL, songs, etc.)*
Project	*posters, projects, reports to illustrate understanding of scientific information or phenomenon employing one or more types of*

	representation.

Results

We focused on the knowledge and beliefs of the three new elementary science teachers regarding instructional representations and how those knowledge and beliefs changed over time. We focused primarily on three criteria that the teachers used in their evaluations of instructional representations. These criteria were: (1) management issues regarding implementation, (2) accessibility and comprehensibility of the representations and (3) how well the representation represented the content. While the teachers also discussed other criteria (e.g. engagement, support of learning goals and safety) their evaluations focused primarily on these three criteria.

We also focused on the new elementary teachers' abilities to integrate their content knowledge with knowledge of their students and pedagogical knowledge to determine how best to represent content in a given situation. In order to gain insight into this part of their PCK development we evaluated their ability to produce alternative representations. In addition, we followed the types of representations that the teachers tended to add to the curriculum materials in order to better support student learning.

Before turning to the results related to teachers' evaluation, selection, and generation of instructional representations, we briefly describe over-arching characteristics of the teachers. T Throughout the study, the teachers evaluated and discussed instructional representations very differently. Whitney is very student-oriented. She centers her curriculum around students' ideas. Even as a first year teacher, she exhibits an integrated knowledge about teaching that allows her to evaluate instructional representations in a sophisticated way. As a teacher, Lisa's strength is breaking up a complex idea into an accessible progression of chunks in order to scaffold student learning. Of all the teachers, she expresses the broadest set of instructional representations and does not seem to favor any particular type. While engagement was a focus for her at the beginning, it decreased in importance over time. Catie focuses on engagement and motivation as well as student learning when developing curriculum materials. She also tries to match the science in her classroom to what she believes is true scientific practice—about half reading and half experiments. To help students make sense of content, she favors data organization (e.g. charts, graphs, tables) as part of scientific practice. With these typical orientations in mind, we turn next to how the teachers evaluated instructional representations based on management issues, accessibility, and representation of the content.

Evaluation Based on Management Issues

Although commonly believed to be the primary focus for new teachers, the teachers in our study did not necessarily prioritize management issues when evaluating instructional representations and the way to present them in the classroom. Each of the teachers prioritized management issues to a different extent. We found that the teachers discussed these issues on three general levels (Table 5). The most basic level in which they spoke about management involved the general concerns that all teachers must balance in the classroom. The factors mentioned most often when evaluating instructional representations were messiness, resources and time. When the teachers drew their students into the discussion in some manner, in addition to the basic management issues, it was deemed a more sophisticated level of thinking about classroom management. In these cases, the teachers might describe distribution of materials or how they would group students, but without any justification, or integration of other ideas related to student learning. At the highest level, the teachers began to integrate concerns about student learning with management issues such as grouping into their discussion.

Management Issues	
Level 1	"Even the peanut butter and jelly, it was like, oh, I'd have to play it out for myself and see how messy that would get." Catie I2-Y1
Level 2	I think I would probably just have two kids working together because I can just, and I would probably, like knowing my kids anyway, pair up a boy and girl with each other because it seems that there is less craziness that goes on when that happens. Catie I2-Y2
Level 3	"I think it's better if they're working in groups of two just because everyone gets a chance, you know, touching everything and trying everything whereas if you have so many kids in a group, like even three, some one gets left out, and four definitely some kids aren't paying attention and don't get a chance to cause there's always someone who will dominate the group at that age so I do like the group of two because then it's really intimate, and the kids can work hands on and be focused and involved in it. So I think grouping of two is good. And working it by yourself, I don't necessarily agree with because you need other people to spur on your own thoughts" Catie I2-Y2

Table 5. Examples of the three levels of management issues that teachers discussed when evaluating instructional representations and how they might use them.

Management issues were a more important consideration for Catie than the other teachers. Throughout the study and in every context, she expressed concern with them. Measuring by frequency alone, she discussed management issues several times more often than the other teachers. Over the three years, neither the frequency nor the level at which she discussed management issues changed. This is not to say that she did not discuss these issues at a sophisticated level. In fact, even in her first year she integrated knowledge of her students into her consideration of management issues. For example, in year one she created a unit on water quality of the local lake. The final projects for the unit involved student-generated instructional representations to communicate their findings to the community, which included building a website and creating and distributing fliers. In describing this, she provides a detailed discussion of how she divided her students among several different final projects and made sure they could all contribute to all of the class' projects. In another example from her first year, she discusses how grouping students in pairs prevents some classroom management problems while still enhancing the students' learning:

> "I would probably put them in groups of two. Um, that way they stand back, they've got someone else and someone else's ideas to kind of you know, bounce back and forth together, and then they're also able to see what's going on for themselves. But you know, there's not this like, "Well let me…" you know, pushing kids aside trying to see this one bottle. They've got their own that they share in between themselves and other kids. But I'd probably put them in groups of two…" Catie I3-Y1 (Level 3)

Like Catie, Lisa also considered management issues at all levels. However, she did not seem to prioritize them because she discussed them only rarely. Similarly, management issues did not appear to be a high priority for Whitney. Because her focus is so student-oriented, the management issues that concerned Whitney most were related directly to students and supporting their learning. For example, she discusses how grouping students in different ways ensures that they think about a demonstration individually. She suggests that students should first reflect individually on a demonstration, then discuss their ideas in small groups to refine their ideas before taking part in a whole class discussion. She believed that this strategy would help students formulate their ideas more fully:

> "…[I'd] do that as a demonstration and show them and ask them and ask them, you know maybe even to write down in their journal first what they think is happening before we talk about it … and then talk in a small group about it and then talk about it as a full class to see what kind of ideas they got once they talked to each other about it…" Whitney I3-Y3

Interestingly, the frequency with which Whitney discussed management issues increased as she gained experience in the classroom. However, she continued to maintain her student-focus and integrate them into her discussion of management issues when evaluating how to present instructional representations in the classroom.

Each of the teachers considered management issues in a different manner in regards to instructional representations. In addition, each followed a different progression in terms of frequency and sophistication through their first years of teaching experience.

Evaluation Based on Accessibility

All three new teachers prioritized accessibility when evaluating how to represent content in the classroom. At times, they did not justify their evaluation of the accessibility of the instructional representations. In these cases, they might just make a declarative statement about whether they thought it was level appropriate or not (Level 1):

"I really think this could work. 3rd grade—sure. I figured, you know, you don't have to get too, too technical in third grade." Lisa Y1-I2 (Level 1)

At other times, the teachers discussed the accessibility of the instructional representations in a more sophisticated manner. They would integrate other factors like students' ideas and their prior knowledge. In addition, they might consider the students' experiences, both academic and real life, as they evaluate level-appropriateness of the representation. The teachers also commonly discussed whether the instructional representation was grade-appropriate based on their own experience as students or teachers. When the teachers justified their evaluations of level-appropriateness with any of these factors, we considered it to be 'Level 2'.

" You know like after reading about it and understanding pressure in general before applying it to this situation and temperature in general before applying it to this situation because otherwise I just don't think … I mean it does say grade levels three to eight, but I don't know, third grade I just, I don't know, even my kids at this point about to go into third grade, I don't think they would understand this." Catie I3-Y3 (Level 2)

The teachers followed different progressions in the way they discussed and evaluated the accessibility of the instructional representations. Catie and Whitney both increased the frequency in which they discussed the accessibility of the instructional representations, while Lisa discussed them with less frequency as she gained experience. Likewise, Catie and Whitney both remained constant in the ways that they evaluated the accessibility. However, Catie discussed accessibility using both declarative (Level 1) and integrated (Level 2) evaluations, while Whitney always used a complex and sophisticated set of factors for her evaluations.

Although the frequency with which Lisa discussed accessibility decreased over time, she did exhibit a positive progression. In her first year, her discussion of accessibility included both declarative and integrated explanations for her evaluation of the representations. In her third year, although there were fewer instances in which she discussed accessibility, her evaluations of the instructional representations were more sophisticated and always integrated with other factors to justify her decisions.

Even from their first year, all three teachers integrated many factors into their evaluations of the accessibility of the instructional representations. However, each of the teachers appeared to prioritize different factors when evaluating the accessibility of an instructional representation. Catie tended to focus on making sure that students have the prerequisite knowledge to make the representation productive. In particular, she tended to suggest modifications that would ensure that students have the proper background knowledge before encountering the representation. For example:

"I mean I guess you could do the experiment, and then read some and then do like talk about conclusions to the experiment and incorporating it in what you read. I guess you could do it that way but I know a lot of, like even our textbooks says do this experiment, then read the chapter, do that experiment, read the chapter, and I just, I don't think that works as well that way because they don't have enough background information like, they're not, I know it's supposed to like rope them in or whatever but I don't think it does as much as if they know what they're doing when they get into it." Catie I2-Y3 (Level 2)

Since Whitney's knowledge and beliefs are student-centered, not surprisingly, she focused her evaluation of accessibility on students' ideas and experiences. She tended to integrate potential student misconceptions and prior knowledge while evaluating the accessibility of an instructional representation and how she would use it. For example, when evaluating the 'Cloud in a Bottle' model for cloud formations, she was concerned with potential student misconceptions:

"I think some of the advantages are like its in a very small environment for them, like the bottle, you know they can see things happening as, you know but then they might start to think of well who's squeezing the earth to make clouds…" Whitney I3-Y2 (Level 2)

In addition, she related the usefulness of certain models to students' real life experiences. Since she taught in California, she discussed how the peanut butter and jelly model of the layers of the earth and geological formations would be more meaningful to her students than students who lived elsewhere:

"…and having them talk about fault lines and, especially here, a lot of them know about that, since we're in California, it's a fault and they know where some of them are." Whitney I2-Y1 (Level 2)

Lisa also integrates consideration of students' experiences and prior knowledge into her evaluation of instructional representations.

"But I don't really think if I was a kid I would be able to make that connection without having the teacher explain it and saying 'this is why'. Because I didn't get it until I read the teacher information. And unless the kids knew all that information about pressure and clouds, they might not be able to make the connection." Lisa I3-Y3 (Level 2)

She was also concerned with the difficulty that students have with abstract content and integrated discussion of how models can help students learn the difficult content.

"The advantages, the way I would use it as an introduction it gets the kids interested in it. It kind of brings up a tough topic in a simplified way…With the mouth and the beak, it's pretty common form of natural selection, one of the most common changes, characteristics of animals and stuff would be the mouth, and I think it would be easy for the kids to associate eating, and you know, you need to eat in order to survive so I think that makes a good connection right there instead of having them, like the types of paws on a dog or a wolf or something. Why did they turn to webfeet or you know stuff like that. It's just a little more abstract, where this is; the kids know they got to eat to survive. They can make that connection right away." Lisa I1-Y2 (Level 2)

The expectations that teachers have for their students play a significant role in their assessment of accessibility. The three teachers in this study have quite different expectations for their students. Catie generally has higher expectations for students despite teaching second grade. In particular, she believes that the ultimate goal is for students to be able to apply their knowledge to new problems. Thus, she tended to believe that students would not have much difficulty transferring their knowledge. While Whitney and Lisa agree that the ability for students to transfer knowledge is important, they believe that the students require more scaffolding in order for them to make distant connections than Catie does. For example, the teachers were asked to evaluate whether students will be able to successfully make the connection the electricity at home and a basic circuit built in the classroom (battery, wires and light bulb). Catie believes that this student-generated analogy would be an acceptable assessment:

"I liked it (the homework assignment). They're talking about lighting in their homes, and they're supposed to just write about a paragraph about their thoughts on the subject. I think I would probably also add like do this on your own. Don't ask for parental, you know, help or anything. Try and do it on your own and think about it by yourself… 'cause they can come up with some really neat things even if they're not right, you know, of what they think, and that's really cool when they're thinking hard about some stuff…" Catie I1-Y2

In contrast, Whitney and Lisa believe that students need more scaffolding to make the distant connection between the rudimentary circuit from the classroom and the electric wiring within a house. For example, Whitney said:

"I think it's kind of a big jump, because they're playing with this stuff, and they've got a little light bulb. And then all of a sudden they have to go home and talk about how their one wire that they can see, and their battery, relates to everything, the lighting in their house, like how, you know. . . I think it pushes them to think about it, and it pushes them to really think, I wonder how this works? But they might not have all of the knowledge to answer that question. They might not know why it works. They might just know that it must be connected to some electricity somewhere. It must be connected to a battery. Because they didn't really talk about anything, they had a battery and a light bulb and wires, so, they could see the wires a lot times, the thing is plugged in, and they could see the light bulb, so there must be a battery in the wall." Whitney I1-Y2

They also discuss specific difficulties that the students might have relating to the analogy and suggest ways to scaffold them. For example, Lisa said:

"I don't know. I don't like it, just because the kids can't see in the walls and they don't know that, you know, once you turn that light switch on, it's going to connect the circuit… The next day, as the teacher I'd bring in and example of a light switch. They didn't have anything, just wire, a ball, and a battery. So then, I would bring in, you know, the light switch or, make a circuit board out of that an show them that this is why, it goes on. Or maybe, I would just show them and then say, 'Alright now, think about what you learned and see if you can connect it. This is what it looks like behind the wall. See if you can connect it then', because I'm sure none of the kids know what it looks like behind the wall and I'm just trying to connect it and make it authentic by connecting it to their home life. You're not doing a good job by just saying, 'Alright, think about how-- how this activity relates to lighting at home.' Because they won't be able to do it." Lisa I1-Y2

Thus, although the teachers all prioritize accessibility in their evaluations of instructional representations, they do so in a very different manner. These differences illustrate the individuality of PCK development in new teachers.

Evaluation Based on Content

When evaluating instructional representations, perhaps the most important consideration is evaluating how well it represents the desired content (Yerrick, Doster, Nugent, Parke & Crawley, 2003). The three teachers did so with varying levels of sophistication. The most basic level of consideration involved only a superficial evaluation of how well the instructional representation represents the content, without any justification or connection to other factors. In the next level of the teachers' evaluation, scientific accuracy plays a role. At the highest level, the teachers integrate those ideas with other factors such as potential student misconceptions, prior knowledge or accessibility.

Over their first three years of teaching experience, evaluation with respect to content became more prevalent in the evaluations of Whitney and Catie as they gained experience. In contrast, Lisa remained constant in the extent of her evaluation with respect to content. In characterizing the *ways* in which each teacher evaluated the instructional representations in relation to content, we see that each teacher remained relatively constant across time—that is, each teacher had a characteristic way of evaluating instructional representations with regard to content. However, the three teachers' characteristic approaches were quite different.

Although Lisa and Catie often made declarative statements about how well the instructional representation represents the content, scientific accuracy entered into the evaluation of instructional representations to at least some extent for all of the teachers, even in their first year of teaching. For example, during Lisa's first year of teaching, she discussed scientific accuracy and was quite critical of the model and what it represented:

"Do they vary in thickness? That might be something that if you want your kids to know that this lay, the peanut butter layer should be thicker than the crust because it's thicker than it. Or, the very outside layer of the earth is the thinnest layer so it should be smaller…it was never addressed" Lisa I2-Y1 (Level 2)

In subsequent years her thinking became more sophisticated. She continued to prioritize scientific accuracy, but integrated other factors into her thinking. In particular, she discussed the different ways that models can be used, and that they are not just useful for observation but to promote student thinking and sense-making.

When considering how well an instructional representation represented the desired content Whitney always evaluated them with some degree of sophistication. Unlike the other teachers, she never made superficial statements without any justification or connection with other factors. Even from the first year, she not only integrated scientific accuracy into her evaluation of a model, she also considered how the content that was being represented fit into the bigger picture of the field. Consistent with her orientation towards students, she also integrates concern with their prerequisite knowledge and potential misconceptions, as well as strategies for communicating the content to students.

… or even being able to show them like earthquakes, like here, especially, talking about when earthquakes happen, they don't happen for, every once in a while there's a big one, because they get so much pressure and being able to show them, there's like there, you know, in the earth's time that's not very long. Just like for you moving the bread it wasn't very long, but our life span's a lot shorter than the earth's life span, so they're just, you know. Their idea of short and our idea of short are totally different and that's why it's a model, you know, just trying to make sure you bring everything back to it's not all the same, you know, scales and stuff like that… Whitney I2-Y2 (Level 3)

In contrast to the other teachers, Catie exhibited a clear progression in the way she evaluates instructional representations in terms of content. In the first year, she does not prioritize content in her evaluation of instructional representations. During year two, scientific accuracy becomes more of a focus of her discussion. She also articulated how the usefulness of the representation is more important than student engagement.

In year three, she began to integrate her consideration of content with other factors. She discussed how a model might lead to student misconceptions, and also linked the use of it to scientific practice. In addition, she discussed strategies for helping students make sense of the content in connection to the instructional representation.

Suggesting Alternative and Additional Representations

One of the important aspects of PCK is for teachers to be able to integrate their content knowledge with knowledge of their students and pedagogical knowledge to determine how best to represent content in a given situation (Yerrick, Doster, Nugent, Parke & Crawley, 2003; Hogan, Rabinowitz & Craven, 2003). In order to gain insight into how new elementary teachers make decisions about how to represent content, we examined the criteria that they used to make those decisions.

Another way to observe their PCK development in regards to representing content is to examine the types of additional representations they can produce to represent the content and support student learning. In order to be effective teachers, they need to have enough knowledge such that they can use it flexibly in many different types of situations in the classroom (Ball & Bass, 2000). One way to illustrate the flexibility of teachers' knowledge is their ability to generate alternative representations for content. We evaluated how well the new teachers were able to do this by tracking the number of alternative representations that they could provide, the type of representations they offered, and how they talked about them. If the alternative suggested resulted in an equivalent representation, it was regarded as a 'Level 1'. Substituting layers of clay for the peanut butter and jelly sandwich would be an example of this type of response. If the representation offered was completely different, or significantly improved how well the content was represented it was considered a 'Level 2'. When the teachers evaluate the new representations and compare them to each other, or the original one, it was considered the to be the highest level, 'Level 3'.

Throughout the study, Catie offered fewer alternative representations than the other teachers. However, she did progress in her ability to do so successfully. In her first year, she made a conservative modification to the peanut butter and jelly model by suggesting that chunky peanut butter might be a more realistic model because the chunks would be more like rocks. Lisa also makes a suggestion for improving the peanut butter and jelly model. Her suggestion of toasting the bread increases the similarity of the model to reality because the crust of the earth is hard, not soft like the bread. In addition, her alternative model also alleviates the need for a knife to create the fault lines, which in turn might prevent some student misconceptions that might be generated by the model:

"I was thinking, you know, toast the bread, but then it would just break. But maybe toasting the bread might work better for the flip, then you actually see the break in the, in the crust. You know what I mean?" Lisa I2-Y1 (Level 2)

By the third year, all of the teachers were able to not only provide a completely different representation for the content, but also evaluate and compare its usefulness relative to the sandwich and/or other model. Catie displayed the most growth in her ability to provide new representations and evaluate them:

"I am sure it's the best you're going to get. I mean, like you could have like a clear container and do like layers of like sand and stuff like that and that would help them to see like the different layers and stuff but you can't bend a bucket of sand, you can't you know like change it like you can a peanut butter and jelly sandwich, you know." Catie I2-Y3 (Level 3)

Throughout the study, Whitney was always able to provide completely different representations of the content. In addition, she tended to evaluate and compare them in regards to content and/or supporting student learning more than the other teachers. In particular, she often discussed how different representations are better for teaching different, but related topics.

She also discussed the different representations she would use to scaffold students such that they could understand the model in question.

> "I think that, like by asking the question first and having them write in their journal and then when you're doing it talking about the earth, because I know that when we did it too like you have to talk about the layers of the earth first. So even if you talk about, you know here's a globe, here's an apple, an apple is like the earth because of this, you know these are the layers in an apple, we're going to use a different representation here using, you know a sandwich as the layers of the earth that we talked about before because I don't think you would start with this as your introductory lesson." Whitney I2-Y3

Whitney was concerned that the "Cloud in a Bottle" model might foster the misconception that smoke is needed to create clouds. Because in her location, clouds were rare, but smoke from forest fires was more common, this was a real concern for her. As she evaluated the model, she discussed how she would use another representation to help prevent those misconceptions from forming:

> "…if I did it I would do a demonstration just because of the matches thing. And my thing with this too is I would look at if there's other ways to do it, to show them multiple ways because … and then they can see that there's, you know more than one way, it doesn't always necessarily happen this way, I'm sure there's other ways to do it...I think it was about condensation, not clouds, but … It had to do with like hot versus, you know hot, you had hot water in a bottle and then an ice cube on top and where the hot and cold met, kind of making a kind of cloud and then that condensed on the sides and made it come down as rain…Forming rain, but it condensed, you know what I mean. It made somewhat of a little bit of a cloud but only if the water's hot enough and the ice cubes cold enough. And it doesn't leak everywhere." Whitney I3-Y3

At times, the teachers suggested using additional instructional representations in order to support student learning. These representations were not different ways of representing the content in questions, but additional supports to help students learn the content. This was observed in the different ways in which each new elementary teacher tended to choose and/or modify the instructional representations to support student learning.

For example, Catie prioritizes organization of data in her science teaching so she suggests implementing representations involving data organization more frequently than the other teachers. When she discussed an activity that was designed to model natural selection, Catie suggests using data organization to as a way to illustrate the effect of natural selection and support student learning:

"you could even, and that might be another thing to add…doing like a graphing activity, you know like…some of the kids with tweezers and then doing another graph and, where it shows like the progression, the decline of the tweezers and the increase of the spoon beaks" Catie I1-Y2

With her strong focus on students, Whitney uses KWL (What We Know, Want to Know, Learned) charts to guide her curriculum. In addition, she tends to rely on analogies and examples to support student learning of the content by relating it to their lives. Unlike the other teachers, Lisa did not favor a particular type of instructional representation. She just seemed to choose the representation she believed best for supporting student learning of the content. To do this, she discussed a broader range of instructional representations than the other teachers. In this way, each of the teachers consistently favored a personal strategy to represent content and support student learning, thus illustrating the individualized pedagogical framework that they are working to develop.

DISCUSSION

How does the teachers' orientation affect their development?

A teacher's orientation toward subject matter teaching and toward curriculum materials can influence their use of supports for their instruction (e.g., Remillard & Bryans, 2004). We wondered how these teachers' orientations would influence how they think about and use instructional representations, which are typically incorporated into science curriculum materials but are not necessarily used effectively. We saw that each teacher's orientation toward science teaching did indeed seem related to their consideration of instructional representations.

Whitney focuses so strongly on students in her practice that she integrates factors related to students' ideas and experiences into her evaluation of instructional representations consistently—even from her first year in the classroom. She exhibited this early integration of knowledge as she considered the accessibility of the representation as well as how well it represented the content. When discussing alternative representations, again she integrated consideration of students' ideas and experiences as she compared and evaluated the different representations. She tends to add analogies and examples to relate the science content to her students' lives, which is consistent with her student focus.

When faced with a complex idea, Lisa can easily break it up into an accessible progression of chunks in order to scaffold student learning. This skill is a type of flexible knowledge that illustrates her PCK development. In keeping with this flexibility, she employs the broadest set of instructional representations into her discussions and does not seem to favor any particular type. She is also relatively balanced in her evaluation of instructional representations, not favoring any particular criteria.

Catie has a strong focus on students learning content. This is illustrated as she evaluated the accessibility of instructional representations and how well they represented the content. Quite often the modifications she suggested were related to making the material more accessible by making sure that the students had the proper background knowledge. In addition, she prioritizes data organization to help students make sense of the content. Therefore, she favors instructional representations such as charts, graphs and tables that can be created by the students individually or as a class as whole to support student learning.

Each of the teachers described their use and evaluations of instructional representations in different ways. All of them could be considered to support a productive learning environment. These differences observed in the teachers' favored instructional representations and strategies illustrates the individual nature of PCK development. Thus, this study contributes to literature on how teachers use and adapt curriculum materials—in particular, how they use and adapt instructional representations within curriculum materials—as well as literature on how elementary teachers' PCK develops. Teachers' decisions about how to represent content is generally linked to their subject matter knowledge (Shulman, 1986; Ball & Bass, 2000). Strong content knowledge enhances teachers' ability to anticipate and deal with students' ideas and difficulties (McDairmid, Ball & Anderson, 1989; Ball & Bass, 2000). Lack of scientific content knowledge often leads teachers to use instructional representations ineffectively (Davis & Petish, 2005; Hashweh, 1987; Yerrick, Doster, Nugent, Parke, & Crawley, 2003).

However, this study suggests that teachers' orientations toward science teaching also have a significant effect on their use instructional representations. Rather than being simply dependent on science content knowledge, or lack thereof, teachers' use of instructional representations is affected by this orientation, and in particular, their orientation relates to how they consider management issues, accessibility, and content in evaluating instructional representations.

Their orientation also relates to the signature representations they choose to incorporate into their teaching regardless of the content being taught. Since most elementary teachers have limited science content knowledge, these orientations may play a stronger role in their development of PCK. These orientations may affect what kind of knowledge gets integrated and interconnected first as the teachers work to develop PCK. If this is indeed the case, the PCK development of beginning teachers is likely to be quite idiosyncratic and individualistic since these orientations incorporate a host of dimensions (Magnusson, Krajcik & Borko,1999),.

Teacher trajectories

In their practice, expert teachers appear to be more prepared to accommodate students' ideas and difficulties (Hogan, Rabinowitz & Craven, 2003). In addition, expert teachers tend to monitor student understanding better during a lesson. Indeed, when comparing expert and novice mathematics instructors, Livingston and Borko (1990) found that during a review lesson, expert teachers were able to address individual student difficulties and questions while covering more content than the novice teachers. In a discussion of teacher development, Fuller (1969) describes the final stage as a time when the teacher can focus more on her students. Though of course these studies represent typical characterizations rather than the specific nuances one sees when one looks at specific individual teachers, these studies indicate that expert teachers are, in general, able to integrate their knowledge of content, teaching strategies and students' ideas more readily than are the novice teachers. This is important because in order for teachers to be successful, they must move beyond the way in which they learn and understand content and generate alternative explanations and representations of the content for students. (Hashweh, 1987).

The differences observed between novice teachers and experts can be explained by the hypothesis that novice teachers have less depth in their knowledge, which in turn is less integrated and accessible than for expert teachers (Borko & Livingston, 1990). Throughout the study, we see the teachers working to build an integrated knowledge set to evaluate how best to represent content. Catie exhibits the clearest progression over her first three years of teaching. She increased the degree to which she considered accessibility of the instructional representations. In addition, she discussed the instructional representations with respect to content and scientific accuracy with greater frequency as she gained experience. While she did not increase the number of alternative representations that she could provide, she did begin to discuss them in a more sophisticated manner over time. By her third year, she was able to compare different representations and evaluating them with respect to how well they represent content and support student learning.

Because she began at a higher level in almost all respects, Whitney's trajectory was much less profound than Catie's. From the very beginning, she evaluated the instructional representations in a very sophisticated way. Her focus on students led her to consider their prior knowledge and experiences and anticipated potential misconceptions when evaluating the accessibility of the representations, even as a first year teacher. In addition, she was able to provide more alternative representations in every situation. Her flexible knowledge was particularly illustrated as she evaluated the different representations in regards to accessibility and how well they represent content and support student learning. The one area in which Whitney grew was in regards to management issues, which became more prevalent in her evaluation of instructional representations. Thus, as she gained experience, she was integrating more factors into her decisions about how to represent content.

Lisa's growth was also not as dramatic as Catie's because like Whitney she was evaluating the instructional representations with a degree of sophistication even in her first year of teaching. Although the frequency with which she would discuss evaluation criteria decreased at times, she generally decreased the amount of solely declarative evaluations that she made, thus increasing the justification she provided for her evaluations. This was especially visible in her evaluation of instructional representation accessibility. In addition, her discussion of engagement decreased over time suggesting that student engagement became less of a priority. Management issues did not appear to be a high priority when she evaluated how to represent content. Instead, her priorities lie in breaking content into pieces such that it became accessible to students.

In order to gain some insight into the flexibility of the new teachers' content knowledge we evaluated their ability to generate alternative representations for content. In addition to following the number of alternative representations that they could provide, we also evaluated the type of representations they offered, and how they evaluated the new representation in relation to the content and/or other representations. When comparing experienced and novice chemical demonstrators, Clermont and colleagues found several differences in their ability to offer alternate representations of content (Clermont, Borko & Krajcik, 1994). The more experienced practitioners were able to provide multiple alternative representations of the same content. In addition, they were able to evaluate the demonstration (representation) in terms of potential student misconceptions that it might generate. In contrast, the novice demonstrators were unable to anticipate potential student difficulties. In addition, the novices were able to provide significantly fewer alternative representations. Borko and Livingston observed a similar pattern with novice and expert mathematics teachers (Livingston & Borko, 1990; Borko & Livingston, 1989). In comparison with the novices, the experts were much better able to integrate concern with students' questions and difficulties while still presenting the planned content. The authors hypothesized that the novice teachers possessed less pedagogical knowledge so the teachers had limited knowledge of potential student difficulties as well as a lesser ability to integrate their knowledge in their decision-making.

However, the teachers in our study were not as easy to categorize. Catie, on the one hand, followed progression similar to that described by Clermont and colleagues (1994). In her first year, she exhibited a limited ability to provide alternative ways to represent content. As she gained experience, she was at times able to provide more alternatives. In addition, she began to discuss them with more complexity, comparing how well they represent the content. However, Lisa and Whitney did not follow the same progression. Lisa began at a higher point in the progression, as she was able to provide multiple alternatives to the representation that she was evaluating. However, there was not a clear progression in her evaluation of them. Like Lisa, Whitney also began at a higher point in the progression. She was also able to provide multiple ways to represent the content even in her first year of teaching, but unlike Lisa, Whitney discussed the representations with a high degree of sophistication.

Although it is generally thought that management issues are a key focus for new teachers, it was not necessarily at the forefront of their consideration as they evaluated how to represent content. In addition, two of the three new elementary teachers prioritized and discussed scientific accuracy of the models even as novice teachers. By her third year of experience, the third teacher was regularly incorporating scientific accuracy into her discussion. All of the teachers built a more integrated framework of knowledge on which to base their decisions about representing content.

Like the teachers in Anderson and colleagues' (2000) study, these teachers followed a variety of trajectories. Each in her own way, however, made progress in her consideration of instructional representations over the three years of the study.

Conclusion

The challenges faced by elementary teachers are daunting. For many, teaching science is one of the most difficult aspects of their work, as they usually possess little science content knowledge. With this comes the challenge of developing PCK, which is necessary for becoming an effective science teacher and to support student learning. This study documents the progress that new elementary teachers make towards developing PCK for teaching science. In particular, this study contributes to the literature on the development of elementary science teachers' PCK (e.g., Appleton, 2003; Davis & Petish, 2005) by illustrating the complexity of the relationships among content knowledge, PCK, and teaching experience over a series of years with a group of beginning elementary teachers. In addition, the results of this study contribute to the thinking of science teacher educators and science curriculum developers. The study demonstrates the ways in which beginning elementary teachers struggle with—but eventually succeed in—analyzing and using instructional representations embedded in science curriculum materials.

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