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ABSTRACT

This paper provides a critical analysis of a professional development model that proposes to improve inquiry science instruction by addressing two components of teacher knowledge: pedagogy and science content. Although this represents an improvement over professional development models that focus on a single area of teacher knowledge, this paper suggests that, in order to impact inquiry science instruction, three pieces of teacher knowledge are required: pedagogy, science content, and pedagogical content knowledge. Without all three components, the impact on classroom instruction will be limited. (Contains 17 references.) (Author/MVL)

Evaluation of a Model for Supporting the Development of Elementary School Teachers' Science Content Knowledge

Alicia C. Alonzo

EVALUATION OF A MODEL FOR SUPPORTING THE DEVELOPMENT OF ELEMENTARY SCHOOL TEACHERS' SCIENCE CONTENT KNOWLEDGE

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Since the release of the National Science Education Standards (National Research Council [NRC], 1996), there has been increased interest in implementing and sustaining inquiry-based science teaching. As school districts and their university and/or industry partners quickly discover, successful inquiry-based science programs require much more support for teachers than just the delivery of a kit full of materials (National Science Resources Center [NSRC], 1997). In addition to significant changes in pedagogy, teachers, particularly at the elementary school level, struggle with the increased demand for content knowledge required by the inquiry approach to teaching science. Because most elementary school teachers are not science content experts, they may hold some of the same misconceptions that their students do about the science curriculum (Schoon & Boone, 1998). In addition, inquiry teaching requires more understanding of and comfort with the content than is required by a more didactic teaching style (Carlsen, 1987; Dobey & Schafer, 1984). Thus, in thinking about how to sustain and improve inquiry science instruction, teacher educators need to consider ways in which to support the development of teachers' science content knowledge. Because efforts to teach science content in traditional university lecture-type courses has proved to be largely unsuccessful, even when accompanied by hands-on work (McDermott, 1997), new models for professional development are needed.

This paper provides a critical analysis of one such professional development model, which proposes to improve inquiry science instruction by addressing two components of teacher knowledge: pedagogy and science content. Although this represents an improvement over professional development models which focus on a single area of teacher knowledge, this paper will argue that, in order to impact inquiry science instruction, three pieces of teacher knowledge are required: pedagogy, science content, and pedagogical content knowledge (PCK) (Shulman, 1986). Without all three components, the impact on classroom instruction will be limited.

Description of the Model

The professional development model analyzed in this paper supports the development of teachers' science content knowledge by providing the experience of investigating a particular area of science content in an inquiry-based environment. Inquiry science teaching is expected to be improved through both increased content knowledge and teachers' authentic experience of learning science in an inquiry environment. The model is depicted in Figure 1.

Consistent with guidelines for effective professional development (Loucks-Horsley, Stiles, & Hewson, 1996), this model allows teachers to engage with a particular content area in a deep manner, over an extended period of time. Their learning is supported by a teacher-scientist pair who function as facilitators, providing (a) questions to investigate and (b) guidance in conducting and interpreting explorations based on these and the teachers' own questions. In this way, the facilitators model inquiry science pedagogy.

Although the blending of content and pedagogy is useful at any stage of teacher development, this particular model has been designed to address the science content needs of elementary school teachers who have been teaching inquiry-based science in their classrooms and would like to obtain a stronger understanding of the content of a particular curriculum unit. These teachers have, for the most part, a level of expertise characterized by the "use" of inquiry science materials (NSRC, 1997), and are struggling with how to translate the curriculum units into rich learning experiences for their students. Because the model provides teachers with opportunities to learn about science content directly aligned with that being presented to their students, it is expected that increased content knowledge will be directly applicable in the classroom, enabling teachers to better guide their students' investigations. However, the model contains no explicit connections to the elementary school classroom. In focusing only on teachers' learning of the science content and their experience of learning in an inquiry environment, the model excludes discussion of how this knowledge can be applied to teachers' work with their students.

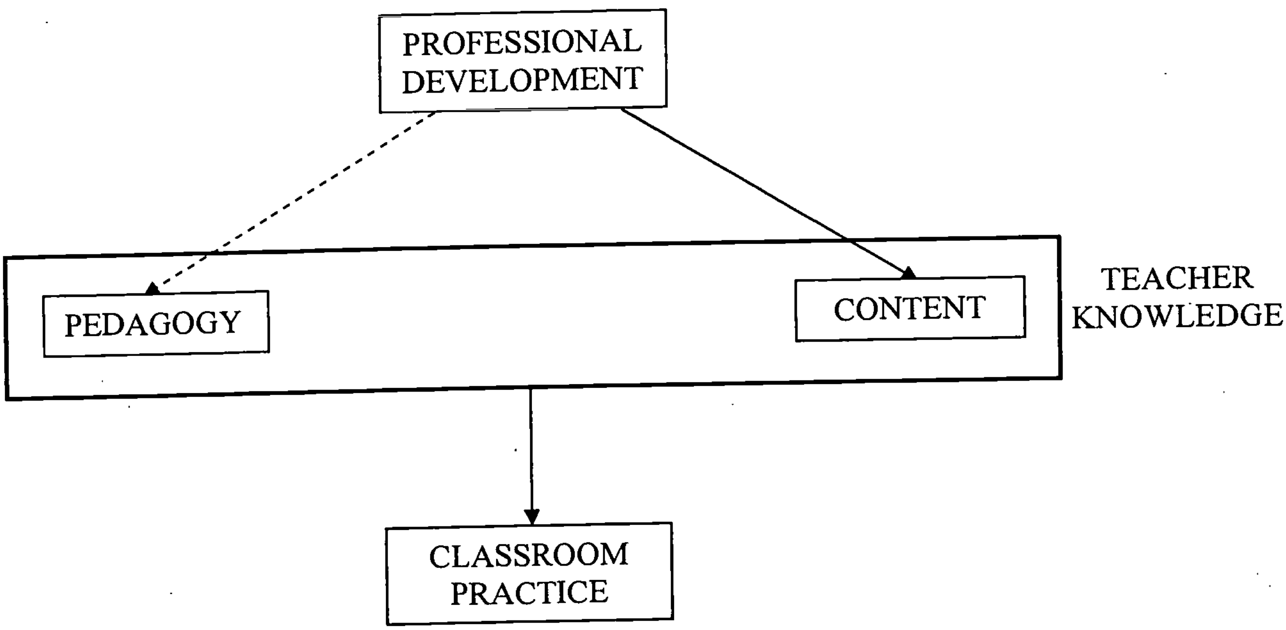

Figure 1. Diagram of professional development model. Direct influences (those explicitly included in the professional development experience) are depicted with solid lines, while indirect influences are depicted with dashed lines.

Theoretical Background for the Model

At its most basic level, this professional development model represents an attempt to interweave content and pedagogy (Post, 1997). It is patterned after the work of Duckworth, Easley, Hawkins, and Henriques (1990), who describe engaging teachers with "the real subject matter of science" and through this, a consideration of themselves and others as learners. As in the work of Duckworth and her colleagues, the content is adult-level science content related to topics taught in elementary school classrooms, while the pedagogy is inquiry pedagogy, or (in Duckworth's case) constructivist pedagogy. Thus, teachers learn in an environment similar to that which they are expected to create for their own students. Although there is often a disconnect between the form and content of professional development programs, in addition to common-sense arguments, this more-encompassing model is well-supported in the research literature (e.g. Shavelson, Copeland, Baxter, Decker, & Ruiz-Primo, 1994).

The mixing of content and pedagogy addresses two key issues which are included in this professional development model. First, although teachers' increased content knowledge is a useful objective by itself, the more pressing goal is improving the effectiveness of teaching for students. Increased content knowledge has limited utility if it is used to create a longer list of facts to impart to students. Rather, it is the combination of solid inquiry pedagogy with increased content knowledge that is needed. Second, inquiry pedagogy, which has roots in the constructivist tradition, has been shown to be effective for both children and adults (NRC, 1999). Therefore, this is a viable framework for the development of teachers' science content knowledge. In particular, teachers are given the opportunity to build upon their previous conceptions of the science content by designing their own explorations and constructing their own explanations, with guidance from both a fellow teacher and a scientist.

Implementation of the Model

This paper focuses on a particular implementation of this model, a course entitled Floating & Sinking (Alonzo, Hartney, Linden, Post, & Stewart, 1997). It was designed according to the components of the professional development model described above. The course addresses the science content contained in the Clay Boats unit (Elementary Science

Study, 1996), part of the district-wide curriculum for third graders at the schools in this study. The Clay Boats unit engages students in initial explorations of concepts related to floating and sinking, through the construction and testing of boats made out of materials such as clay, foil, and waxed paper. The Floating and Sinking course provides teachers with the opportunity to engage in an in-depth exploration of concepts related to density for a total of 24 hours.

The Floating & Sinking module begins with an elicitation of teachers' prior knowledge and an activity in which they predict and test whether a variety of household objects will float or sink when placed in water. Next, teachers explore the question, "What variables affect floating and sinking?" This is followed by investigations of both weight and water displacement. Teachers return to the task of predicting floating/sinking behavior by using the results of their previous inquiries to make predictions about mystery cylinders. Next, they consider floating/sinking behavior in liquids other than water. Finally, they rely on all of their investigations to invent a definition of density and explain its role in determining whether an object will float or sink.

Method

The work described in this paper is part of a larger study to examine the effects of the Floating & Sinking course on teaching and learning in the Clay Boats unit. Of particular interest in evaluating the professional development model is data related to teachers' content knowledge and its effects on classroom inquiry science instruction. Although the larger study included teachers who were not part of the Floating & Sinking professional development experience, this paper will focus exclusively on the seven teachers who participated in the course.

Before and after the Floating & Sinking course, each teacher completed an extensive paper-and-pencil assessment of her content knowledge related to floating and sinking. An additional content question was included in an interview conducted before the teachers taught the Clay Boats unit each year. See the Appendix for content knowledge questions considered in the following analysis. These questions were developed through consideration of (a) knowledge of floating and sinking required to fully explain phenomena encountered in the Clay Boats unit and (b) common misconceptions about floating and sinking, as revealed in the research literature (e.g. Biddulph & Osborne, 1983) and observations in the first year of the study.

Because the study spanned two years, teachers were observed teaching the Clay Boats unit twice: once before and once after their participation in the Floating & Sinking course. While they were teaching the unit, three to five observations were conducted, including extensive field notes and audio-tapes, which were subsequently transcribed. The observation piece of this study allows a unique perspective on the effects of science content knowledge on inquiry science instruction. Although there have been a few studies which document the effect of science content knowledge on pedagogy (e.g. Carlsen, 1987), to our knowledge, there have been no studies which examine the effects of content knowledge on the science content which is presented to students. In this study, such analysis is possible, including documentation of the misconceptions teachers presented to their students.

Results

Teachers' growth as a result of the professional development program Floating & Sinking can be examined along two dimensions: content knowledge and use of content knowledge in instruction.

Trajectories for Growth in Content Knowledge

In order to document how teachers' content knowledge changed as a result of their participation in the Floating & Sinking course, an analysis of teachers' answers to content knowledge questions was conducted and described along a continuum of knowledge about floating and sinking. This analysis focused on the knowledge required to fully explain phenomena encountered in the Clay Boats unit. In particular, the final stage of the trajectory (Level 4) is exemplified by the ability to generate a complete explanation of why boats float, as indicated by the interview question and the "clay ball" question. This requires making the connection between the concept of density and the phenomenon of floating boats, and represents the most complicated instance of floating: an open object. At a slightly lower level of understanding (Level 3), teachers can explain the floating/sinking behavior of the most complicated closed objects, hollow objects. This understanding is demonstrated by teachers' explanations of the role of air in floating and sinking in terms of how air affects the density of an object (the "air" question). At Level 2, teachers provide a definition of density (the "density" question) and identify its role in the floating/sinking behavior of the solid objects (the "mystery cylinder" and "material" questions). Teachers at Level 1 do not recognize the crucial role of density in floating and sinking. Instead, they cite various factors related to floating and sinking to explain whether an object will float or sink. Finally, Level 0, the beginning of the trajectory, represents a point at which teachers hold major misconceptions about floating and sinking. For example, a common misconception was the belief that the amount of water is a crucial factor in determining whether an object will float or sink (the "amount of water" question).

Content knowledge trajectories for each of the seven teachers are represented in Figure 2. In order to illustrate these trajectories, the cases of Ms. Innes, Miss Florillo, and Ms. Oren are described in detail below.

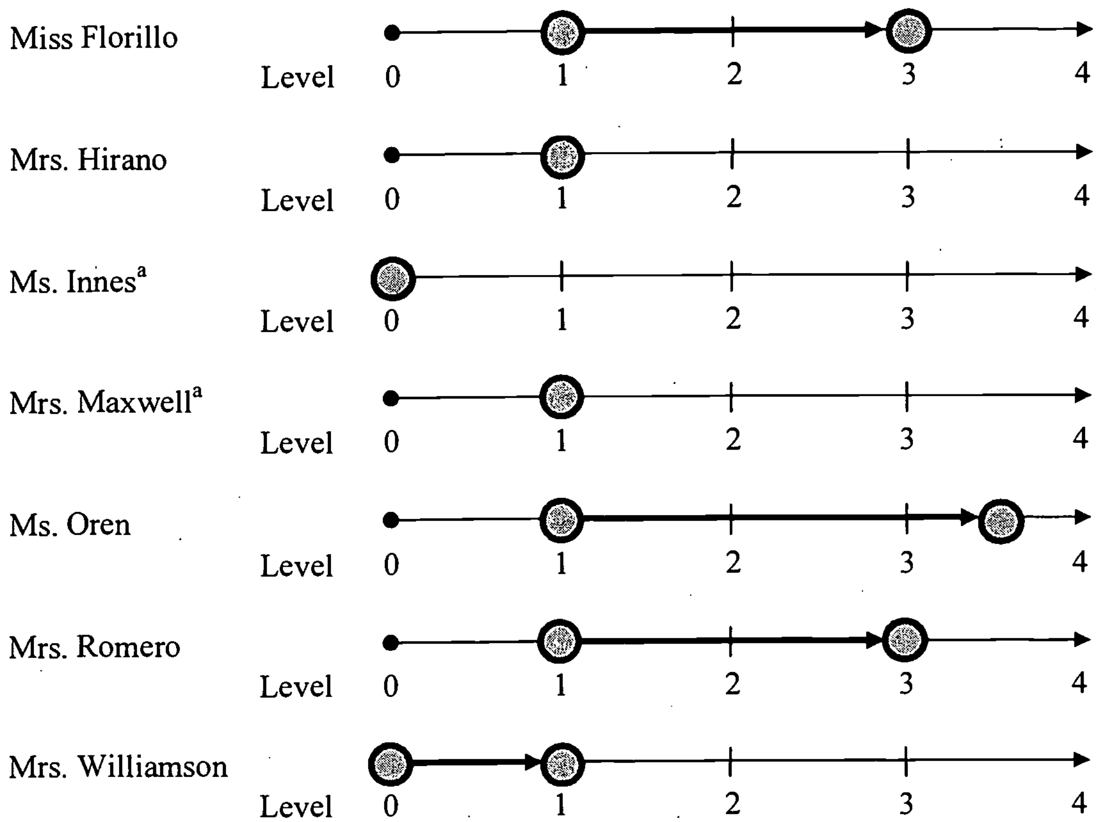

Figure 2. Trajectories for Growth in Content Knowledge.

[a] Content knowledge information obtained only through initial content knowledge assessment, interview, and classroom observation.

Ms. Innes

Both before and after the Floating & Sinking course, Ms. Innes did not make a connection between her precise definition of density and the phenomenon of floating boats. In both years, her explanation for boats' ability to float included surface area, the distribution of weight, and the amount of water. In addition to data from the interview, classroom observations revealed that Ms. Innes retained two misconceptions after the Floating & Sinking course. She strongly believed that larger amounts of water would increase a boat's ability to float (even if the boat were not touching the bottom of the container). In both years, she had students conduct an investigation in order to prove this. In addition, she guided students towards an understanding that the material cargo was made of (not its weight) was crucial in determining the how much cargo a boat could hold. Significantly, despite some substantial misconceptions about floating and sinking, Ms. Innes was viewed as the science content expert by the other participants in the Floating & Sinking course, so that her incorrect ideas were often accepted as truth by the other teachers.

Miss Florillo

Before the Floating & Sinking course, Miss Florillo had vague ideas regarding floating/sinking phenomena. In describing a strategy for predicting whether a mystery cylinder would float or sink in water, she explained that she would place the cylinder in a different liquid (the "mystery cylinder" question). However, this was not related to density or to any other property of the object or liquid. To explain why a piece of clay can float when shaped as a boat (the "clay ball" question), she said, "It has to do with the surface area and density of the clay." However, later in the interview, she said that she didn't really know what density means. She recognized that density and weight are different but could not explain their relationship (the "density" question). Miss Florillo was aware that it was possible for solid objects to float and thought that air played a role in determining floating/sinking behavior. However, she did not understand how air influenced whether an object would float or sink. Her response to the interview question involved explaining the phenomenon of floating boats in terms of surface area and weight distribution.

After the Floating & Sinking course, Miss Florillo articulated a correct understanding of the role of density in determining whether solid objects will float or sink (the "mystery cylinder" question). She also gave a complete explanation of the role of air in the floating/sinking behavior of hollow objects in terms of the effect of air on an object's density (the "air" question). However, when discussing boats in the interview question, her explanations relied solely on her previous ideas about surface area and weight distribution . Interestingly, her newly-acquired definition of density (the "density" question) was expressed in terms of weight per square unit. Perhaps this was a means of reconciling new information about the critical role of density in floating and sinking with her intuitive sense that surface area was an important factor.

Ms. Oren

Before the Floating & Sinking course, Ms. Oren had a solid foundation for understanding the concept of density. She defined density as weight per square unit and described a strategy for predicting whether a solid object would float by an indirect density comparison. In answer to the "mystery cylinder" question, she said, "I can weigh the cylinder. I can compare the weight to a cylinder of the same size that does float. I would compare its weight to its size." Her explanations for floating hollow objects and boats involved weight distribution and surface area.

After the Floating & Sinking course, Ms. Oren's answers revealed the co-existence of her old ideas, along with new information obtained from the course. Her answer to the "mystery cylinder" question involved a precise and detailed explanation of the role of density (of both object and liquid) in determining the floating/sinking behavior of solid objects. However, in response to the "density" question, she restated her original definition for density, involving square units, but used volume units in an accompanying example. This seems to indicate either confusion between volume and area or a failure to differentiate between the two.

To answer the "air" question, Ms. Oren gave a clear explanation for the role of air in floating and sinking. She wrote, "Solid objects also can float when you change the shape which therefore changes the volume. Air becomes part of the volume." Although this explanation could also be used in considering the phenomenon of boats' floating, Ms. Oren's response to the "clay ball" question revealed that she had not yet made this extension. She relied on her old ideas about weight distribution to explain how a clay boat can float.

Her answer to the interview question also revealed a mixture of old and new ideas. She listed both density and the distribution of weight as factors affecting a cruise ship's ability to float. And later in her answer, she said, "Air is part of the mass, and so that changes the whole density of, well, it changes the, it's a variable that affects if something's going to float or not." While she seems to have a tentative understanding of density and its role in floating and sinking, this has not completely replaced her ideas about weight distribution and surface area.

Trajectories for Use of Content Knowledge in Instruction

The analysis of teachers' use of content knowledge in their teaching of the Clay Boats unit focused on an examination of the transcripts of classroom discussions, as well as a more general look at the science content presented each year. Any indication of teachers' use of content knowledge, particularly questions and dialogues with students, was culled from the transcripts. In addition, lessons and other direct importations from the Floating & Sinking course were noted.

Several types of content knowledge use were observed, representing various levels of pedagogical implementation. At the final stage of the trajectory (Level 3), teachers made extensive use of their content knowledge to guide students' learning. Ms. Oren exemplified this level of content knowledge integration, by consistently questioning students' statements about the role of weight in floating and sinking, suggesting that students consider additional factors in floating/sinking behavior, and designing inquiries for students to explore their ideas about weight. Teachers at Level 2 also incorporated science content knowledge into their classroom; however, this represented direct instruction: telling students facts about floating and sinking, rather than using content knowledge to guide students to their own understanding of the concepts. Level 1 represents an effort to incorporate science content knowledge to guide students' learning. However, there are limited examples of this type of dialogue or questioning present. At Level 0, there is no evidence of the use of content knowledge. Evidence from the Floating & Sinking course is limited to the direct importation of lessons from the course.

For each of the seven teachers, trajectories for the use of content knowledge are represented in Figure 3. The trajectories reveal no change in how teachers used content knowledge in their instruction, although two teachers (Mrs. Maxwell and Ms. Innes) did incorporate more content knowledge into their pre-existing teaching strategies. In order to illustrate these trajectories, the cases of Mrs. Hirano and Mrs. Maxwell are described below.

Mrs. Hirano

The main influence of the Floating & Sinking course in Mrs. Hirano's classroom seemed to be the incorporation of a lesson directly from the course. She had her students predict and test the floating/sinking behavior of a variety of household objects, including many of the same ones used in the course. However, this was not used as a starting point for getting students to think about factors involved in floating and sinking. The activity remained isolated from the rest of the Clay Boats lessons.

In both years, there were rare examples of Mrs. Hirano's use of content knowledge to guide student thinking. In year one, Mrs. Hirano encouraged her students to think about bigger boats holding more cargo, but this seemed to be related to the room inside the boat, rather than to any consideration of the density of bigger and smaller boats. During the lesson involving

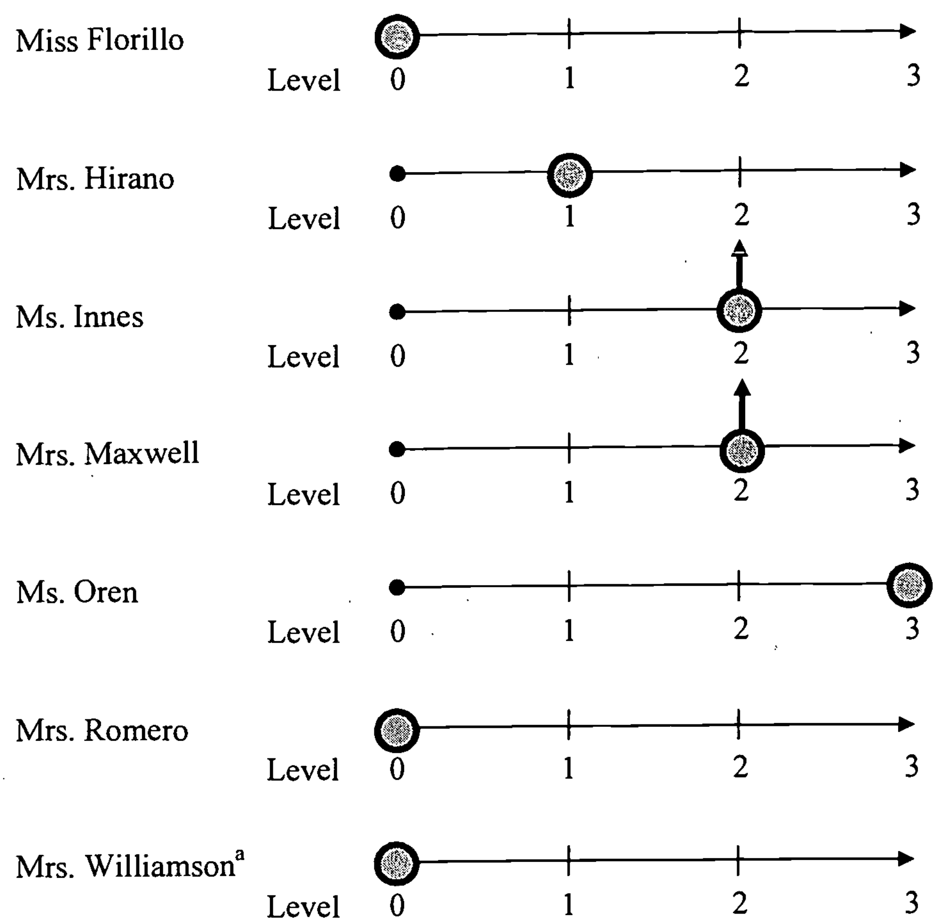

Figure 3. Trajectories for use of content knowledge in instruction. The horizontal axis represents the use of content knowledge dimension, while vertical arrows indicate increases in the content knowledge evident during instruction.

[a] No pre-course observations available.

household objects, there were two separate dialogues in which Mrs. Hirano focused students' attention on the role of weight in floating/sinking: one which emphasized the importance of weight and one which questioned the importance of weight. The former dialogue occurred after students observed an empty film canister floating and Mrs. Hirano asked students to predict what would happen if she added a marble to the film canister:

> Students: Sink!
> [Mrs. Hirano adds a marble to the film canister, but it still floats.]
> Student: It gained weight.

Student: It's floating.
Mrs. Hirano: Did the weight matter? What will happen if I add more marbles?
Student: It will sink.

Although Mrs. Hirano seemed to be pointing students in the direction of considering weight, she did not use her content knowledge to follow through with this dialogue.

Mrs. Maxwell

Mrs. Maxwell imported two lessons directly from the Floating & Sinking course and introduced the definitions of floating and sinking that she had learned. Like Mrs. Hirano, she repeated the lesson on predicting and testing whether household objects would float or sink in water. In addition, she tried to repeat the lesson on water displacement with her students. In the Floating & Sinking course, she had measured the volume of water displaced by various floating and sinking objects and compared this to (a) the volume of the sinking objects and (b) the weight of the floating objects. However, without the graduated cylinder or triple beam balance used in the Floating & Sinking course, she was not able to demonstrate these relationships to her students. She tried to engage students in measuring water displacement, by recording the water level in a small cup with a piece of masking tape. However, from discussions during this activity, it was not clear that her students understood what she meant by water displacement. She appeared to have difficulty in translating her experience into something that third graders could understand, particularly without the equipment she had used in the course.

Mrs. Maxwell used content knowledge from the unit to supplement her existing teaching strategy. In both years, she relied on song lyrics to "explain" floating and sinking: "What makes an object float/Reasons there are three/Surface tension, weight displaced, and lesser density." In year two, she added information from the Floating & Sinking course to the definition of water displacement she presented to her students, telling them that the weight of water displaced is equal to the weight of the floating object. However, she seemed to be referring to the weight of the cargo in students' boats, rather than that of the entire object (boat plus cargo). In year one, Mrs. Maxwell treated density as something obvious and not worth defining. In her paper-and-pencil assessment before the Floating & Sinking course (the "density" question), she revealed that this was probably because she didn't have a definition of this term herself. In year two, she attempted to define density for her students, but her explanation was a bit confused, and the example she used to illustrate the concept confounded weight, volume, and density.

General Teacher Change Patterns

Examining the trajectories of these seven teachers, some patterns emerge. Not surprisingly, change in teachers' content knowledge was greatest for those concepts directly addressed during the Floating & Sinking course, either through direct investigation or discussion. The greatest improvement was observed for teachers' understanding of general rules for floating/sinking of solid objects, the role of air in floating/sinking behavior, and water displacement. All three of these topics received extensive coverage in the Floating & Sinking course. However, these new ideas co-existed with old ideas which were unchanged by the course. Teachers who were able to give clear explanations of density and its role in solid objects' floating/sinking behavior, often reverted to explanations involving surface area or weight distribution when explaining why boats float. This was sometimes accompanied by alternative definitions of density, which involved square units, rather than volume.

Other teachers had less well-developed understandings of density by the end of the Floating & Sinking course. They did not seem to recognize the critical role of density in floating and sinking, and continued to list a variety of factors related to floating and sinking. Although there was some change in the factors mentioned (for example, a decreased emphasis on weight), these were not related to density as an overarching concept in floating/sinking. In addition, when ideas from the course were mentioned, these tended to be repetitions from the course, rather than expressions of ideas in the teachers' own words.

The most common effect of the Floating & Sinking experience was for teachers to try to import lessons and/or information from the course directly into their third grade classrooms. In general, there was very little evidence of any use of content knowledge in guiding students' inquiry experiences.

Discussion

The results presented above have implications for revising the professional development model on which the Floating & Sinking course was designed, both to improve teachers' content knowledge growth, and to improve their use of that content knowledge in elementary school classrooms.

Model Revision for Improved Content Knowledge Growth

As currently designed, the Floating & Sinking course starts with an exercise intended to elicit teachers' pre-existing ideas about floating and sinking. As is common in elementary school classrooms, this takes the form of a "KWL" chart, asking the participants to list what they know ("K") and what they want to know ("W"), with the expectation of returning later to fill in what they have learned ("L"). However, the results detailed above indicate that this is not enough. Teachers' misconceptions may not be elicited by a KWL chart. Instead, specific questions, such as those included in the paper-and-pencil assessment, must be asked and analyzed to determine teachers' pre-existing ideas. The results show that this form of professional development may be effective in changing teachers' content knowledge, but only in areas explicitly addressed.

Teachers in this study explained the phenomenon of boats' floating with surface area and weight distribution both before and after the Floating & Sinking course. Although some teachers gained an understanding of the role of density in floating and sinking, and several were able to explain how forming a boat shape from a ball of clay represented a change in density, these new ideas co-existed with their previous ideas about surface area and weight distribution. Without direct discussion of surface area and weight distribution, these explanations retained their salience for the teachers.

Perhaps related to co-existence of explanations involving both surface area and density, teachers did not seem to have a clear understanding of the distinction between area and volume, before or after the Floating & Sinking course. Throughout the course, density was defined using volume, but this was never directly contrasted with area, so that some teachers continued to use volume and area interchangeably.

Finally, the Floating & Sinking course never explicitly addressed the issue of the amount of water. Ms. Innes, viewed as the content expert by her colleagues, had a strongly-held belief that a boat would float "twice as well" in twice as much water. As this was not explicitly addressed in the course, she retained this belief. In fact, it is possible that she influenced other teachers, such that they also held this belief by the end of the course.

Model Revision for Improved Use of Content Knowledge: Specifying Intended Impact

The tendency of teachers to directly import lessons from the Floating & Sinking course into their classroom is not surprising, given the usual science professional development that is offered to elementary school teachers. All of the teachers in the study had received school-district-provided training in how to use the inquiry-based science kits that constituted the district's elementary science curriculum. They received one day-long training for each of the four kits in the curriculum at their grade level. During these training sessions, teachers engage in the unit as if they were the students in their class. The teacher facilitator acts as the teacher, occasionally interjecting management tips into the training. But, the general idea is that teachers will have experienced the unit as their students will. They will then take the lessons that they experienced (acting as students) and teach them in their classrooms.

The professional development model described here is a significant departure from these training sessions in the way in which the experience is expected to be used in the classroom. Rather than using specific lessons with their students, the model assumes that the impact on classroom instruction will require an additional level of transfer. The expectation is that teachers will apply the pedagogy they have experienced without directly applying the experiences themselves. In addition, a further level of transfer is required in that the teachers are not expected to directly teach the content knowledge that they acquired through these activities to their students, but rather to use this knowledge to guide their students in activities only peripherally related to what they experienced during the Floating & Sinking course.

However, discussion of how the professional development experience is expected to influence classroom instruction is entirely absent from the professional development model. Without a competing model for how to use the experience in their classrooms, it is reasonable that teachers will use the model with which they are familiar: using the content of the professional development directly in their classrooms. Although the teachers were repeatedly told that "this is only for you, not for your students," they were all interested in the course because they wanted to teach the Clay Boats unit more effectively. Therefore, in the absence of any other explanation of how the Floating & Sinking course was intended to influence their classroom instruction, they borrowed lessons from the course for use with their students.

The professional development model needs to be revised to include explicit discussion of what the experience is expected to provide for teachers and how this is expected to influence their work in the classroom. The effectiveness of the model is drastically reduced when teachers are expected to make these connections without any guidance.

Model Revision for Improved Use of Content Knowledge: Incorporating PCK

Most teachers showed little or no evidence of incorporating content knowledge into their inquiry science instruction. This seems to be related to their understanding of inquiry pedagogy as being "content-free." A separate analysis of data from the larger study (Alonzo, 2002) reveals that most teachers expressed the view that inquiry means "not telling the students the answers." This understanding does not include moving students towards "the answers." By focusing on the "not telling" part of inquiry pedagogy, teachers are missing the crucial role of the instructor in guiding students to an understanding of the science content. But, in fact, many teachers did not view learning science content as a primary goal of elementary school science. Therefore, a discussion of the science content goals of the Clay Boats unit may be a useful starting point for exploring how teachers' content knowledge might be used to guide students to an understanding of this content.

Although the facilitators of the Floating & Sinking course used their content knowledge to guide the inquiry experiences of the participating teachers, this was not explicitly addressed. Because the use of content knowledge is something that goes on in the facilitators' heads, merely modeling inquiry pedagogy does not allow the participants to understand how content knowledge is used to guide inquiry. Therefore, the teachers were able to experience learning in an inquiry environment, without understanding all that is required to create and sustain such an environment. Explicit discussion of how science content knowledge is used generally in inquiry science pedagogy and more specifically in investigations related to the Clay Boats unit are critical to ensuring that the professional development experience has significant classroom impact.

For those teachers who attempted to move beyond direct importation of lessons, to use the content knowledge from the Floating & Sinking course in their classrooms, a further barrier was encountered. Even those who had gained a significantly greater understanding of the adult concept of density were unable to relate this to their third graders in an effective manner. During the Floating & Sinking course, there was very little discussion of the relationship between the content of the course and that of the Clay Boats unit. Therefore, teachers were largely left to make this connection themselves, with varying results.

Since teachers' primary motivation to participate in professional development stems from a desire improve what happens in their classrooms, it makes sense to include the relationship to the classroom as an essential component of their experience. However, this professional development model neglects this crucial piece by focusing only on teachers' content and pedagogical knowledge. The missing connection to the classroom is pedagogical content knowledge (PCK), which details how content knowledge can be used in conjunction with inquiry pedagogy to further students' learning.

Therefore, the professional development model described in this paper (and depicted in Figure 1) must be revised to include pedagogical content knowledge. A sketch of this new model is shown in Figure 4.

Conclusion

The need for professional development for inquiry science is acknowledged by the National Science Education Standards: "The current reform effort requires a substantive change in how science is taught; an equally substantive change is needed in professional development practices" (NRC, 1996, p. 56). However, clear research on effective models of professional development are crucial for this effort.

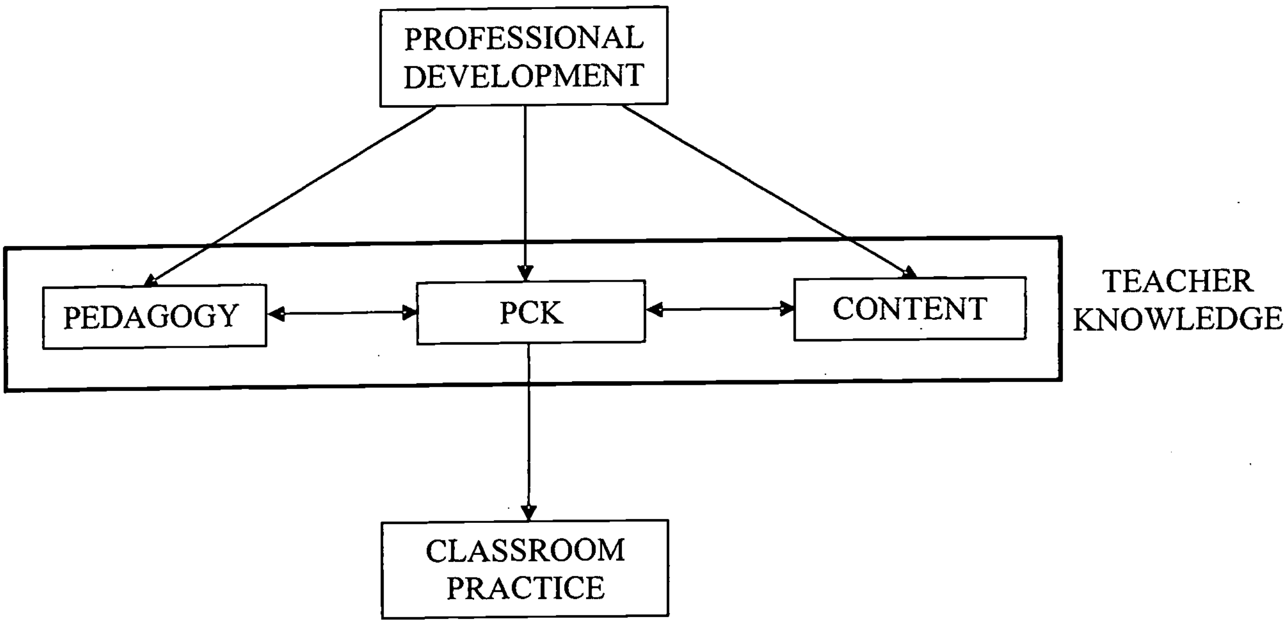

Figure 4. Diagram of revised professional development model.

This study represents an effort to evaluate one proposed model of professional development: a blending of content and pedagogy. However, the results indicate that it is not enough to provide science content knowledge in an inquiry-based learning environment. Teachers must be aware of the professional development model and how it is expected to impact their classroom work. Even more critically, teachers' pedagogical content knowledge (Cochran, 1992; Shulman, 1986), the bridge between pedagogy and content must also be addressed. Therefore, a new model is needed which incorporates these three aspects of teacher knowledge: pedagogy, content, and pedagogical content knowledge.

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Appendix

Selected Floating & Sinking Items

Interview Question

Suppose a student asks you why cruise ships float when they are so heavy. What sort of explanation would you give to him/her? (Plus a follow-up question: Would your answer be different if you were speaking to a colleague?)

Pre-/Post-Course Assessment Questions

1. Suppose you have been given a solid cylinder of gallium arsenide. How many different ways can you think of to determine if this cylinder will float in water? The only restriction is that you may not place the cylinder in water. [The "mystery cylinder" question.]

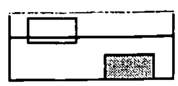
2. One of your colleagues says that he doesn't understand why changing the shape of a piece of clay can allow it to float since it is still the same material. How would you explain this to him? [The "clay ball" question."]

3. Another colleague explains that one of her students was convinced that his boat would have floated if he had more water in his container. Because it was the end of the lesson and she doesn't have a sink in her room, the teacher didn't pursue this issue with the student. However, now she has been thinking about whether the amount of water makes a difference and is wondering why or why not. How would you respond to answer her question? [The "amount of water" question.]

4. Two teachers have been discussing how to determine if something will float or sink. One teacher says that he has heard that density has something to do with floating and sinking. Another teacher says that weight determines what will float and what will sink, and adds that she thinks density is just a fancy word for weight. Both teachers agree that they don't really have a

clear idea about what density means. What would you say to help them sort this out? [The "density" question.]

5. A final colleague says that she is confused about the role of air in floating and sinking. Her students have been mentioning air as an important factor, but she thinks that it is possible for a solid object to float. How would you explain this to her? [The "air" question.]

6. This is what happens when you place a block of wax ( ) and a block of aluminum ( ) in the water... 

Suppose you have...

1) a large block of wax which weighs more than the original block of aluminum and

2) a small block of aluminum which weighs less than the original block of wax.

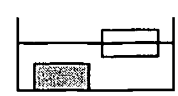
For each block... What would happen if you placed it in the water? (Check one.)

____ It would definitely float.

____ It would definitely sink.

____ There is not enough information to determine if it will float or sink.

[The "material" question.]

7. Suppose you have two blocks of identical size, but made from different materials. As shown, one block sinks, while the other one floats half above, and half below the water. 

For each block... What would happen to the water level in the container if the block were removed from the water? (Check one and describe.)

____ The water level would remain the same.

____ The water level would go up, by an amount determined by...

____ The water level would go down, by an amount determined by...

[The "water displacement" question.]

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