Abstract

Constructivist approaches were able to reconcile epistemological issues in integrated mathematics/science methods courses because of similarity in learning processes. Six sections (N=87) of an integrated mathematics/science education course were analyzed with mixed methods. Preservice teachers participated in a 5E inquiry-based lesson on biological classification and a mathematics problem-solving lesson on polyhedra. Preservice teachers were asked why it was possible to derive a mathematical formula for polyhedra and not organisms and what this implies about the difference between the epistemologies of mathematics and science. The notion of “simplicity” was triangulated as nearly every response (96%) was coded as “justification and simplicity” in the content analysis, and “simple versus complex” emerged from the constant comparison method. Implications include the use of an appropriate approach to solve an authentic problem which has aspects of both mathematics and science.

The integration of the teaching and learning of mathematics and science in the classroom has been acknowledged and emphasized for over 100 years. In 1902, E.H. Moore, the president of the American Mathematics Society, emphasized the disciplines’ interconnectedness and implications for teaching (Frykholm & Glasson, 2005); and today, multiple science, mathematics, and technological professional societies support the integration of science and mathematics teaching and learning through reform documents (Berlin & Lee, 2005). This includes the: National Research Council (NRC hereafter) (1996), National Council of Teachers of Mathematics (NCTM hereafter) (2000), National Science Teacher’s Association (2003), American Association for the Advancement of Science (AAAS hereafter) (1998), and International Technology Education Association (2007). These reform documents ultimately led
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to standards-based documents known as the National Science Education Standards (NRC, 1996) and the Principles and Standards for School Mathematics (NCTM, 2000), both of which propose the integration of the teaching and learning of science and mathematics in the elementary classroom.

The integration of the teaching and learning of mathematics and science has been framed in various ways by the science and mathematics education community, and several types of integration have been proposed (Berlin & Lee, 2005). According to Davison, Miller, and Metheny (1995) the five types of integration are: (a) discipline specific integration, (b) content specific integration, (c) process integration, (d) methodological integration, and (e) thematic integration. The reasoning for these types of integration is to make these disciplines relevant to students and applicable to their lives (Davison, et al., 1995). However, for integration to occur, obstacles must be overcome. The obstacles to integration include: (a) differences in the epistemology of mathematics and science; (b) varying understanding of teachers’ pedagogical and content knowledge (Frykholm & Glasson, 2005); (c) teachers’ frustration due to difficulty of integration (Koirala & Bowman, 2003); and (d) administrative and school structures (Wicklein & Schell, 1995).

Many elementary teacher education programs have integrated mathematics/science methods courses to prepare preservice teachers for the teaching of mathematics and science. Although the disciplines of mathematics and science are philosophically similar (see Lakatos, 1970; Popper, 1995), and the teaching of mathematics and science are recommended to be based on constructivist based philosophies (Cobb, 1990); there are fundamental epistemological issues between the disciplines which preservice teachers should understand (Lederman & Niess, 1998). Surprisingly, there is little empirical research on how preservice teachers can understand the
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similarities and reconcile the differences in epistemologies. Since 2000, few studies have been published on integrated mathematics/science courses. This is probably because integration has become more challenging due to standardized testing and accountability issues (Berlin & White, 2012). The purpose of this study is to illustrate how constructivist approaches may be able to reconcile epistemological issues in integrated mathematics/science methods courses due to similarity in learning processes.

Literature Review

Although integration seems to have strong philosophical support (see Freudenthal, 1973; Roebuck & Warden, 1998; Rutherford & Ahlgren, 1990), little empirical evidence exists for integration (Berlin & Lee, 2005; Schwartz, Gfeller, & Lederman, 2001; West, Vasquez-Mireles, & Coker, 2006). Furthermore, there is little empirical research on how integration may be able to reconcile issues in the epistemologies of mathematics and science. Since 2000, few studies have been published on the topic of integrated mathematics/science courses; this may be due to challenges which stem from standardized testing and accountability (Berlin & White, 2012). Interestingly, no study has investigated how constructivist approaches centered on process integration may be able to reconcile issues in epistemologies in an integrated mathematics/science methods course. This is very surprising considering the emphasis of constructivist approaches to mathematics and science since the early 1990s. In fact, no study has investigated this at the elementary, middle, or secondary level. The following literature review is what is known of integrated courses, or the integration of mathematics and science for the teaching and learning of mathematics and science in the classroom. Special attention was paid to studies which used process integration.
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Morrison and McDuffie (2009) studied preservice elementary teachers who took a science methods course while learning about data analysis in their mathematics methods course. Using an inquiry-based approach, teachers were asked to communicate data they had collected through displays. Results showed that teachers made meaningful connections between disciplines. Koirala and Bowman (2003) used all five types of integration in a team-taught, middle-level, integrated course. Preservice teachers’ understanding of integration was increased, but teachers became frustrated when integration became difficult. Marbach-Ad and McGinnis (2008) studied a preservice program which prepares specialist teachers in elementary or middle school science and mathematics education. After completing the program, survey results showed that science teachers continued to make connections to mathematics based on what they learned as part of the program. Basista and Mathews (2002) created a summer institute for in-service middle and high school teachers which centered on the integration of mathematics and science. The program used inquiry-based instruction for science and was found to enrich teachers’ pedagogical and content knowledge. Frykholm and Glasson (2005) studied secondary preservice science and mathematics teachers in which teachers collaborated to form meaningful interdisciplinary units. Although conceptual frameworks were constructivist in nature, the forms of integration were mainly discipline specific, content specific, and thematic, with some process integration. Utley, Moseley, and Bryant (2005) studied changes in teacher efficacy beliefs in mathematics and science education method courses. The courses were not integrated, but the researchers looked for similarities between personal teaching efficacy and outcome expectations and found a direct relationship between the two. The researchers inferred that content-specific efficacy may be correlated and, therefore, it can be inferred that a content-specific connection (i.e., integration) played a part in the relationship. Foss and Pinchback (1998) investigated a
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professional development endeavor for in-service elementary teachers. The main form of integration was content specific, and content knowledge was enriched. Wicklein and Schell (1995) studied various types of integration in the secondary setting. Findings included the need for innovation and effort in curriculum redesign for success of integration. Stinson, Harkness, Meyer, and Stallworth (2009) presented the five types of integration depicted as various scenarios to in-service, middle school science and mathematics teachers. The teachers chose integration scenarios which included content knowledge or activities, but failed to identify other forms of integration. In a related study, Meyer, Stinson, Harkness, and Stallworth (2010) used the scenarios with interviews and found that process integration, pedagogical integration, and concept specific integration were the most frequent models used by in-service middle school mathematics and/or science teachers.

Research Questions

1. When constructivist approaches to teaching are used in an integrated elementary mathematics/science method course, to what do preservice teachers: a) attribute the ability to derive a mathematical formula for similarly-grouped polyhedra and not similarly-grouped organisms?; b) believe that the ability to derive a mathematical formula for similarly-grouped polyhedra and not similarly-grouped organisms implies about the difference between epistemologies of mathematics and science?

2. Which areas of epistemology describe preservice teachers’ responses to questions 1a and 1b?
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Theoretical Foundation

Learning Processes

It has been proposed that constructivist approaches may be able to reconcile issues in the epistemologies of mathematics and science because of similarity in processes (Miller & Davison, 1999). The National Science Education Standards (NRC, 1996) and the Principles and Standards for School Mathematics (NCTM, 2000) both emphasize problem-solving approaches. These are approaches centered on science and mathematics problems which students are asked to solve, and in which the solution is not presented by the teacher. The problems are created by teachers who take into account their students’ collective prior knowledge, abilities, and experiences. The problems are meant to create some form of cognitive dissonance and include a component of group work. This approach varies greatly from traditional approaches in which students are given the solution with the problem, work independently, and are asked to practice solving slightly different forms of the problem. The general thought is that problem-solving enables students to transfer approaches, understanding, and knowledge outside of the classroom and to novel situations. Problem-solving by students is conspicuously similar to the problem-solving by scientists and mathematicians.

The problem-solving approaches for mathematics and science have different names, yet similar learning processes. The approach in which teachers of science are asked to use is called inquiry, and the approach in which teachers of mathematics are asked to use is (confusingly) called problem-solving. Teachers who use these two approaches ask their students to use associated learning processes to solve problems in the mathematics and science classroom. Examples of learning processes in mathematics include communication and representations, and in science include exploration and engagement (Bosse, Lee, Swinson, & Falconer, 2010). These
Figure 1. Connections Among Learning Processes From Mathematics and Science Education.

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learning processes are both a way to know mathematics and science, and a goal of mathematics and science. For example, a goal of the mathematics learning process known as communication for students is to communicate mathematics with others; but the process also leads to the learning of mathematics (Bosse et al., 2010). Bosse et al., (2010) compared the five NCTM mathematics learning processes with the well-known and often used inquiry-based 5E model for science (see Figure 1). The researchers found that each disciplines’ learning processes had similar descriptors. Results from the study showed that NCTM process standards for mathematics and the inquiry-based 5E model for science share 41 of 51 descriptors. For example, communication in mathematics and elaborate in science both ask students to justify solutions to problems. This implies that the disciplines of science and mathematics have similar learning processes, and therefore similar epistemologies.

Areas of Epistemology

As with the teaching and learning of mathematics and science, many similarities exist between the epistemologies of the disciplines (Schwartz, Gfeller, & Lederman, 2001). The epistemologies of mathematics and science, also known as the natures of science and mathematics, refer to the disciplines’ ways of knowing (Lederman & Niess, 1998). Total agreement does not exist for the epistemologies of science (Lederman & Niess, 1998) or mathematics (Hersh, 1997); however, reform documents call for students to understand elements of epistemological underpinning (see AAAS, 2009; NRC, 1996).

The most obvious similarities between disciplines’ epistemologies include: (a) knowledge is subject to change, (b) a propensity to simplify, (c) consistence with other disciplinary knowledge, and (d) need for justification (see Table 1). The knowledge base of both
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disciplines has the ability to change based on new information or reasoning. Both disciplines have an affinity for parsimony through models and other representations. The disciplines share the need for interconnectedness which builds confidence in validity. And lastly, both mathematicians and scientists must argue their ideas to either change or influence the knowledge base.

Table 1

*Four Areas of Epistemology*

<table>
<thead>
<tr>
<th>Area of epistemology</th>
<th>Nature of science</th>
<th>Nature of mathematics</th>
</tr>
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<tbody>
<tr>
<td>Certainty (C)</td>
<td>Tentative (subject to change); connections between observations and inferences/evidence and conclusions influenced by human creativity and imagination and social/cultural values</td>
<td>Dynamic (subject to change)</td>
</tr>
<tr>
<td>Simplicity (I)</td>
<td>Models serve to explain phenomena yet are not exact replicas; internally consistent with currently accepted scientific knowledge</td>
<td>Interrelated and connected by logical chains of reasoning</td>
</tr>
<tr>
<td>Source (O)</td>
<td>Empirical observations and interpretations which are theory laden (subjective); human creativity and imagination, internally consistent with currently accepted scientific knowledge</td>
<td>Human creativity and imagination; arbitrary, yet consistent with other mathematical ideas</td>
</tr>
<tr>
<td>Justification (J)</td>
<td>Empirical; internally consistent with currently accepted scientific knowledge</td>
<td>Logical deductive proof based on abstract, nonempirical mathematical objects</td>
</tr>
</tbody>
</table>

What may be the most obvious epistemological difference between the disciplines is that science uses the real world for the source and justification of knowledge (i.e., empirical evidence and data), while mathematics may not necessarily have a basis in the real world (Lederman & Niess, 1998; Schwartz, Gfeller, & Lederman, 2001). For example, mathematics is considered to be viewed in “…terms of pure logic…and as an activity of intuitive constructions” (Lederman & Niess, p. 282, 1998), while scientific knowledge is based upon empirical observation of the natural world. Therefore, knowledge in science and mathematics is falsified in two different
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ways. Scientific knowledge can be falsified by continual observations that violate theories, and mathematics can be falsified by logical inconsistencies.

Methodology

Six sections of an integrated science and mathematics education course at a northeastern masters-level college in the United States were analyzed. Preservice teachers (N=87) were sophomores and juniors in a dual undergraduate elementary/special education major and were required to take an integrated course title “Teaching Science and Mathematics in the Elementary School.” The length of the course was between 15 and 16 weeks, with the first half of the course devoted to science education and the second half to mathematics education. Classes were held three days a week (Tuesday, Wednesday, and Friday) for 50 minutes, and preservice teachers were also enrolled in a practicum course which met once a week in a local elementary school. Each section was taught by the same instructor, and each practicum course allowed preservice teachers to team teach at a local elementary school.

Preservice teachers were asked to participate in an inquiry-based science lesson and problem-solving based mathematics lessons every Tuesday, throughout the semester. The purposes of these lessons were for preservice teachers to: (a) experience the inquiry and problem-solving approaches; (b) enrich science and mathematics content knowledge; (c) determine how to create similar, developmentally-appropriate lessons for elementary students; (d) and understand the epistemologies of mathematics and science.

A typical inquiry/problem-solving lesson began with the presentation of a scientific or mathematical problem central to an intellectual goal (e.g., biological classification, Euler’s Formula, etc.). The problems were constructed with the preservice teachers’ collective beliefs,
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knowledge, and abilities in mind, and were meant to create some form of cognitive dissonance or disequilibrium. Preservice teachers worked in small cooperative groups to solve the problem.

During the third week of the course, preservice teachers participated in a 5E inquiry-based lesson on biological classification. At the start of the lesson, preservice teachers were presented with a three-set Venn diagram worksheet (see Figure 2). The three sets were labeled annelids, cnidarians, and chordates. Preserved organisms in plastic jars were placed on three separate tables in the classroom. Four annelids were placed on one table, four cnidarians on another table, and five chordates on a third table. Preservice teachers were asked, using observation, inference, logical thinking, and prior knowledge, to find the similarities within the organisms on each table, and to find the differences between the groups of organisms at each table. These characteristics were to be written in the appropriate six spaces on the three-set Venn diagram.

After about five minutes of instructions, the preservice teachers were given approximately 30 minutes to work in groups and complete the task. During this time, the instructor moved among the groups, probed the preservice teachers’ ideas, asked for explanation to the reasoning used for the grouping, but did not evaluate answers. Typical responses to probing for the similarity of cnidarians included “squishy and didn’t have bones (Student 1, personal communication, September 2010)”, “they could sting (Student 2, personal communication, February 2011)”, and “they were symmetrical (Student 3, personal communication, September 2012).” After 30 minutes, the preservice teachers were asked to place their worksheet on the document camera which projects to a smart board. Preservice teachers were asked to be prepared to present, and justify their answers to anyone who disagreed. At this time, preservice teachers were also asked to make any changes to their Venn diagram because they would be graded with the rubric found on the worksheet.
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Figures 2 and 3. Preserved Organisms Worksheet and Screen Capture of Geometric Solids Applet

During the 13th week of the course, preservice teachers participated in a mathematics problem-solving lesson. Preservice teachers were given individual laptops and asked to look at a NCTM Illuminations geometric solids applet (see Figure 3). This applet allows one to rotate and count the faces, vertices, and edges of five regular polyhedra (i.e., cube, tetrahedron, octahedron, dodecahedron, and icosahedron). For example, Figure 3 shows an icosahedron with two highlighted faces, one highlighted edge, and one highlighted vertex. Preservice teachers were then asked to: (a) work in pairs to find the relationship between the number of faces, vertices, and edges for the five polyhedra; and (b) create a formula by symbolically reducing/abstracting the relationship between faces, vertices, and edges. The instructor also informed the preservice teachers that their formula should include, at the very least, the symbols V, E, F, =. It was also recommended that preservice teachers create a data table to tally the polyhedra’s characteristics and to look for patterns in the data; although this might not be necessary to solve the problem.
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After about five minutes of instruction and a quick demonstration of the applet, the preservice teachers were given approximately 30 minutes to work in pairs and solve the problem. During this time, the instructor moved among the pairs, probed the preservice teachers’ ideas, and asked for explanations for their reasoning while not evaluating answers. Typical responses to probing included “I’m plugging in different numbers (Student 4, personal communication, November 2010),” and “I’m using trial-and-error to solve the problem (Student 5, personal communication, November 2012).” After 30 minutes, preservice teachers were asked to share their answer and processes with the class. Preservice teachers discovered Euler's Polyhedral Formula which is V - E + F = 2.

The day after the polyhedra lesson (Wednesday), preservice teachers were asked the following questions in class and asked to individually write down their answer on a sheet of paper: You participated in two lessons in which you were asked to compare examples of (a) organisms, and (b) solids (polyhedra). In both cases you looked for similarities. Why were you asked to create a formula for the solids and not the organisms? What does this tell you about the difference between mathematics and science? Responses were collected.

Methods

A mixed methods approach was used to answer the research questions. A qualitative method known as the constant comparison method was used to inductively answer research question 1, and a quantitative approach known as content analysis was used to deductively answer research question 2. This mixed approach is most appropriate to answer the research questions because the combination of qualitative and quantitative is complementary and can triangulate data to robustly answer research questions (Denizen, 1978). Mixed methods have
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been shown to be successful, practical, predictive, and have the ability to increase validity
(Teddlie & Tashakkori, 2003).

_**Constant comparison method**_

Questions 1a and 1b were answered through a constructivist framework using the
constant comparison method. The method is variable and transformable depending on one’s
perspective. This method was chosen because no theory based on empirical evidence has been
posited which could capture the complexity of the preservice teachers’ responses through
quantitative means. The cross comparison method leads one to rich and robust descriptive and
explanatory categories which illustrate relationships (Lincoln & Guba, 1994). These
relationships are especially important to answer research questions 1a and 1b which ask for
differences in epistemologies through similar learning processes. This method started with
coding responses by attaching codes, or labels, to pieces of text that are relevant to a particular
theme or idea. Then passages of text were grouped into patterns according to the codes and
subcodes (Miles & Huberman, 1994) and a focus coding table was created (see Table 2). After
looking over the responses along with the focus coding table, memos were written to study and
understand the preservice teachers’ responses (see Table 3). All of the themes stated by the
preservice teachers were connected to the content analysis, and were expanded upon in the
findings portion of this study.

Table 2

_Focused Coding_

| Perennial versus tentative | Simple versus complex | Quantitative versus qualitative |
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Table 3

Memos

Perennial Versus Tentative
The theme that emerged most often was that mathematics is associated with perennial knowledge and concepts, while science is associated with tentative knowledge and concepts. Many preservice teachers wrote that Euler’s formula, and therefore mathematics, will always be correct throughout time. Science, on the other hand, changes with time. Some responses included: “…mathematics is more consistent than science…in science things are constantly changing (Student 8, personal communication, November 2011).” “Science is something that is always changing…. (mathematics) does not change (Student 9, personal communication, December 2010).” “Science is always changing…. (mathematics)…is universally accepted and unchanging (Student 10, personal communication, April 2012).”

Simple Versus Complex
Another theme that emerged was the association with polyhedra and mathematics with simplicity, and the organisms and science with complexity. Preservice teachers stated that all the polyhedra were simple and had the same three characteristics, while the organisms had multiple characteristics that could be difficult to quantify. The simplicity of polyhedra allowed one to count the faces, edges, and vertices of the solid, and the complexity of the organisms did not allow one to create a formula to describe the organisms. Preservice teachers’ responses included: “It would be much more difficult to create a clear-cut formula for … organisms because I believe there are more variables to consider (Student 11, personal communication, April 2012).” “The organisms are not necessarily made up of the same properties, whereas the polyhedra were only made up of faces, edges, and vertices (Student 12, personal communication, April 2011).”

Qualitative Data Versus Quantitative Data
The last theme that emerged from the data was the associations between the polyhedra and mathematics with quantitative data, and the organisms and science with qualitative data. Preservice teachers responded that it was easier to use numbers in mathematics than science, and that using numbers in science is not always helpful. Preservice teachers also stated that science uses processes like observation and inference which yield qualitative data. Preservice teachers stated that mathematics is centered on numbers and relationships which can be described with numbers. Examples from responses include: “With the science experiment, we were evaluating similarities with words and descriptions, but in the math lesson we were using numbers to describe similarities (Student 13, personal communication, December 2011).” And “…in our [science] experiment…our observations dealt more with describing the physical traits and characteristics of the organisms. In math, however, we dealt more with numbers and created a formula that could relate the faces, edges, and vertices together (Student 14, personal communication, November 2011).”
/content analysis was used to answer research question 2. Content analysis is a systematic and quantitative empirical method that describes the content of text (Berelson, 1952; Krippendorff, 2004) by identification and understanding of terms, phrases, or other characteristics (Holsti 1969). Krippendorff (2004) defines the method as a technique for making replicable and valid inferences from data. Holsti (1969) defines it as a method for creating inferences by objectively identifying specified information. Content analysis is used to study large data sets and is often associated with mass communication research, but is also common in educational research. Examples of past use of content analysis in education include investigations in school mission statements (Stemler & Bebell, 1998) and studies in effective professional development (Author, 2011).

Content analysis was used to answer this study’s second research question because it can be used to describe the content of the preservice teachers’ responses in a quantitative and replicable fashion. That is, by using a priori categories (i.e., the four areas of epistemology) content analysis can be used to determine: (a) which area of epistemology described why one could create a formula for the solids and not organisms and, (b) what this implies about the difference between mathematics and science.

Since content analysis is replicable, reliability is important. Reliability is the degree to which a particular community would agree upon data (Krippendorff, 2004). The two types of content analysis reliability measures are intra-rater and inter-rater. Inter-rater reliability measures reproducibility, or how often different raters code the same text with the same results. Differences in inter-rater reliability are usually due to raters’ poor understanding of categories or coding rules. Intra-rater reliability measures stability, or how often the same rater chooses the
same code for the same text, try after try. Low scores in intra-rater reliability are usually due to poor understanding of categories, coding rules, cognitive changes within rater, and simple bookkeeping error (Weber, 1990).

Since content analysis is replicable, it is important for raters to have appropriate backgrounds and qualifications that are shared by a large population of potential raters (Krippendorff, 2004). Peter and Lauf (2002) recommend that raters have the same cultural, educational, and professional background. The four raters (denoted K, A, L, and J) used for the content analysis were American-born, graduate students who held undergraduate degrees in elementary/special education. The training session for content analysis began with the researcher explaining to the four raters the goal of the task: to categorize 87 preservice teachers’ responses into one of the four areas of epistemology (denoted J, I, O, C in Table 1). The raters were provided with copies of the 87 responses, a document which contained the areas of epistemology (see Table 1), and an empty draft-coding sheet (see Table 4 for a completed example). The raters were asked to record one of the four areas of epistemology to the draft-coding sheet or to place an X in the appropriate cell for an unanswered response. When the raters completed the first round of coding, they were asked to email their responses to the researcher. Twenty-four to 48 hours later, the researcher asked the raters to reshuffle the responses and recode the responses. They were also reminded not to look at their previous draft-coding sheet. When the second round of coding was complete, raters were again asked to email their draft-coding sheet. This ended the training session which took about 3-4 hours per rater. The raters were then paired to begin the analysis. K and Ally were paired, and L and J were paired. Raters were asked to reshuffle the 87 responses and recode the responses together. Twenty-four hours later, the raters emailed their draft-coding sheet (see Tables 7 and 8).
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Table 4

Completed Practice Draft-Coding Sheet for Rater A

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<td>1</td>
<td>O</td>
<td>11 J</td>
<td>21 J</td>
<td>31 O</td>
<td>41 J</td>
<td>51 J</td>
<td>61 O</td>
<td>71 O</td>
</tr>
<tr>
<td>2</td>
<td>J</td>
<td>12 I</td>
<td>22 I</td>
<td>32 J</td>
<td>42 J</td>
<td>52 I</td>
<td>62 J</td>
<td>72 I</td>
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<td>3</td>
<td>I</td>
<td>13 J</td>
<td>23 I</td>
<td>33 X</td>
<td>43 I</td>
<td>53 J</td>
<td>63 I</td>
<td>73 I</td>
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<tr>
<td>4</td>
<td>J</td>
<td>14 J</td>
<td>24 J</td>
<td>34 J</td>
<td>44 I</td>
<td>54 I</td>
<td>64 J</td>
<td>74 I</td>
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<td>5</td>
<td>I</td>
<td>15 I</td>
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<td>35 J</td>
<td>45 I</td>
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<td>40 J</td>
<td>50 I</td>
<td>60 J</td>
<td>70 J</td>
<td>80 J</td>
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</table>

The draft-coding sheets from K and A (see Table 5), and L and J (see Table 6) were measured for inter-rater reliability with Cohen’s kappa (K). The researcher recorded the number of agreed-upon cases and the total number of cases. Then the numbers were inputted into ReCal, an online reliability web service which uses the following formula to calculate Cohen’s kappa (Freelon, 2010): 

\[ K = \frac{P_{\text{agreed}} - P_{\text{chance}}}{1 - P_{\text{chance}}} \]

\( P_{\text{agreed}} \) is the percent of cases agreed upon and \( P_{\text{chance}} \) is the percent of cases agreed upon by chance alone. Two days after the paired content analyses, raters were asked to individually recode the responses for intra-rater reliability.

Table 5

Raters K and A Final Draft-Coding Sheet (before collapse)

<p>| | | | | | | | | |</p>
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<td>52 I</td>
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<td>23 I</td>
<td>33 X</td>
<td>43 I</td>
<td>53 J</td>
<td>63 J</td>
<td>73 I</td>
</tr>
<tr>
<td>4</td>
<td>J</td>
<td>14 J</td>
<td>24 I/J</td>
<td>34 J</td>
<td>44 I</td>
<td>54 I</td>
<td>64 J</td>
<td>74 J</td>
</tr>
<tr>
<td>6</td>
<td>J</td>
<td>16 I</td>
<td>26 J</td>
<td>36 J/I</td>
<td>46 I</td>
<td>56 J</td>
<td>66 J</td>
<td>76 J</td>
</tr>
<tr>
<td>7</td>
<td>J</td>
<td>17 I/J</td>
<td>27 I</td>
<td>37 I</td>
<td>47 J</td>
<td>57 J</td>
<td>67 J</td>
<td>77 J</td>
</tr>
<tr>
<td>8</td>
<td>J</td>
<td>18 J</td>
<td>28 I</td>
<td>38 C</td>
<td>48 O</td>
<td>58 J</td>
<td>68 J</td>
<td>78 J</td>
</tr>
<tr>
<td>9</td>
<td>I</td>
<td>19 I/J</td>
<td>29 J/I</td>
<td>39 J</td>
<td>49 O</td>
<td>59 J</td>
<td>69 J</td>
<td>79 I</td>
</tr>
<tr>
<td>10</td>
<td>I</td>
<td>20 J</td>
<td>30 J</td>
<td>40 J</td>
<td>50 X</td>
<td>60 J</td>
<td>70 J</td>
<td>80 C</td>
</tr>
</tbody>
</table>
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Table 6

*Raters L and J Final Draft-Coding Sheet (before collapse)*

<table>
<thead>
<tr>
<th>1 O</th>
<th>11 J</th>
<th>21 J</th>
<th>31 J</th>
<th>41 J</th>
<th>51 J</th>
<th>61 J</th>
<th>71 I</th>
<th>81 I</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 J</td>
<td>12 J</td>
<td>22 I</td>
<td>32 I</td>
<td>42 J</td>
<td>52 I</td>
<td>62 J</td>
<td>72 J</td>
<td>82 J</td>
</tr>
<tr>
<td>3 I</td>
<td>13 J</td>
<td>23 X</td>
<td>33 X</td>
<td>43 J</td>
<td>53 I</td>
<td>63 I</td>
<td>73 J</td>
<td>83 I</td>
</tr>
<tr>
<td>4 I</td>
<td>14 I</td>
<td>24 J</td>
<td>34 I</td>
<td>44 J</td>
<td>54 I</td>
<td>64 J</td>
<td>74 I</td>
<td>84 I</td>
</tr>
<tr>
<td>5 I</td>
<td>15 I/J</td>
<td>25 J</td>
<td>35 J</td>
<td>45 I</td>
<td>55 J</td>
<td>65 I</td>
<td>75 J</td>
<td>85 J</td>
</tr>
<tr>
<td>6 I</td>
<td>16 I</td>
<td>26 J</td>
<td>36 I</td>
<td>46 I</td>
<td>56 I</td>
<td>66 J</td>
<td>76 J</td>
<td>86 O</td>
</tr>
<tr>
<td>7 O</td>
<td>17 J</td>
<td>27 O</td>
<td>37 I</td>
<td>47 J</td>
<td>57 I</td>
<td>67 I</td>
<td>77 I</td>
<td>87 J</td>
</tr>
<tr>
<td>8 J</td>
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<td>28 J</td>
<td>38 J</td>
<td>48 I</td>
<td>58 J</td>
<td>68 I</td>
<td>78 I</td>
<td></td>
</tr>
<tr>
<td>9 I</td>
<td>19 C</td>
<td>29 I</td>
<td>39 I</td>
<td>49 I</td>
<td>59 J</td>
<td>69 I</td>
<td>79 I</td>
<td></td>
</tr>
<tr>
<td>10 J</td>
<td>20 J</td>
<td>30 I</td>
<td>40 I</td>
<td>50 I</td>
<td>60 I</td>
<td>70 J</td>
<td>80 O</td>
<td></td>
</tr>
</tbody>
</table>

**Findings**

**Constant Comparison Findings**

Research question one asks: When constructivist approaches to teaching are used in an integrated elementary mathematics/science method course, to what do preservice teachers: (a) attribute the ability to derive a mathematical formula for similarly-grouped solids and not similarly-grouped organisms?; (b) believe that the ability to derive a mathematical formula for similarly-grouped solids and not similarly-grouped organisms implies about the difference between epistemologies of mathematics and science? Research question one is essentially the question asked to preservice teachers the day after the polyhedra lesson. Three themes emerged from preservice teachers’ responses to the questions (see Tables 2 and 3).

The first emergent theme is *perennial versus tentative*. Preservice teachers believe that mathematics is associated with perennial knowledge and concepts, while science is associated with tentative knowledge and concepts. The preservice teachers viewed the polyhedra and mathematics as unchanging while they recognized organisms and scientific knowledge as changing. Although this is an over simplification, this is one difference between the
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epistemologies of mathematics and science. For example, mathematical conjectures that have been proven are no longer viewed as tentative since they are arguments which any educated, intelligent, rational person would accept (Delvin, 1994). However, mathematics is not perennial, yet it may seem to be in relation to science. For example, comprehensive axiom set theories in mathematics have been falsified (Lederman & Niess, 1998), and questions that were once believed to be unanswerable were answered as mathematics progressed.

Another theme which emerged was simple versus complex. The association between polyhedra and mathematics was described with simplicity, and the organisms and science with complexity. It is believed that 3D geometric solids like the polyhedra are derived from reality and have been abstracted and reduced. In fact, 3D geometric polyhedra are taught to children at a young age (NCTM, 1996). This is probably because young children interact with forms of these polyhedra in everyday life (e.g., soccer balls, dice, etc.). The organisms were seen as complex compared to the polyhedra, because the organisms were not abstracted or reduced. They had been placed into groups based on Linnaean classification. This form of classification is one of two that biologists and paleontologists routinely employ. Because the organisms are complex, classification based on the Linnaean system is often difficult. For example, there are many organisms in the fossil record which paleontologists cannot classify.

The last theme which emerged was qualitative data versus quantitative data. Preservice teachers made associations between the polyhedra and mathematics with quantitative data, and the organisms and science with qualitative data. Once again, this is an oversimplification but makes sense if one discipline is compared to the other. It is an oversimplification because scientists often use numbers to represent observation and other scientific processes. This is especially true in physics, chemistry, and geology. On the other hand, mathematics was once
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viewed as a science of quantity (Cajori, 1893), yet today this does not hold true. Mathematicians often use qualitative data in group theory and geometry. For example, lines of symmetry for 2D and 3D shapes are often described with qualitative data, and some proofs (e.g., Pythagorean’s Theorem) are based on qualitative data.

Content Analysis Findings

Research question two is: Which areas of epistemology describe preservice teachers’ responses to questions 1a and 1b? After raters K and A, and L and J submitted their draft-coding sheets (see Tables 5 and 6), inter-rater reliability of the two draft-coding sheets were calculated (see Table 7, second row). Cohen’s kappa, which has a range between 0 and 1, was calculated and found to be 0.094. This is a low score because 0 means no agreement after chance and 1 is total agreement after chance. A low kappa means one of two things: the rater training was poor or some categories were so closely related that raters could not differentiate between the two. Closer observation of the two draft-coding sheets showed that simplicity (I) and justification (J) were interchangeable. In other words, raters rated similar responses with either only an I or J.

Table 7

Inter-rater Reliability Scores for Four Raters

<table>
<thead>
<tr>
<th>Raters</th>
<th>Percent Agreement</th>
<th>Cohen’s Kappa</th>
<th>N Agreement</th>
<th>N Disagreement</th>
<th>N Cases</th>
<th>N Decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>K A and L J</td>
<td>49.3%</td>
<td>0.094</td>
<td>37</td>
<td>38</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>(Before collapse)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K A and L J</td>
<td>93.3%</td>
<td>0.51</td>
<td>70</td>
<td>5</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>(After collapse)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This prompted the collapse of simplicity (I) and justification (J) into one category. After the collapse, kappa increased to 0.51 (see Table 7, third row). This collapse was not a way to
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manipulate the data because as the categories decrease, chances of a higher K decrease. Also, as categories decrease there is a greater need for variety in the data. Cohen’s kappa punishes coding that does not have varied responses, and this did occur in the collapsed category analysis. This is obvious because although rater agreement is high (93.3%), kappa is only 0.51. This means that 51% of the data are coded or transcribed to a degree better than chance (Krippendorff, 2004). There is no standard for kappa, and Krippendorff (2004) recommends that kappa reflects the cost of drawing a wrong conclusion. For example, if a content analysis would affect one’s life, as in a court case, it is best to have a high kappa (Krippendorff, 2004). Social science research accepts lower kappa scores for tentative conclusions. Table 8 reports kappa for inter-rater reliability. All of these scores were high with K between 0.78 and 0.95.

Table 8

Intra-rater reliability scores for four raters

<table>
<thead>
<tr>
<th>Rater</th>
<th>Percent Agreement</th>
<th>Cohen’s Kappa</th>
<th>N Agreement</th>
<th>N Disagreement</th>
<th>N Cases</th>
<th>N Decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>88.3%</td>
<td>0.783</td>
<td>68</td>
<td>9</td>
<td>77</td>
<td>154</td>
</tr>
<tr>
<td>A</td>
<td>92.2%</td>
<td>0.858</td>
<td>71</td>
<td>6</td>
<td>77</td>
<td>154</td>
</tr>
<tr>
<td>L</td>
<td>97.6%</td>
<td>0.957</td>
<td>82</td>
<td>2</td>
<td>84</td>
<td>168</td>
</tr>
<tr>
<td>J</td>
<td>90.5%</td>
<td>0.827</td>
<td>76</td>
<td>8</td>
<td>84</td>
<td>168</td>
</tr>
</tbody>
</table>

The areas of epistemology which describe preservice teachers’ responses to questions 1a and 1b are as follows: 72 of 75 (96%) of responses were coded as justification and simplicity, 3 of 75 (4%) of responses were coded as source, and 0 of 75 (0%) were coded as certainty (see Table 9).

Table 9

Number of Agreed Occurrences

<table>
<thead>
<tr>
<th>Area of epistemology</th>
<th>Justification (J)</th>
<th>Simplicity (I)</th>
<th>Source (O)</th>
<th>Certainty (C)</th>
<th>N agreement</th>
</tr>
</thead>
</table>

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<table>
<thead>
<tr>
<th>Number of occurrences (before collapse)</th>
<th>22</th>
<th>12</th>
<th>3</th>
<th>0</th>
<th>37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of occurrences (after collapse)</td>
<td>72</td>
<td>3</td>
<td>0</td>
<td>75</td>
<td></td>
</tr>
</tbody>
</table>

Conclusions and Implications

The answer to research question one was: (a) perennial versus tentative, (b) simple versus complex, and (c) quantitative data versus qualitative data. The answer to research question two was: (a) 72 of 75 (96%) responses were coded as justification and simplicity, (b) three of 75 (4%) responses were coded as source, and (c) zero of 75 (0%) were coded as certainty. Because mixed methods studies are used to triangulate data and improve validity, one must look at the results, make obvious connections, and draw conclusions. The obvious connection between the results of the two methods is the concept of simplicity. Nearly every response in the content analysis was coded as justification and simplicity as the area of epistemology, and simple versus complex described one of three themes from the constant comparison method. Both disciplines have an affinity for parsimony through models and other representations. Model-making is a descriptor for learning processes in mathematics and science, and representation and explanations are the learning processes for the disciplines (Bosse, et al., 2005). The polyhedra and the organisms were examples that fit into scientific and mathematical models. To some extent, the reason it is easier to find a formula for the polyhedra and not the organisms is because the polyhedra are simpler than the organisms. The polyhedra are idealized forms that seem to be found in the natural world. Yet, they have been abstracted and reduced for mathematics. The organisms haven’t been reduced; however, the instructor provided preservice teachers with strong examples which represent the various groups of organisms. For example, all the organisms in the chordates group held backbones. There are chordates that do not have
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backbone, but these organisms would have served as poor examples of the chordate model for the Linnaean system.

The second and weaker connection, is source (4%) and quantitative versus qualitative. As previously mentioned, mathematics is considered to be viewed in “…terms of pure logic…and as an activity of intuitive constructions” (Lederman & Niess, p. 282, 1998), while scientific knowledge is based upon empirical observation of the natural world. The preservice teachers were asked: to what do you attribute the ability to derive a mathematical formula for similarly-grouped solids and not similarly-grouped organisms? Preservice teachers used the science process skill of observation, which is tied in with the learning process exploration, to qualitatively describe the organisms. They used the learning process, reasoning and proof, to look for quantitative connections between the faces, vertices, and edges of the polyhedra. Preservice teachers seemed to understand that this was a difference, yet they probably did not understand why the difference existed.

Why is it possible to derive a mathematical formula for polyhedra and not organisms? The answer is that the disciplines can be similar in learning processes, but are different in the approaches and questions asked. Question 1a is centered on similarities in learning processes and 2b is centered on differences in approaches. This fundamental difference in the two questions can probably explain why the focus coding findings were centered on mutually exclusive differences. Specifically, associating the terms perennial, simple, and quantitative data with mathematics, and tentative, complex, and qualitative data with science. Since the answers to 1a and 1b appeared in a dualistic form (similarity versus differences), the students’ responses addressed question 1a which was centered on similarities. If the students answered question 1b, their responses would have stated that science and mathematics are different in the
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approaches and questions asked. If the students answered both question 1a and 1b, their responses would have been that science and mathematics are similar in learning processes, but are different in the approaches and questions asked. Two preservice teachers did answer 1b. One preservice teacher wrote, “In general, this demonstrates to me how mathematics and science – though very much integrated in some ways – are distinct subjects because of the content they study (Student 6, personal communication, April 2012).” Another wrote “…no formula was created in the science/organism activity because there wasn’t a need for a formula (Student 7, personal communication, December 2011).”

Preservice teachers must not only understand the similar learning processes, but they must understand the inquiry-based and problem-solving approaches as a whole. They must understand that the approaches are not the sum of their parts (i.e., similar learning processes). If teacher educators are to use constructivists approaches focused on the similarity of processes to reconcile epistemological issues in integrated mathematics/science courses, it may be best to also focus on differences in approaches beyond those illustrated in this study. In other words, the next step may be to allow students to choose the appropriate approach to solve an authentic problem which has aspects of both mathematics and science. For example, students can be presented with a classic, simple machines problem centered on the balancing of levers. The problem could be presented as follows: the students are not told if the problem is a science or mathematics problem and are asked to solve it using the approach of their choosing. Students are given a lever balanced on a fulcrum and various weights. Students are then asked to create a formula which could predict, only knowing the amount of weight and the weight’s distance from the fulcrum, whether the lever will be balanced or not. Students are then given all the supplies. At this point students can either derive the formula through inquiry, or choose to not use the
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supplies and solve the problem with problem-solving. After students decide on which approach to use, they can solve the problem and justify their reasoning for the approach that they used. This type of activity along with the activities illustrated in this study should be able to reconcile epistemological issues in integrated mathematics/science methods courses, and courses that are not integrated.

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