Changes in Teachers' Ability to Design Inquiry-Based Lessons During a Two-Year Preparation Program

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Abstract: Current reforms require teachers to design effective inquiry-based lessons. This is a challenging task particularly for preservice teachers who may not have experienced inquiry learning, and who do not posses a large repertoire of teaching strategies, or knowledge of student thinking in the domain. Here we report on the development of preservice teachers' lesson designs in the context of a two-year certification program with four consecutive methods courses. These courses included multiple opportunities to plan and implement inquiry-based lessons and units. We analyzed the lesson-designs of 15 preservice teachers. These lessons were generated as part of clinical interview conducted at the end of each course. Analysis of lessons revealed growth in the teachers' ability to: (a) craft appropriate questions to gather students' preconceptions and drive inquiry lesson, (b) anticipate students' prior knowledge and attend to the broader context of the curriculum, and (c) create more relevant investigations.

Introduction

Current reforms advocate teaching scientific inquiry, which "refers to the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work" (National Research Council, 2000, p.1). Teaching science through inquiry is congruent with constructivist perspectives of a more student-centered approach that promotes the learning of both science content and practices in a social setting (Anderson, 2007). However, over the past several decades, science educators and researchers have used and defined inquiry differently in their classrooms, curricula, and research projects. Historical definitions of inquiry in the classroom have ranged from traditional hands-on laboratories to open ended student-driven investigations (Windschitl, 2004). In this study we define model-based inquiry teaching as a form of inquiry that emphasizes the role of models in scientific practice, in particular, the use of models to build, revise and argue about scientific knowledge. Successful teaching of inquiry, model-based or otherwise, is challenging for most teachers particularly preservice teachers (Schwarz & Gwekwerere, 2007; Windschitl & Thompson, 2006). In a study of preservice elementary teachers, Hayes (2002) found that preservice teachers struggled in their new roles as teachers of inquiry. Specifically, he uncovered three major difficulties: letting go, going with students' interests, and asking the right questions. It was challenging for the teachers to let go of the didactic approach to teaching and move toward more student-centered instruction.

Teaching is a complex process that involves conceptualization of the teacher's intent and then the execution of the plan in the context of the classroom given the particulars of student ideas and responses to the plan. Lesson plans reflect teachers' thinking and the multiple decisions that teachers make before actual instruction begins (Duschl & Wright, 1989). While lessons plans do not usually reflect the nuances and complexities of implementation, they can provide a reasonable picture of the ways in which knowledge of inquiry is applied to instructional design. In this paper, we examine the ways in which preservice teachers' ability to plan (but not implement) inquiry-based lesson designs changes over the course of four consecutive science Methods courses in a two-year preparation program.

Theoretical Framework

Lesson planning and design are windows to teaching practices. Planning refers to teachers' conceptualization and formulation of courses of action in a lesson, which has a profound influence in teachers' classroom behavior and students' learning (Shavelson, 1987). In planning and preparation, teachers demonstrate their knowledge of content and pedagogy, knowledge of students, selection of instructional goals, knowledge of resources, design of coherent instruction, and assessment of student learning (Danielson, 1996).

Several studies have explored aspects of experienced teachers' lesson planning process. Peterson, Marx, & Clark (1978) investigated the relationship between teacher planning, teacher behavior, and student achievement. The study focused on 12 experienced teachers who taught social studies lessons to three groups of high school students. Findings from the analysis of planning statements of the teachers indicated that the largest portion of planning focused on the content and selecting activities to be taught. A comparably small number of planning statements concerned the materials and the learner, and a very small number of planning statements mentioned lesson objectives. Brown (1988) conducted a case study of 12 middle-school teachers' yearly, unit, weekly, and daily planning. Analysis of written plans, think-aloud, and a questionnaire, indicated that the common factors that affect teachers' planning included student ability (very often), district curriculum guides, orderly transition between activities, student attention, standardized tests, and undergraduate training (rarely). Brown (1993) conducted a longitudinal study of two novice secondary teachers' instructional planning. In this study, she saw that cooperating teachers' planning practices, university professors' classes, textbooks, and curriculum guides influenced lesson planning. Duschl and Wright (1989) investigated the teachers' decision making models for planning and teaching of science of 13 high school teachers. They found that selection, planning, and designing of instructional tasks were dominated by considerations about student development, objectives set by the curriculum, and accountability pressures. However, teachers paid little attention to the scientific theories involved. These studies pertain to in-service teachers and highlight the complexity of the lesson design task and the different factors that influence teacher decision-making and planning.

The state of affairs regarding preservice teachers' lesson planning is similarly complex. Several research efforts to develop preservice teachers' ability to design lessons, specifically inquiry-based, have met with mixed success (Friedrichsen, et. al., 2009; Schwarz & Gwekwerere, 2007). Friedrichsen, et.al, (2009) analyzed the lessons developed by four teachers in a certification program: two interns and two full time (alternative route) teachers, to investigate differences between the two groups. Their analysis of the lessons revealed that both groups relied primarily on their subject matter knowledge and general pedagogical knowledge to plan the lessons. Both groups of teachers lacked topic specific knowledge about learners, instruction, curriculum, and assessment. Friedrichsen and colleagues found that a typical lesson for both groups began with the teacher asking questions, followed by a lecture and guided practice designed to memorize and practice the lecture material; these lessons were mostly teacher centered. Their research suggests that preservice teachers, in either route, do not tend to take students' prior knowledge and curriculum into account when designing lessons, nor do they have the necessary pedagogical content knowledge to address specific ideas that students may have about the content.

On the other hand, research by Schwarz and Gwekwerere (2007) suggests that by using highly scaffolded frameworks for instructional design, preservice teachers can begin to develop lessons that are more reform oriented. Schwarz and Gwekwerere (2007) used a guided inquiry and modeling instructional framework (termed EIMA) to support K-8 preservice science teachers in developing lesson plans and units. The preservice teachers learned and used the EIMA framework for their instructional activities and lesson planning in one science method course. Their findings suggest the framework was successful in helping teachers increase the use of different models to engage students, and move toward a more reformed based approach to teaching (i.e. conceptual change, inquiry, and guided inquiry). However, at the end of the semester, these researchers found that the preservice teachers still struggled with the concepts of scientific models and modeling.

In a different study, Windschitl, Thompson, and Braaten (2008) used the Heuristics for Progressive Disciplinary Discourse (HPDD) framework to improve preservice teachers' epistemic discourses in science. Their research showed that while most preservice teachers improved their knowledge of the function and nature of models, they failed to incorporate it into their inquiry lessons. Windschitl et al., (2008) thus showed that with appropriate scaffolding preservice teachers could improve their concepts of scientific models, concepts that Duschl and Wright (1989) had previously found to be challenging for teachers. These studies highlight the challenges that preservice teachers face when trying to use inquiry approaches in their instructional design.

In our Methods courses, preservice teachers engaged in designing, revising, and implementing inquiry based lessons in four consecutive courses. The intensive focus on lesson design was part of Methods II and Methods III, which are described in the next section. We anticipated that our preservice teachers would increase their attention to students' learning, curricula, and scientific models in their lesson plan and design over the four courses. More specifically, we hypothesized that the initial lesson designs would focus on the selection of activities from curricula and textbooks in ways that are similar to what Peterson, Marx, & Clark (1978) found in their study. Given the findings from the studies by Brown (1988) and Duschl and Wright (1989), we predicted that lessons would begin to focus on students' learning and development. Focusing on student ideas is challenging for teachers to do but is central to the constructivist approach. In contrast to Duschl and Wright's (1989) findings, however, we hypothesized that our preservice teachers might be better at focusing on scientific knowledge building (models and theories); ideas that are at the core of scientific inquiry.

Methods

Study Context

A qualitative approach was used to understand the extent to which the preservice teachers' ability to design lessons change over time. The participants are fifteen (4 male and 11 female) preservice teachers enrolled in a two-year biological science teacher education/certification program in a large university in the north east of the U.S. All preservice teachers have at least 30 credit hours in Biological Sciences before entering the program. Specifically, one teacher has a PhD in Biology, four have Bachelors of Science in Biology, and ten are in their forth year of a five-year Biological Sciences or related (e.g. Animal Sciences, Ecology and Natural Resources, and Environmental Science) programs. Moreover, two teachers have extensive research experiences, one as a senior scientist and the other as a researcher/laboratory manager, in commercial laboratories and another two worked as research assistants at the college during their undergraduate programs. As part of the certification program, students completed four subject-specific Methods courses in consecutive semesters. All courses were taught by one professor, the second author of this paper. In the first method course, Methods I, preservice teachers were engaged in science inquiry activities, readings, and discourse that promoted their understanding of scientific inquiry and theory development. During this course, the teachers, as a class, developed a framework for model-based inquiry that was to inform their lesson development in the subsequent course. The second course, Methods II, was a design-based course in which the teachers, in small groups, developed extended model-based inquiry units about selected topics in biology. In this course, teachers were introduced to several design frameworks including Learning for Use (Edelson, 2001) and Backwards Design (Wiggins and McTighe, 1999). At the end of this course they developed and implemented a single model-based inquiry lesson in their observation placement classrooms. The third course, Methods III, was a weekly seminar associated with their 15-week student teaching internship. Teachers were placed in local middle and high schools with teachers who may or may not have been familiar with reform-oriented science teaching. In this course, the teachers planned and implemented numerous lessons. They were required to extensively reflect on two short inquiry based units that they developed and implanted in their student teaching placements. In the final course, Methods IV, teachers conducted action-research projects aimed to develop their skills as reflective practitioners. Teachers used data collected during their student teaching to answer practical questions related to the use of the model-based inquiry approach in the science classroom.

Data Sources and Analysis

We conducted clinical interviews with each teacher at the end of each of the four Methods courses. The interview protocol had four tasks that included defining model-based inquiry, critiquing a lesson, designing a lesson, and evaluating students' written work examples. In this report we focused on the analysis of the third task: the lesson design. We created two comparable versions of this task for counterbalancing purposes and each version was alternated across the four end-of-course interviews. Version A had three objectives for the topic of photosynthesis, while version B had similar objectives for the topic of cellular respiration. The teachers were given the objectives, asked to plan a lesson or short set of lessons that would address the objectives given to them, and then prompted to explain their lesson. This design task lasted for about 5-10 minutes.

Data analysis for this task began with the identification of essential features of inquiry-based lessons (e.g. hook, procedures, investigations, and assessment) and the systematic description of interrelationships among these features (Wolcott, 1994). The development of our coding schemes proceeded through an iterative process of application to the data set and refinement of the codes to capture relevant emerging themes in the data (Corbin & Strauss, 2008; Merriam, 1998). The first coding pass gave us a list of the different activities in the lesson (e.g. questions, investigations, student modeling, etc.) that teachers described in their interviews. We then examined these to identify patterns of change.

Through recurrent comparison of transcripts from interviews at different points in time we were able to identify shifts in the nature and quality of teachers' lesson designs with regard to several dimensions: (a) specificity and suitability of teacher *questions*, (b) *student-centeredness* of lesson*,* and (c) development of *investigations.* We will describe these dimensions in detail in the next section. Within the first dimension, we counted the specificity and suitability of the question to drive the need to know and students' prior knowledge in the lesson. For example, the following questions were constructed by teachers to drive a lesson on photosynthesis: (1) "how do plants grow, what do they need, what are they made up of, what are they made from" and (2) "I pose a question to the students on how do plants and humans work together in order to survive." In the first question, the teacher proposed specific questions to gather students' preconceptions about photosynthesis using plants' growth, sources of energy, and its composition. On the other hand, the second question was too broad and less suited to drive the lesson on photosynthesis. Students will most likely mention plants as a source of food and shelter to answer the question, which are correct but beyond the topic of the lesson. Moreover, the question did not clearly reflect the teacher's intention of using the question to deliver concepts such as human consumption of oxygen from plants and plant use of carbon dioxide from humans.

Within the second dimension, we coded the number of lessons that were procedural or activity oriented. These lessons have a set of activities that were predetermined by teachers, have no indication whether students' preconceptions will change the lesson, and reflected teacher-centered approach of teaching. We also coded the number of lessons in which teachers' voiced students' ideas, for example, Nadia mentioned during her planning that "[students] understand [energy being stored] and in carbohydrates, not only do they get how the molecule is being synthesized but they also get why for the energy and this energy is stored in molecular bonds," which indicated her sensitivity to students' knowledge. Furthermore, within the first dimension, we coded the number of lessons in which there was attention to the broader context of curriculum and to students' prior knowledge. These lessons contained careful sequencing of activities with respect to science content and scaffolding of students' knowledge.

Lastly, within the *investigations* dimension we counted how many investigations were open *or unstructured* (e.g. investigations that asked students to create their own experiments with minimal directions from the teacher). We counted how many of the lessons had investigations that provided specific data to the students, this included investigations using experimental data from a published science experiment or purposeful teacher constructed data.

Results

Specificity and suitability of Teachers' Questions

Most teachers mentioned *questioning* as one of the essential parts of a science lesson. These questions were often posed to students in the beginning of the lesson to serve as a motivator or hook, to guide the activities in the lesson, and to ascertain students' preconceptions about the topic. In analyzing the questions that the teachers created for their lessons, we found that lesson questions from the interviews of the third and fourth Methods courses were more specific and suitable for the topic than the questions generated from the interviews in the first and second Methods courses. In other words, teachers' seemed better able to form more specific and more suitable questions as the courses progressed (see Figure 1).

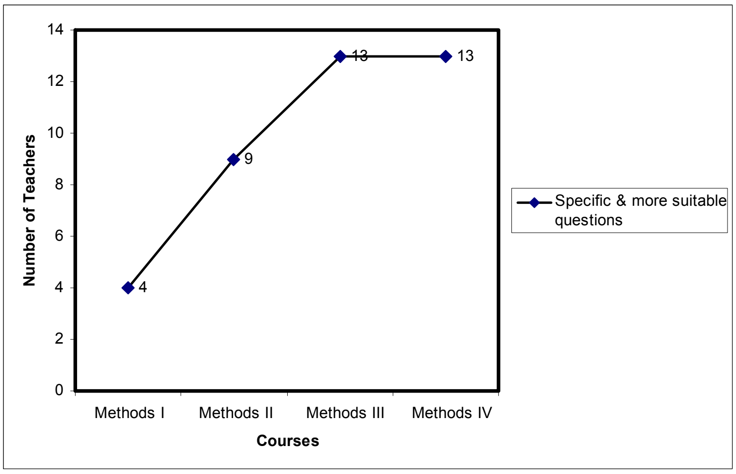

Figure 1. Specificity and suitability of Teacher Questions

Clare's questions from the second and fourth Methods courses are provided below as illustrative examples. In both cases Clare was designing a lesson on photosynthesis and her questions were posed at the beginning of the lesson.

> First, have a discussion with the class and maybe a hand-out about the purpose of photosynthesis and maybe what the students think what the purpose is and umm call out students to write on the board the main ideas and the key players in this process (Clare, Methods II)
>
> [Ask students] how plants get their energy and see what generates from that. (Clare, Methods IV)

Clare's question in Methods II is problematic in that it requires that students know the term photosynthesis and the idea of a biological process as having a purpose is somewhat teleological. It is unlikely that such a question would yield substantive participation from students; nor would it reveal relevant prior conceptions that, while incorrect, may be suitable building blocks (as students may not associate these ideas with the scientific name for the process). Her second question is couched in terms that students are likely familiar with (energy) and is more likely to enlist broader class participation and useful insights about students' prior knowledge. While the first question involves a more specific term (photosynthesis), it is the second question that specifically deals with the objectives of the lesson, namely, understanding the process by which plants get their energy.

Student-Centeredness of Lessons

We also found shifts in the extent to which the designed lessons were student-centered. These changes included a decrease in the number of procedural or activity-focused lessons, an increase in voicing students' ideas in the lessons, and an increase in attending to broader context of the curriculum and prior knowledge of students (see Figure 2).

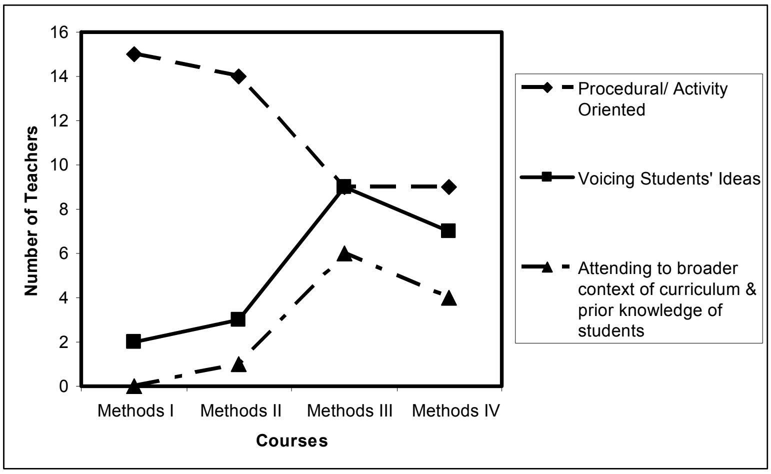

Figure 2. Student-Centeredness of Lessons

Specifically, almost all the lessons (93% to 100%) that the teachers created in the first two courses were procedural or activity-driven. For instance, Jackie's lesson about cellular respiration was primarily teacher-driven with students engaging in some inquiry practices, like model building, but, even then, they work with existing literature.

> Well, I think I would start with just a brief introduction of what cellular respiration is. And then I would have the students make a naïve model based on this pathway, like the overview that I give them of cellular respiration. And, in the model, I would want them to explain…[pause] from there I would probably give them literature. So then I would have them make – revise their naïve model based on that information. They will have to read about it, they will talk about it in small groups, possibly of two to three individuals in a group… discuss it, and make up a new model. (Jackie, Methods I)

Although Jackie included models and modeling in her lesson, there was no indication of how the students' naïve models or revised models will influence the course of instruction or the sequence of activities in the lesson. The majority of lessons in interviews from Methods I and II were similarly teacher-centered. In many cases, the lesson was an amalgam of activities that the teacher was familiar with (often from their own experiences as learners) without a clear connection to the lesson objectives and without any reference to students' expected level of understanding or the broader curriculum context. In addition, while the teachers described activities and practices that were inquiry-oriented, there was little consideration of students' prior knowledge or how the students' models/explanation could influence the lesson.

However, in the lessons designed during the interviews of Methods III and IV, 46% to 60% of teachers voiced-out students' ideas in the lesson and they began to attend to broader context of the curriculum in terms of what students might have already learned (and what prior knowledge they may have as a result). By "voicing-out" students' ideas, we mean that the teachers would speculate what sorts of responses they may get from students, often acting out student talk. Teachers also paid greater attention to potential difficulties that students may have in an activity. Christine's lesson exemplified this case. She mentioned possible conceptions or ideas that her students may have regarding where plants get their food.

> I would start by asking how plants get their food if they don't get it by eating things. The kids are going to be like "Venus flytrap eats flies" but that is the exception to the rule. So kind of get kids to think about how plants are stationary so how are they able to get food. See if anyone knows that plants make their own food, so ask them to explain a little more along those lines. But I am pretty sure that kids in high school don't have a grasp on photosynthesis so umm after that, say let's take a look at things that plants do have access to, like sunlight, air, nutrients, soil, water and then, from there, break down air because it is a mix of gases. Get them to kind of isolate carbon dioxide plants make oxygen. (Christine, Methods III)

Christine's lesson is more student-centered compared to Jackie's lecture-based lesson and she actually voiced out what students might say in response to her questions (Venus flytrap eats flies), and what knowledge they may have that she can build on. In another example, Catherine viewed her line of questioning as contingent on students' conceptions.

> First, I would have them do an initial model of, "how do animals get their energy?" And that would just be so they can get their ideas out there, and I can also see what they're thinking about this. I'm hoping that one of them would say, "food," because then, maybe I, with enough questions, I could pull out of them, "glucose." I'm assuming they've already learned about plants, with photosynthesis. And, so maybe I'd give them a data sheet, with information about …. [pause] or maybe my line of questioning might be, well, "what do chloroplasts store?" and try to get them along that line of thinking so maybe I can get them to come around and say, like, "oh, I guess maybe humans or other animals need glucose for energy." (Catherine, Methods III)

Like Catherine and Christine, teachers became not only cognizant of the students' prior knowledge and experiences but also willing to change the lesson based on what students brought to the lesson. Lastly, a number of teachers (26% to 40%) began to attend to the broader context of curriculum. This included consideration of the sequence of topics in a unit (or over a semester) and references to prerequisite knowledge that students must have prior to the lesson. In the following example, Nadia mentioned the concepts that her students learned before the lesson, the knowledge that they have to contribute in the lesson.

> Of course how I start it depends on what they learned before that. And I just took an example that I had in school. We learned carbohydrates before that and I actually did that on purpose. I did the bio-molecules before and I would do that again because it is a nice flow. Throughout the bio-molecules, they get the idea about the energy being stored… So they have this previous knowledge already and they know plants do that at least high school, they know plants do photosynthesis and build sugars and they mostly know that, at least in high school that is the case. So it is not hard to ask the connection. (Nadia, Methods III)

Nadia's teaching experiences in Methods III helped her reflect on the sequence of topics and what students are expected to know based on that sequence.

Nature of Investigations

Another dimension of change was the teachers' ability to design *investigations* for their students. These changes included a decrease in open or unstructured activities, and an increase in providing data to students (see Figure 3).

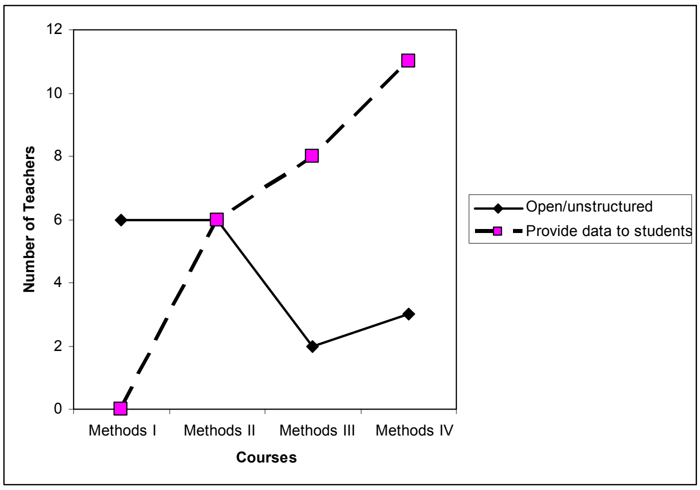

Figure 3. Development of Investigations

Less than half (40%) of teachers in Methods I and II proposed investigations that were open-ended or ill-structured. For example, Jake proposed a discovery-type of investigation in which the students, rather than him, would design and execute relevant experiments.

> I am trying to think of something more specific [investigation] but I can't think of it. I mean in general I would have them do that [experiments with carbon dioxide and oxygen] and it wouldn't necessarily be something that I designed. But I mean I would definitely give them the tools and let them play around with it and see to see what they were able to come up with. (Jake, Methods I)

Interestingly, we noticed a decline in open-ended investigations in the interviews from the last two courses. We believe that this may be due to teachers' realization (from to their experiences during their student teaching internship) of how challenging it is to implement open or unstructured investigations in the classroom. Instead of open-ended investigations, teachers tended to suggest investigations where teacher provides data to students or teacher-guided investigations.

In terms of providing data to students, we found that after Methods II, more than half of the teachers (60%) suggested investigations that involve providing data to students. Jake in Methods III, chose to provide data to his students, instead of giving them an open-ended problem, to address the same concept of energy in photosynthesis. Jason mentioned the data he would provide, the purpose of activities and the target concepts of the lesson. He also used an authentic problem context and data to motivate students to learn the material (the fertilizer runoff problem).

> Then I would give them some data that when there is fertilizer runoff, the amount of algae in the lake increase and the fish are still alive. But as the amount of algae kept going up and the fish are still there… but as the algae increased some more, fish eventually drops off. And I would have them revise their model based on this and I would anticipate that the first one will say something about the fertilizer and the second one will be the algae that somehow killed them. And I would have them either ask them to do an experiment that when you put a plant in the light and one in the dark and put a pH indicator and blow in it, using bromothyl blue in it, and the light will filter back to blue cause it took the CO_2 out and the dark it will turn the same or yellow to show that there is more CO_2. (Jake, Methods III)

Providing data to students or finding data for students to look at allowed teachers to focus on concepts that they wanted their students to learn, reduce open-ended or ill-structured activities, and promote other scientific practices such as analyzing data and modeling.

Conclusion and Implications

The purpose of this study was to examine the changes of teachers' ability to design lessons as they progressed through a teacher certification program. Based on our analyses of the lesson design task in their end-of-course interviews, we characterized several dimensions along which there seemed to be shifts in teachers' abilities. The first was an increase in their ability to craft specific and better suited questions to gather students' preconceptions and drive the inquiry activities in their lessons. In the initial interviews, teachers' questions were typically too broad, which mirrors findings of Friedrichsen, et.al. (2009). However, the teachers in our study, given its longer duration, developed more specific and more suited driving questions in the last two Methods courses.

We also identified a trend of increased attention to student thinking and the boarder curriculum, and the use of more student-centered instructional approaches. In the first and second Methods courses, our teachers developed lessons based on selected activities similar to what Paterson, Marx, and Clark (1978) saw in study of their twelve experienced teachers. However, in Methods III and IV, our preservice teachers started to attend to students' prior knowledge and larger curricular context in designing their lessons. They started to voice-out students' ideas in the lesson and they began to attend to broader context of the curriculum in terms of what students might have already learned. This was similar to what Duschl and Wright (1989) found in high school science teachers' attention to student development in their lesson planning and instructional decision making, and what Brown (1988) found in the lesson planning of middle school teachers. Moreover, the progression to a more student-centered lesson and increased attention to the broader context of the curriculum suggests an increase in teachers' knowledge of learners, knowledge of context, and pedagogical content knowledge (Abell, 2007; Friedrichsen, et.al, 2009). The last dimension of changes was found in the teacher-developed investigations. These changes included a decrease in open or unstructured activities and an increase in providing data to students. We believe that the decrease of unstructured activities was due to the teachers' realization of how challenging it is to implement his kind activity. The shift of providing data to students allowed teachers to focus on concepts that they wanted their students to learn and on other scientific practices (e.g. modeling and data analysis).

In terms of scientific inquiry in the lessons, we saw that preservice teachers used the strategy of having students create naïve models (prior to any formal instruction) to gather their pre-conceptions about the question and designed investigations based on student learning. The model-based inquiry practices were congruent with the efforts of Schwarz and Wright (1989) and Windschitl, Thompson, and Braaten (2008). Analysis of Methods courses showed that after Methods II, which focused on instructional design, we noted increases in specificity and suitability of teachers' questions, and an increase in the number of lessons in which teachers provided students with data to analyze. After Methods III and IV we observed increases in student-centeredness of lessons (voicing of students' ideas and attending to broader context of the curriculum). Lastly, after Methods II, we saw a decrease in unstructured activities and an increase in providing data to students as part of investigations. We believe that changes in Methods II were due to the extensive focus on instructional design and multiple design frameworks in this course and the changes in Methods III occurred due to teachers' teaching experiences, interaction with students, and analysis of students' works. This latter development is congruent with the shift in focus from self (perceptions of one's capabilities as a teacher) to a focus on students and learning (Darling-Hammond & Baratz-Snowden, 2005).

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