Res Sci Educ (2013) 43:1135–1154
DOI 10.1007/s11165-012-9303-4

Factors Influencing Science Content Accuracy in Elementary Inquiry Science Lessons

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Published online: 3 July 2012

Abstract Elementary teachers face increasing demands to engage children in authentic science process and argument while simultaneously preparing them with knowledge of science facts, vocabulary, and concepts. This reform is particularly challenging due to concerns that elementary teachers lack adequate science background to teach science accurately. This study examined 81 in-classroom inquiry science lessons for preservice education majors and their cooperating teachers to determine the accuracy of the science content delivered in elementary classrooms. Our results showed that 74 % of experienced teachers and 50 % of student teachers presented science lessons with greater than 90 % accuracy. Eleven of the 81 lessons (9 preservice, 2 cooperating teachers) failed to deliver accurate science content to the class. Science content accuracy was highly correlated with the use of kit-based resources supported with professional development, a preference for teaching science, and grade level. There was no correlation between the accuracy of science content and some common measures of teacher content knowledge (i.e., number of college science courses, science grades, or scores on a general science content test). Our study concluded that when provided with high quality curricular materials and targeted professional development, elementary teachers learn needed science content and present it accurately to their students.

Keywords Elementary education · Inquiry science · Preservice students · Science content accuracy · Science content knowledge

Introduction

New demands for elementary teachers to engage students in authentic scientific inquiry and evidence-based discourse while simultaneously providing them with a strong foundation of

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science content knowledge (Michaels et al. 2008; Krajcik and Sutherland 2010; Osborne 2010) provides a renewed urgency to the long-running debate over whether or not elementary teachers possess adequate science content knowledge for science teaching and how best to support them in acquiring this knowledge. Significant numbers of studies continue to suggest that elementary teachers lack needed science background, may be poorly prepared to guide students in developing both science content and process skills, and often pass their misconceptions on to their students (Kruger and Summers 1988; Kruger 1990; Atwood and Atwood 1996; Abd-El-Khalick and BouJaoude 1997; Krall et al. 2009; Burgoon et al. 2011).

Expectations for elementary teachers have always been incredibly high. While most are educated as generalists, elementary teachers are required to teach multiple subjects to a diverse range of learners. Within science, they must be prepared with enough background in the earth, physical, and life sciences to guide authentic experiences that help students construct their own understanding of natural phenomena, while fielding student questions, correcting misconceptions, and responding effectively to unique and varied student ideas. They must help students develop a deep conceptual understanding of science, scaffolded on a framework of key facts and vocabulary, while also conveying the nature of science by engaging students in authentic scientific inquiry (NRC 2000). Finally, good practice dictates that they place student learning within the broader context of the natural environment, local community, and world society as a whole (Davis et al. 2006).

Inquiry science pedagogy provides an ideal framework for helping students develop strong skills in problem solving and critical reasoning while simultaneously acquiring a broad knowledge of science content (Varelas et al. 2008; Minner et al. 2010). But teaching inquiry science in an elementary classroom is a challenging task. Elementary teachers using inquiry pedagogy must engage students in genuine scientific exploration. Depending on the particular lesson, they must be prepared to guide their students to generate testable questions, design experiments, plan procedures, carry out investigations, report their findings, analyze results and draw conclusions, while challenging them to create scientific explanations by constructing and evaluating scientific arguments based on evidence (e.g., Duschl et al. 2007; Zembal-Saul 2009; Krajcik and Sutherland 2010; Minner et al. 2010; Osborne 2010). Thus, teaching elementary science via inquiry is a highly complex task, requiring a high level of planning and preparation as well as on-the-spot decision-making to meld multiple factors including the instructional context, knowledge of how children learn, how learners are likely to think and what they will find confusing, pedagogical knowledge, and science content knowledge. Skilled teachers successfully combine these factors into a specialized pedagogical content knowledge essential for effective teaching (Schulman 1986, 1987; Zembal-Saul et al. 2002; Appleton 2006; Davis et al. 2006; Ball et al. 2008). Pre-service and new teachers in particular may find this a daunting task, and while they may enthusiastically embrace "hands-on" inquiry science pedagogy as a method of engaging students, they may do so without also conveying accurate science content knowledge.

With few exceptions, previous studies of elementary teacher science subject matter knowledge have been based on conventional measures of science competency including content tests, number and grades of college science courses, or self-reports in lesson plans and lesson reflections. However, scores on science content tests may not accurately reflect the content that is ultimately conveyed to children, and teachers' self-reports of what they plan to teach may not be a reliable indicator of what they actually do teach in the classroom (Shavelson 1983).

The purpose of this study was to empirically determine the accuracy of science content presented in elementary inquiry science lessons in relation to the teacher's science background, content preparation, and use of instructional materials. The present study is unique in that the accuracy of the science content actually delivered to children in elementary classrooms was analyzed for a relatively large number (81) of lessons, for 27 preservice education majors and their 27 cooperating teachers for whom science background, resources, and attitudes towards science were known. The goal of the study was to determine what factors were significantly associated with the content accuracy of elementary inquiry science lessons in order to inform how we might best support this aspect of learning to teach science.

Theoretical Background

A large body of literature suggests that there is a direct correlation between student achievement and teachers' preparedness to teach science (Perkes 1967; Wright et al. 1997; Darling-Hammond and Youngs 2002; Krall et al. 2009). The teacher-knowledge research of the 1980's is replete with studies attempting to show that "teachers who know more teach better" (Poulson 2001). Most attempts at science education reform have been based on this assumption. But exactly what teachers should know and how they should acquire this knowledge has been a topic of active debate (Cochran-Smith and Lytle 1999).

Nature and Effects of Teacher Content Knowledge

Early studies of teacher science content knowledge suggested that elementary school teachers had limited content knowledge in at least some subject areas, and, in particular, did not feel confident to teach science (Wragg et al. 1989; Bennett and Carre 1993; Stoddart et al. 1993; Edwards and Ogden 1998). Many elementary teachers held scientific ideas closer to those of their students than scientists, often holding the same misconceptions as the children they were teaching (Kruger and Summers 1988; Stofflett and Stoddart 1994; Wandersee et al. 1994; Ginns and Watters 1995; Atwood and Atwood 1996; Harlen 1997; Harlen and Holroyd 1997; Parker and Heywood 2000). Teachers teaching topics for which their knowledge was greater asked more demanding questions and gave students more opportunities to speak (Carlsen 1991). Newton and Newton (2001) found that teachers with more science background asked almost twice as many questions relating to "cause/effect" as teachers with less science background, and concluded that science content knowledge could facilitate content-related discourse. Teachers with less content knowledge spent more time "telling" their students science facts and less time guiding them to construct knowledge through inquiry. Poulson (2001) argued that the conclusion drawn from these studies was that the lack of teacher content knowledge was problematic, and that teachers could not teach what they did not know, a "deficit model of teachers' knowledge," that led to a stronger focus on subject knowledge in initial teacher training, in-service courses, and professional development. Abell (2007) summarized findings that teachers lacking science content knowledge spent more time lecturing, relied more heavily on textbooks and seatwork, avoided class discussions and spontaneous questions from students, asked fewer causal questions, and failed to develop important science concepts. Studies published since her review continue to suggest that elementary teachers have significant gaps in their science content knowledge and hold misconceptions in common with their students (Kikas 2004; Leite et al. 2007; Dawkins et al. 2008; Krall et al. 2009; Burgoon et al. 2011).

Subject content knowledge is a crucial part of a teacher's repertoire. Adequate science content knowledge guides the planning of an effective inquiry lesson (Luera et al. 2005), helps a teacher respond effectively to comments and questions, increases a teacher's confidence and fluency when leading discussions, and provides a teacher with examples and explanations that connect with prior knowledge and ground student investigations in real-life experiences. Concerns that poor science background knowledge will translate into poor teaching, either by communicating fewer concepts or by perpetuating misconceptions, have translated into demands for greater science preparation for teachers. However, in an era when economic resources for education are shrinking, and preservice preparation programs are already crammed with required courses, the question of how and when to effectively deliver science content support to teachers is critical.

Preservice Preparation in Science Teaching

Although classroom science education has undergone radical changes in the past two decades, college preparation in science for most elementary education majors has been slow to reflect these changes and only occasionally includes experience with authentic inquiry. Undergraduate science course work frequently consists of large survey courses taught in a lecture format. There is often little opportunity for individual experimentation or "hands-on" learning. These courses can fail to engage students deeply enough to achieve conceptual understanding and serve as poor models for later teaching of inquiry-based science (Abd-El-Khalick and BouJaoude 1997). Many preservice teachers report early negative experiences of science that may influence their future attitudes towards teaching science (Young and Kellogg 1993). Future elementary teachers frequently express a lack of confidence in their background and ability to teach science (Appleton 1995; Harlen 1997; Yoon et al. 2011). Michaels et al. (2008) point out, "Undergraduate science rarely emphasizes reflection on scientific knowledge, and participation in science is rarer still." Teacher education programs tend to focus on "helping student-teachers learn how to teach, and not what to teach." (Abd-El-Khalick and BouJaoude 1997, p. 676). Although recent improvements to educational methods courses have addressed some of these issues (e.g., Zembal-Saul et al. 2000; Trundle et al. 2002; Trumper 2006), the time available for preservice teacher preparation in science is often extremely limited relative to the vast amount of information that must be conveyed (Appleton 2006). Halim and Meerah (2002) showed that preservice teachers' pedagogical knowledge for promoting conceptual understanding in physics was limited by their lack of basic content knowledge. Trainee teachers with poor content knowledge had difficulty explaining scientific ideas, and created analogies that embodied their own misconceptions. Their abilities to anticipate children's misconceptions and to transform science subject matter appropriately for pupils were impeded by their own poor content knowledge. Novice elementary teachers may underestimate the range of their student's ideas about science and may lack the general pedagogical knowledge that veteran teachers have gained through experience. They may misunderstand and misuse instructional representations and analogies provided in curriculum materials in ways that render them scientifically inappropriate for the concepts at hand (Davis and Petish 2005). While new elementary teachers may enthusiastically adopt the use of "hands-on" inquiry science activities with the goal of engagement, interest, and motivation of their students, it is possible that they may do so without also successfully representing and conveying accurate science content knowledge.

Purpose of the Study

Few studies adequately address the factors that influence an elementary teachers' ability to deliver accurate science content in the classroom. Much of the teacher education literature is based on case studies of small numbers of teachers and tends to focus explicitly on academic preparation and its effect on content knowledge

(Davis et al. 2006; Abell 2007). Multiple choice and short-answer type content tests may not provide adequate assessments of the type of science knowledge needed for the classroom, and essays, interviews, and self-reports from lesson plans may not be accurate predictors of what a teacher will actually teach *in the classroom*. In some cases, mentoring, professional development, and cultural exchanges within their profession may have more influence on how a teacher will teach science than their academic preparation. Without better information on elementary teachers' understanding of the science concepts they are expected to teach, and better insight into how they can best be supported and prepared to convey good science content in the classroom, our efforts to improve teaching and learning, revamp curriculum, and inform policies for certification and professional development, will be incomplete (Ball et al. 2008; Metz 2009; Krall et al. 2009).

The purpose of this study was to determine the accuracy of science content presented in elementary science lessons in relation to the teacher's science background, content preparation, and use of instructional materials. The study examined the *in classroom* science content accuracy of 27 preservice teachers and their cooperating teachers/mentors during the preservice teachers' science methods and student teaching years. Science content accuracy was examined in relation to multiple factors including:

- grade level
- science topic area
- use of classroom science kit-based resources (i.e., FOSS-Full Option Science Systems and STC-Science and Technology for Children)
- years of teaching experience (in-service teachers)
- college-level science preparation
- performance on a science content test
- level of comfort with the science content in the lesson
- ranked preference for teaching science compared with other elementary subjects
- ranked quality of mentoring received (student teachers)

Methodology

This study utilized a mixed methods approach using both survey and observational data to examine the classroom teaching practice of 27 preservice elementary education majors at a northeastern university during their science methods course, and, a year later, during their student teaching year. Additionally, we examined a science lesson taught by each student's cooperating teacher, in order to determine the type of modeling they experienced during this final practicum before certification. The science content accuracy of the resulting 81 videotaped science lessons was compared with the students' and teachers' written reflections and self-commentaries, as well as with various measures of their science content knowledge and preparation. Science content accuracy was assessed relative to multiple factors including grade level, science topic area, the availability and use of classroom science kit-based resources, the participants' years of teaching experience, academic preparation, performance on a science content test, reported level of comfort with the science content in the lesson, and ranked preference for teaching science versus other elementary subjects.

Participants

The 54 individuals (51 females, 3 males) who participated in this study were elementary preservice and inservice teachers who consented to join a research study that followed the progress of the preservice teachers in learning to teach science from their science methods course (year 1), through student teaching (year 2). The preservice group had an overall grade point average of 3.2, with an average GPA in science of 2.85. The majority of participants were majoring in psychology (30 %) followed by English (22 %) and communications (11 %); no one majored in a science discipline. When asked to rate their science background knowledge on a 5-point Likert scale (i.e., "outstanding," "good," "so-so," "pretty shaky," and "awful"), none of the students selected either "outstanding" or "awful," but the majority (61 %) rated their background knowledge as "so-so" by the end of their science methods course.

Of the 27 cooperating teachers, 20 taught science using the Science and Technology for Children (STC) and Full Option Science Systems (FOSS) science kits. In reporting their preference for teaching science compared with other subjects, only five rated science last, while 15 ranked science as their first or second highest rank. Two of the cooperating teachers had 5 years or less of teaching experience; 22 of the 27 cooperating teachers had been teaching for 10 or more years.

Setting

The regular teaching placements assigned to preservice teachers by the Office of Teacher Education at the university were used in this study. Preservice teachers are routinely placed in some kit-based and some non-kit-based classrooms. The kit-based classrooms are in districts that use a common science curriculum using STC and FOSS kits selected to provide the best fit for the state's Grade Span Expectations that, in turn, are connected to the statewide science assessment. The inservice teachers in this group receive on-going professional development specifically related to the kits at their grade levels. In the non-kit districts, teachers use a variety of other science resources (e.g., textbooks, internet-based lessons) and do not have systematic professional development related to the science units of study. All cooperating teachers are assigned from a pool of teachers selected for their general quality as a teacher (though not necessarily in science), good record of working with student teachers, grade level needed by the preservice student (elementary preservice teachers must have field experiences in two different grade levels: 1–3 and 4–6), and district permission allowing participation in the research study.

During a 2-credit methods course, preservice elementary education majors received instruction and experiences in inquiry-based science teaching techniques. They were encouraged to use open-ended explorations and investigations, having students actively think about and participate in the investigation process, developing lesson concepts through student discovery (NRC 2000; Minner et al. 2010). Preservice students were encouraged to "open up" their lessons by considering to what degree decisions about the questions to be investigated, procedures followed, data gathered, and results communicated were made by themselves as the teacher, or by their elementary students (Colburn 1997). Their capstone assignment was to plan and teach an inquiry lesson in an elementary classroom. For these preservice participants the videotaped science lesson was repeated during their student teaching year. Additionally, the cooperating teacher of each student teacher agreed to participate by allowing videotaping of a science lesson that they routinely taught in the classroom. All participants were told to, "Select an inquiry or discovery lesson that involves problem solving…. with the highest level of openness possible." Despite these directions, all of the lessons examined in this study by preservice participants and most (but not all) lessons by inservice teachers tended to be strongly teacher-directed and exemplified a guided inquiry design (NRC 2000; Minner et al. 2010).

All participants were asked to provide a written lesson plan for a lesson that included an opening, exploration, closing, and assessment. They were asked to be explicit about the science concept and/or process objectives of their lesson, and to connect their lesson objectives to National Science Education Standards (NRC 2000) and state's science Grade Span Expectations. Although participants knew in advance that their lesson would be videotaped, their choice of lesson topic was often determined somewhat randomly by the calendar schedule of available kits in the district at the time or by the current curriculum being covered in the classroom at the time of videotaping. Comments from many of the inservice cooperating teachers suggested that they were teaching "their regular lesson" on the particular topic, typical of what they would generally teach. After completing the science lesson in their elementary classrooms, each of the three groups (methods students, student teachers, and cooperating teachers) viewed a videotape of their lesson and wrote a commentary reflecting on the lesson.

Data Sources and Analysis

Videotaped Science Lessons

The 81 in-classroom science lessons were analyzed individually for the accuracy of their science content using *StudioCode*™, an advanced video coding and analysis software. Each time a science concept was presented, its accuracy was rated on a scale of 0–3, with 0= wrong, 1=partly correct, 2=mostly correct, and 3=all correct. An instance was rated "partly" or "mostly" correct when some portion, but not all, of a teacher's statement was accurate. When a teacher gave the correct concept, but a poor example, it was coded as "mostly correct." For example, correctly stating that appropriate habitat is necessary for an animal's survival and giving several correct examples, but then incorrectly placing one animal in the wrong habitat was coded as "mostly correct." When the teacher's explanation of the concept was incomplete, but the examples given were correct, it was coded as "partly correct." For example, correctly identifying an object's mass, but then using the terms "mass" and "weight" interchangeably, or confusing distance, time, and speed as variables used to describe the movement of a vehicle, but correctly explaining the effect of friction on the vehicle were coded as "partly correct." In the few instances when a teacher's statement was inaudible, it was coded as "N/A=not able to code."

Each instance of science content discussion was evaluated for accuracy, whether it was a new concept presented for the first time or the same concept repeated. The percent accuracy of science content for each participant's video lesson was based on the weighted sums of concept instances coded as follows:

$$\%\ \text{accuracy} = n1(3) + n2(2) + n3(1) + n4(0) / \ (n1 + n2 + n3 + n4)*3$$

where:

n individual instances of science content presentation and
n is weighted: 3=all correct, 2=mostly correct, 1=partly correct, 0=wrong

Inter-rater Reliability

Two research scientists, each with more than 25 years of expertise in life, physical and earth/space science, coded over 1,500 instances of content accuracy in the videotaped lessons. Independent determinations of accuracy scores were compared for 12 of the 81 lessons (15 % sample) to determine the degree of inter-rater reliability between the coders. The first five lessons were inter-calibrated to determine that there was good consistency between the two coders. Seven more lessons were added later to determine inter-rater reliability. The correlation between calculated percent accuracy scores by the two coders was 0.87, indicating a high level of agreement.

Post-Lesson Self-Reflection

Following their videotaped lesson in the classroom, participants were required to view their lesson and write a reflection on the strengths and weaknesses of their lesson as well as indicating their level of confidence with teaching the content. Participants were asked "How comfortable were you with the science content/processes you were teaching?" They were also asked to document the resources that they used in creating their lesson. Excerpts from these reflections were examined in order to assess the teachers' awareness of the accuracy in their lessons.

Science Content Test

All participants were given an elementary science test that was designed by Horizon Research, Inc. for 4th, 5th or 6th graders, previously used to examine elementary student science achievement in NSF-sponsored Local Systemic Change (LSC) projects across the United States (Overstreet 2002). This assessment was selected for its connection with what elementary students would need to know, thus providing a comparison of teacher knowledge related to expectations for their students. In 2001, HRI piloted 78 items with approximately 3,000 students in 12 LSC projects across the country. Overall *p* values and differential item functioning for item performance for limited English proficient (LEP) versus English-fluent students and for white students versus students of color were examined to allow removal of biased items. Analysis of the piloted items resulted in a 52-item assessment with five sub-scales (Table 1). Two additional items not associated with these sub-scales were added at the beginning of the test to build confidence. In the spring of 2002, an additional 12 items along with the previous 52 were piloted yielding a final assessment with 53 items (Overstreet 2002).

Background Questionnaire

All participants completed a questionnaire describing their background and beliefs about teaching inquiry science. The regression analyses in this study utilized questionnaire data related to:

- preference for teaching science relative to reading, writing, social studies, and math (all participants),
- number of college-level science credits taken (all participants),
- GPA of science courses (preservice only),
- rating of science background knowledge (all participants),

Table 1 Subscales characteristics for HRI science achievement test

Scale	Number of items	*p* value range	Reliability
Life science	10	0.39–0.79	0.67
Earth science	12	0.78–0.97	0.65
Physical science	10	0.39–0.81	0.66
Electricity and magnetism	10	0.55–0.90	0.63
Nature of science	10	0.41–0.80	0.66

- years of teaching experience (cooperating teachers), and
- quality of science lesson mentoring by cooperating teachers (student teachers).

Multivariate Analyses

Multiple regression analysis was used to identify the factors that predicted the content accuracy of an inquiry lesson. Conventionally, designs with categorical independent variables use analysis of variance (ANOVA) and designs with continuous independent variables are analyzed by multiple regression analysis (MR). However, MR is a more general model where both continuous and categorical independent variables can be used with results from coding analyses (Hays 1994). Since we had both categorical and continuous independent variables, we used MR analysis as the statistical tool to analyze our quantitative data. Moreover, given that our research question was to identify predictive factors that influenced science content accuracy, we believe that MR was the most appropriate method since it tests whether discrete independent variables (treatment groups) have an effect on the outcome variable after removing the variance for which continuous predictors (covariates) account (Hays 1994). In combining qualitative and quantitative data for this mixed methods analysis, qualitative observational data were quantified to produce numerical indices such as percent content accuracy and rating scores of quality based on rubrics. When general patterns were found from quantitative analysis, we then supplemented them with qualitative descriptions from the participants' written reflections and observations.

Results

Science Content Accuracy Lesson Scores

A total of 81 video lessons (27 methods students, 27 student teachers, 27 cooperating teachers) were analyzed for science content accuracy. Three lessons (from 2 methods students and 1 student teacher) lacked enough science content to be successfully coded. For the remaining 78 lessons, the average percent accuracy of science content was 81 % (range 57–96 %, $n=25$) for methods students, 85 % (range 56–100 %, $n=26$) for student teachers, and 91 % (range 50–100 %, $n=27$) for cooperating teachers (Table 2). For the cooperating teachers, 20 of the 27 teachers presented science content with greater than 90 % accuracy, while only half (13) of the student teachers and one-quarter (7) of the methods students achieved this accuracy (Fig. 1). A *t* test indicated the cooperating teachers' science content accuracy scores were significantly higher ($t=2.65$, $p=0.01$) than those of their preservice students.

Regression Model Predicting Science Content Accuracy

A multiple regression model testing the significance of ten different variables in predicting science content accuracy scores showed that the three most significant factors were (1) access to kit-based lesson resources, (2) grade level, and (3) a preference for teaching science. The effect of each of these factors is described more fully below. In preliminary analyses, all relevant variables were included in a full model (Table 3), which allowed us to examine the effects of interactions among variables. For example, it was possible that the effects of kit resources could vary across different groups or across grades. However, none of the interactions proved statistically significant and, therefore, were excluded from the full model shown in Table 3. In other words, the effects of kit resources were consistent across groups and grades, making the interpretation of main effects much clearer.

The model was used to examine the effect of the ten variables on the lesson content accuracy scores of each group individually (methods students, student teachers, cooperating teachers) and also for student teachers and their cooperating teachers combined (Tables 3 and 4). We did this for two reasons: first, to increase statistical power by increasing the sample size, and second, to examine the similarity between student teachers and cooperating teachers in their use of kit resources, grades they teach, and their preference for teaching science. In order to model possible differences between student teachers and cooperating teachers in their content accuracy, we created a variable called “Group”. Three continuous independent variables; “content test scores,” “comfort level with science content,” and

Table 2 Descriptive statistics

Variables:		Combined Group			Methods Students			Student Teachers			Cooperating Teachers		
		N	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
Kit	Kit-based	48	89.9	10.36	9	81.6	13.65	19	89.4	10.34	20	94.1	5.88
	Non-kit	30	79.4	13.30	16	81.1	9.57	7	73.7	15.27	7	81.4	18.53
Grade	Lower grades 1–3	33	80.6	13.38	15	79.4	10.76	9	78.8	16.02	9	84.2	15.34
	Upper grades 4,5	45	89.8	10.50	10	84.0	11.15	17	88.6	11.09	18	94.1	7.97
Preference for teaching science	1 (Lowest)	9	77.0	14.59	3	80.0	13.89	1	89.7		5	72.6	16.06
	2	14	84.0	13.46	10	79.2	12.62	1	100.0		3	94.7	6.81
	3	20	86.2	12.25	6	82.7	10.97	10	83.4	12.86	4	98.3	2.87
	4	24	88.9	10.28	5	85.8	7.56	9	85.8	14.28	10	93.2	5.29
	5 (Highest)	11	88.4	13.43	1	74.0		5	83.8	17.16	5	95.8	3.03
Group	Methods students	25	81.2	10.93									
	Student teachers	26	85.2	13.54									
	Cooperating teachers	27	90.8	11.67									

Mean percent content accuracy is shown for each participant group relative to variables “Kit”, “Grade”, and “Preference for Teaching Science”

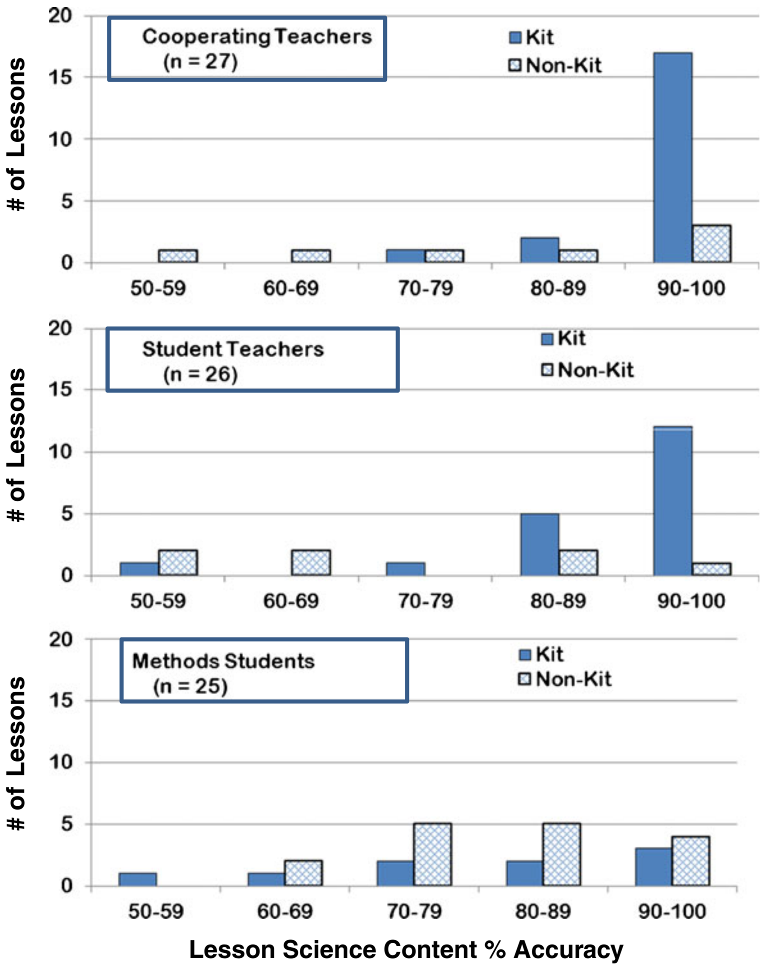

Fig. 1 The distribution of lesson content accuracy scores for the three groups (cooperating teachers, student teachers, and methods students) for kit-based and non-kit-based lessons

"preference for teaching science" were used consistently across all three groups. However, variables for "science credits" and "science GPA" were applicable only to methods students, "quality of mentoring" and "mentor content accuracy" were applicable only to student teachers, and "years of teaching experience" was relevant only to cooperating teachers.

The full model explained over 60 % of the variance in content accuracy for student teachers (R^2=0.617, p<0.05) and for cooperating teachers (R^2=0.658, p<0.01) (Table 3); however, it did not explain significantly for methods students (R^2=0.361, p>0.05). In searching for a parsimonious model, we excluded non-significant variables and the resulting final model is presented in Table 4.

Effect of Kit-Based Resources

For the 78 coded lessons, 60 % (48) were derived from science kits and 40 % (30) were non-kit-based lessons. The science kit lessons were present in classrooms that worked with a

Table 3 Summary of multiple regression analysis for variables predicting content accuracy of inquiry science lessons (full model)

	Methods students (MS)			Student teachers (ST)			Cooperating teachers (CT)			Combined (ST, CT)		
Variable	*B*	SE B	*β*	*B*	SE B	*β*	*B*	SE B	*β*	*B*	SE B	*β*
Kit	−1.55	5.16	−0.07	10.92	5.11	0.39*	9.22	3.77	0.35*	12.33	2.93	0.45**
Grade	6.23	5.31	0.29	3.86	5.67	0.14	6.91	4.13	0.28	9.23	2.81	0.36**
Group										6.24	2.86	0.26*
Content test score	0.63	0.37	0.42	0.29	0.37	0.14	−0.14	0.27	−0.07	−0.002	0.22	−0.001
Comfort level	2.38	4.16	0.14	0.19	3.96	0.01	−2.58	3.10	−0.13	−2.18	2.32	−0.11
Preference	2.32	2.20	0.23	−0.48	2.70	−0.04	4.52	1.28	0.54**	3.21	1.16	0.32**
Science GPA	−9.34	3.74	−0.58*	0.90	3.70	0.05						
Science credits	−0.59	0.64	−0.22									
Quality of mentoring				3.13	2.05	0.30						
Mentor content accuracy				0.26	0.21	0.25						
Years of experience							−0.31	0.26	−0.21			
R^2	0.361			0.617*			0.658**			0.527**		

* $p<0.05$, ** $p<0.01$

hands-on science curriculum composed of three 2-month long FOSS and STC kits. The cooperating teachers in these classrooms were supported with on-going teacher professional development in content and inquiry methodology related to the kits at their grade levels. Nine of the 25 methods students, and 19 student teachers presented kit-based lessons (Table 2), however the preservice teachers did not have the advantage of the professional development provided with the kits.

Access to kit-based science resources made a significant difference to the content accuracy of lessons presented by the cooperating and student teachers, but not to methods

Table 4 Final model for predicting content accuracy of inquiry science lessons

	Methods students (MS)			Student teachers (ST)			Cooperating teachers (CT)			Combined (ST, CT)		
Variable	*B*	SE B	*β*	*B*	SE B	*B*	*B*	SE B	*β*	*B*	SE B	*β*
Kit	−2.28	4.86	−0.10	14.38	4.94	0.52**	8.26	3.56	0.32*	11.93	3.16	0.41**
Grade	6.85	4.52	0.31	9.26	4.77	0.35	9.39	3.22	0.39**	8.63	2.97	0.32**
Group										6.46	2.76	0.25*
Preference	1.87	2.13	0.18	0.82	2.49	0.06	4.28	1.12	0.52**	3.11	1.16	0.30**
Science GPA	−7.56	3.57	−0.47*	−1.68	3.48	−0.09						
R^2	0.230			0.496**			0.605**			0.447**		

* $p<0.05$, ** $p<0.01$

students (Fig. 1). For the three participant groups combined, the mean percent accuracy of science content for kit-based lessons (90 %) was significantly higher ($t=3.66$, $p<0.001$) than for non-kit based lessons (79 %), and "kit-based lesson" was a significant predictor of content accuracy for cooperating teachers ($p<.05$), and for student teachers ($p<.01$), but not for methods students (Table 4).

The lack of a "kit" effect seen in the methods students may be partially explained by the fact that only 35 % of the preservice teachers were placed in kit-based classrooms in their methods year while 73 % of these same students had access to kit-based resources in their student teaching year. Additionally, the methods students were only in the classrooms for 3 h per week at times that may not have coincided with science lessons. Many reported having little or no exposure to kit-based science even in the districts that routinely used kits.

Effect of Grade Level

Science content accuracy was higher for all groups at upper grade levels (grades 4, 5) compared to lower grade levels (grades 1–3; Table 2) and grade level was a significant predictor of content accuracy for the combined group ($p<0.01$) and for cooperating teachers ($p<0.01$), but not for the preservice groups (Table 4). We wondered whether the effect of grade level might be an artifact of the type of kits or their content used in lower versus upper grades; however, our regression analyses showed that the effect of kit resources was consistent across groups and grades.

Effect of Preference for Teaching Science

A stated preference for teaching science relative to other subjects was a significant predictor of high content accuracy for cooperating teachers and for the student teacher/cooperating teacher combined group ($p<0.01$; Table 4). Over half of the cooperating teachers ranked their preference for teaching science highly. Student teachers also tended to be enthusiastic about teaching science with more than half ranking science as a first or second choice (Table 2). However, there was no significant relationship between lesson accuracy and student teachers' preference for teaching science.

Traditional Measures of Science Content Knowledge

There was no relationship between the percent accuracy of the science content in the videotaped science lessons and test scores on an elementary science content test for any of the groups. The average score on the science content test was 79 % for the preservice teachers and 82 % for the cooperating teachers. Both groups obtained their best scores on questions in the life sciences (mean=90 % preservice teachers, 92 % cooperating teachers) and received lowest scores for questions about electricity and magnetism (mean=50 % preservice teachers, 57 % cooperating teachers).

Similarly, the content accuracy of the science lessons was not related to the number of college-level science courses taken by either preservice teachers or cooperating teachers. Science GPA was not a significant predictor variable in the regression model for student teachers, and was only marginally significant as a factor in content accuracy for methods students (Table 4). Given the non-significant R^2 for the model, we believe that science GPA was not a good predictor of lesson accuracy.

Effect of Science Topic and Comfort Level with Science Content

Our students and cooperating teachers presented lessons in the life sciences (13 lessons), earth sciences (26 lessons), electricity and magnetism (9 lessons), and physical sciences (30 lessons). There was no significant difference in the mean percent accuracy among the science topic areas, and although teachers exhibited misconceptions in both kit-based and non-kit-based lessons, misconceptions were more prevalent in the non-kit lessons. When science content inaccuracies were analyzed on a case-by-case basis from the videotaped lessons, no single common area of content weakness was apparent. Teachers struggled with misconceptions across a variety of topics including concepts of buoyancy, density, properties of matter, characteristics of solids and liquids, and the difference between size and mass. A number of teachers were confused about animal classification and habitat (e.g., snakes characterized as invertebrates and bats as insects), and a number of methods students and student teachers struggled to explain the defining characteristics of living and non-living things and the requirements for life. Some had misconceptions about the differences between rocks and minerals and soil and "dirt." In some cases, teachers began their lesson on firm footing, but then provided "real life examples" that were incorrect. The greatest problems arose in non-kit lessons for teachers who designed investigations for their students that were intended to generate "inquiry" but did not adequately demonstrate the concepts being taught. For example, one preservice teacher attempted a lesson on the characteristics of living versus non-living things by having her second grade class pretend to be archeologists and dig various items out of a plastic tub filled with sand, and then classify them as "living" or "non-living." The children had enormous difficulty reconciling the fact that they were prepared, "like archaeologists," to be digging up "fossils," but in fact, were finding many inert non-living things in their tub of sand. They had no criteria by which to gauge "living" versus "non-living" in what they were observing and no category for "once living." When this methods student was asked to reflect on her lesson she wrote,

> I think I actually could have done a better job dealing with students' misconceptions and questions. This was an area of my lesson that I was unsure about. I was nervous about what to do if I didn't know the answer to a student's question, but I found I had a harder time correcting their misconceptions without giving the answer. A lot of the students thought that a shell wasn't a living thing. I tried to explain it to them by asking them where shells come from and some said animals but most said the beach. I then asked them if animals had shells and at that point they understood, but I felt like I gave them the answer and they didn't figure it out themselves. (Jamie; accuracy score=69 %)

This comment reflects a common misconception among our methods students that the role of the teacher in inquiry science lessons includes *never* providing a direct answer to elementary students' questions. Preservice students clearly needed practice in inquiry teaching in order to successfully guide children to construct their own knowledge through investigation and questioning. However, this approach is predicated on a carefully constructed inquiry lesson designed to make it possible for students to construct understanding on their own. We found that, particularly in non-kit classrooms, teachers had difficulty designing investigations where variables were sufficiently controlled to yield results that made sense within the context of the science content being taught. When teachers tried to explain the inconsistent outcomes of poorly designed investigations to their students, they tended to stray into content inaccuracies and misstatements.

Many of our preservice teachers reported feeling generally unprepared to teach science due to a lack of science content knowledge. “I honestly don’t feel prepared to teach the material because I don’t think I know it that well” and “I am nervous about my knowledge of the content” were common sentiments. Many of the student teachers reported learning the science content with their elementary students as they were teaching it. Comments from student teachers included,

> Looking back, I can say that I am much more confident teaching both the science content and processes to my students now, than I had been in the past. Unfortunately, it seems that I am much more confident with the science content once the unit is finished, rather than the beginning and middle. Once I had the opportunity to teach the lessons and observe my cooperating teacher teach the lessons, I gained a lot more knowledge regarding content in particular (Corey; lesson accuracy score=91 %).
>
> In the beginning of the science unit I had a lot of trouble with the science content. Through the kit I became more confident with my knowledge because I was learning it as I was teaching it (Kristy; lesson accuracy score=80 %).
>
> I was pretty comfortable with the science content I was teaching. Since I had created my unit and written up this lesson plan in November I was very excited to teach it. Being that it was my own lesson and not from the kit, I think that made me feel very comfortable teaching the lesson (Laura; lesson accuracy score=69 %).

One of our most troubling findings was that one-quarter of participants (9 methods, 6 student teachers, 4 cooperating teachers), had lesson content accuracy scores less than 80 %, yet reported being “very comfortable” or “comfortable after prep” with the science content that they presented in their lessons. This finding suggests that some teachers were unaware that they lacked necessary science content knowledge or that they passed their misconceptions on to their students.

Finally, there was no relationship between lesson content accuracy and cooperating teachers’ years of teaching experience, and neither the cooperating teacher’s lesson accuracy score or the “quality of mentoring” they provided were significant predictors of lesson accuracy for student teachers (Table 3).

Characteristics of Lessons with Low Science Content Accuracy

Eleven participants (4 methods, 5 student teachers, 2 cooperating teachers) presented lessons with less than 70 % science content accuracy. Eight of the eleven lessons were non-kit lessons that included poorly controlled experiments, confounded by numerous variables that, as presented, did not deliver the intended science content, and/or were developmentally inappropriate for elementary students. Teachers of these lessons struggled to correct fairly complicated student misconceptions and provided inaccurate explanations of the science being observed. Although most succeeded in the “mechanics” of a classroom inquiry investigation, the science content that they presented was incomplete and inaccurate.

Significant Predictors of Science Content Accuracy in Elementary Inquiry Science Lessons

In summary, a multiple regression analysis of the factors affecting science content accuracy found different patterns for the three groups studied (Table 4). For the preservice methods students a weak negative relationship was found between accuracy and science GPA. For student teachers, being supported by the use of science kits was the only significant predictor variable, accounting for 50 % of the variance in lesson accuracy. Cooperating teachers who used kit-based resources, who taught upper grades, and who reported a preference for teaching science, had significantly higher content accuracy scores than their counterparts with this model explaining 60 % of the variance in content accuracy scores. Finally, the combined data for student and cooperating teachers showed that teachers who used kit-based science resources, taught upper grades, and who preferred teaching science over other content subjects had significantly higher science content accuracy than their counterparts, explaining 45 % of the variance among participants.

Discussion and Implications

This analysis of 81 in-classroom inquiry science lessons showed that the majority of inservice elementary teachers and many preservice teachers presented lessons with good science content accuracy. Despite recent research that continues to suggest that elementary teachers have a limited understanding of standards-based science concepts (Kikas 2004; Rice 2005; Leite et al. 2007; Dawkins et al. 2008; Krall et al. 2009; Burgoon et al. 2011), this study showed that experienced teachers are doing quite well with science content in their classrooms, and that, given good instructional materials, they will learn the science content needed to ground their inquiry lessons. Few studies have empirically evaluated the content accuracy of actual in-classroom science instruction. Weiss et al. (2003) observed 55 elementary science classes, rating the general quality of science content addressed by each lesson as a whole. They reported that K-5 science lessons were usually accurate with respect to science content but were weak in regards to "sense-making and wrap-up". Frequently, teachers lacked the ability to adjust their instruction to match student understanding and found it difficult to ask questions that enhanced student learning.

In this study, an important factor in determining science content accuracy was whether or not the participant chose to teach a science kit-based lesson. Science kits supplied the teacher with required science content and, of equal importance, provided workable, grade-appropriate investigations that yielded clear evidence in support of the science concepts being studied. Teachers who designed and taught lessons without science kits were more likely to stumble into misconceptions and content inaccuracies as they tried to explain the variable outcomes of poorly designed classroom investigations. When we examined low-accuracy lessons closely, we found that poorly designed inquiry investigations generated confusing results that tended to rapidly mire the teacher in content misconceptions and inaccuracies. Well-designed classroom investigations are crucial to making meaning of the results so that accurate science content can be delivered by the lesson.

A preference for teaching science was a significant factor in predicting content accuracy for the inservice teachers in this study. Our interviews showed that for teachers to be comfortable with the rapid, "on their feet" instruction required for teaching authentic inquiry science, they needed to feel well grounded in the science content that they were teaching. Previous studies have shown that teachers' lack of confidence in their science content knowledge can undermine their feelings of competence to teach science (Perkes 1975; Shallcross and Spink 2002), can negatively affect their further development of content knowledge (Nilsson and Van Driel 2010) and can present a formidable roadblock to their mastery of inquiry science teaching (Yoon et al. 2011). However, their learning of science content is best done within the context of their teaching (Ball 2000). Both our preservice novices as well as our experienced teachers reported that they preferred learning science content along with their classes. This tendency to "learn as they teach" argues strongly for good supporting science materials and professional development in practice. Professional development is especially helpful to early-career teachers learning science content (Davis et al. 2006) and appropriate curriculum materials can situate teacher learning within their daily practice, allowing them to acquire both subject matter knowledge as well as disciplinary practice contextualized within their lessons (Davis and Krajcik 2005). Professional development in practice, in concert with good quality materials may be the most efficient method for mitigating elementary teachers' lack of academic preparation in science.

Our results also suggest that conventional methods of assessing teacher content knowledge (content test scores, number of college science courses) are not reliable predictors of a teacher's demonstrated content knowledge in the classroom. Lesson content accuracy was unrelated to our participants' science background, as measured with content tests or number of college science courses, suggesting that trying to "cram in" additional science content knowledge through extra courses will not be as valuable as lesson-specific support and professional development. This result is similar to findings by Luera et al. (2005) who concluded that simply taking more traditional science courses did not improve their student teachers' ability to create an inquiry lesson.

The content accuracy of science lessons of preservice teachers in their methods year was unrelated to the accuracy of lessons that they went on to teach in their student teaching year, suggesting that our students are not "pre-destined" to teach science poorly, either by their attitudes or their science background. Our key finding is that content accuracy in elementary science lessons was very closely related to the quality of instructional materials available.

An unexpected outcome of this study was that science content accuracy increased in higher grades. The reasons behind this result are unknown, but it may be that teachers place less relative importance on science compared with other subjects, particularly in younger grades. Additionally, primary teachers may underestimate the depth of the science content that is presented even in younger grades.

An advantage of this study over individual case studies was that it examined the in-classroom practice of a relatively large number of teachers, and analyzed what they actually taught, rather than what they reported that they were likely to teach. However, a distinct disadvantage to this type of study was that there were many variables that were difficult to control. Because our teachers chose their own science lesson, with varying levels of difficulty, we could not compare accuracy on the same lessons or topics taught by all participants. As our preservice teachers were assigned randomly to kit or non-kit districts, we had much less control over multiple variables that could influence the accuracy of the lesson. These factors, in concert with the inherent complexity of teaching a good inquiry science lesson, meant that our statistical model could account for only a portion of the variability in content accuracy (60 % for inservice teachers, 50 % for student teachers). Nevertheless, we believe that this study demonstrates that given high quality materials, combined with topic-specific professional development support, elementary teachers can present inquiry lessons with good science content accuracy. Based on our findings, these factors are more effective than other means of addressing the issue of content accuracy such as requiring more college-level science courses for elementary teacher preparation students.

Acknowledgments This research was supported by a grant from the National Science Foundation (Grant No. ESI-0455685). The authors would like to acknowledge the generous assistance of Sally Beauman and Elaine Mangiante who assisted us with logistics of the data collection.

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