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Use of Schema Theory and Multimedia Technology to Explore Preservice Students' Cognitive Resources During an Earth Science Activity

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Meaningful integration of multimedia technology into the three-dimensional learning promoted by the Next Generation Science Standards (i.e., Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas) is critical in helping students to understand science. Furthermore, preservice teachers need to be able to engage in argument from evidence, as recommended by the National Research Council, before they can help students develop argumentation in the classroom setting. This study explored the dialogic arguments and conversations of five female African American preservice graduate elementary education students enrolled in a science methods course. Students carried out a Crime Scene Investigation Toolkit in Earth science that was created by the New York Hall of Science. Schema theory and Marshall's (1995) knowledge types provide an explanatory framework to explore and explain participants' dialogue. The findings show that schema theory has implications for understanding participants' cognitive resources during an activity that integrated multimedia technology resources within a three-dimensional science investigation. The use of schema theory as a framework shed light on participants' dialogues and was important in understanding how to integrate multimedia technology meaningfully into the three dimensions of the Next Generation Science Standards.

This study explored the cognitive resources of five Black female preservice elementary education majors during a fictitious crime scene investigation incorporating Earth science concepts. The Crime Scene Investigation Toolkit (CSIT), formerly called Crime Scene Investigation Technology, was created by the New York Hall of Science (NYSCI). The goal of the NYSCI CSIT was to use technology as a tool to integrate three-dimensional learning that supports the performance expectations of the *Next Generation Science Standards* (NGSS Lead States, 2013) – that is, the dimensions of Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas.

The CSIT uses a real-world crime situation to introduce students to claims, evidence, and reasoning about Earth science disciplinary core ideas and mathematics to solve a crime, as they use and learn digital multimedia technology. The name change of the activity reflected NYSCI's goal to go beyond using technology simply as a substitute for paper; for example using digital portfolios in place of paper portfolios. As an NYSCI project manager stated, "Many students are familiar with Google maps, but they aren't as familiar with actually exploring map layers or thinking about other uses for maps, [such as] identifying patterns" (M. Labriole, personal communication, February 11, 2019). The need for activities that integrate science with technology and mathematics to engage nonscience majors and promote critical thinking has been echoed by education researchers across science, technology, engineering, and mathematics (STEM) education fields (e.g., Burrows et al., 2017).

In this investigation students engaged in dialogic discourse as they explored Earth science concepts, calculated the slopes of unknown topographical contour maps, and used various multimedia data as evidence to solve a crime – a vandalism of the town archivist office that destroyed town records. Students were tasked with dating torn and unidentified maps.

Flick and Bell (2000) indicated that science should not be an afterthought when integrated with technology. Rather, technology learning should accompany the learning of science, and students should be able to take advantage of technology as they learn science. In the NYSCI CSIT, the digital technology is multimodal, and the tasks allowed students to acquire technology skills as they went back and forth between the various forms of technology to create claims, analyze evidence, and reason. Students had the opportunity to learn technology as they learned science.

Students were required to have their computers to incrementally access guided presentations with electronic emails and other supporting evidence. Digital multimedia technology took on various forms. Textual and visual information were provided in PowerPoint electronic slideshow presentations, which students accessed incrementally. The first presentation provided students with options for online digital portfolios and the option to use their smartphones to capture photos and videos.

Given the time constraints of the course, students were encouraged to fully explore and use one of these options (see http://www.sites.google.com/site/googlioproject/home), with the understanding that Google Sites and a Gmail account worked best for schools. Graphics included known and unknown digital contour maps. Students downloaded Google Earth to explore terrains. They looked at Google maps and Google images to better understand how the visual evidence can be used to understand contour maps and vice versa.

An audio radio broadcast (accessible only to me, the instructor/researcher) was shared with students at the appropriate time. Technology resources were integrated into the learning of Earth science concepts and Earth systems. Students were provided these technology resources prior to the investigation and accessed them as needed during the activity. These included time-lapse video clips and interactive time-lapse showing the formation and changes in various landforms. All of the digital multimedia technology data provided the evidence from which students would carry out discussions and argue claims (NYSCI CSIT).

While some information could have been substituted with nondigital paper formats, such as the digital maps, there were advantages to using technology, as was encouraged by NYSCI CSIT. Kaufman and Flanagan (2016) performed various studies that compared students' performance on digital versus nondigital platforms. Their findings showed that students' default construal was low-level thinking for the digital platform and that the nondigital (paper) platform promoted more higher level thinking.

The more frequent correct answers in the paper form compared with more incorrect answers in the digital form support the tendency for students to be oriented toward immediacy and concreteness when using digital platforms. However, their studies also show that this default and incorrect tendencies could be mediated by priming to trigger abstract thinking prior to engaging in a digital platform, as well as by promoting the use of "how" and "why" higher level tasks in the digital mode (Kaufman & Flanagan, 2016).

Thus, the use of digital multimodal technology is more likely to promote talk and arguments among students than is the paper mode. The NYSCI CSIT investigation consists of guiding questions that promote both abstract and concrete concepts. Students are not simply presented with digital multimedia, they are tasked with the goal of solving a crime by generating claims, evidence, and reasons.

Argumentation, one of the scientific practices of the NGSS (NGSS Lead States, 2013), is supported by the lessons. Argumentation involves the use of data as evidence to construct arguments and assess the weakness of arguments in science (National Research Council [NRC], 2012). Argumentation is advantageous as a student-oriented approach to learning science (Osborne, 2010; Osborne, Erduran, Simon, & Monk, 2001) and has a positive effect on science learning in teacher preparation (Boran & Bag, 2016; McDonald, 2014; Rebello & Rebello, 2012; Zohar & Nemet, 2002).

This study also addressed the need for a framework for analysis that would provide insights into students' cognitive resources. It was important to consider the advantages and disadvantages of current methods of analysis that reduce students' dialogues to numbers and codes (Nielsen, 2013; Tippett, 2009) based on the number of rebuttals and counterarguments.

The need for a framework that enables comparison across studies was also echoed by 42 science education researchers in argumentation at a recent annual meeting of the National Association for Research in Science Teaching (Henderson, McNeill, Gonzalez-Howard, Close, & Evans, 2018). Therefore, this study explored schema theory as an explanatory and exploratory framework for understanding the cognitive resources within students' dialogic discourse and dialogic argumentation.

Theoretical Framework

Schema Theory

The idea of a schema and oversimplification of the use of the word *schema* to mean "patterns" have long been debated (Bartlett 1932; Krasny, Sadoski, & Paivio, 2007; Marshall, 1995; McVee, Gavelek, & Dunsmore, 2007). However, Marshall's (1995) amalgamation of the various perspectives of a schema and its application to explain problem solving in mathematics still holds promise for an operational use of schema theory as a holistic approach to understanding and explaining learning across domains. Marshall argued that the word schema in cognitive science defines five levels of schema abstractions that range from examining the microfeatures, or smallest element of a type of knowledge, to an individual schema component or knowledge type, to the level of schema knowledge that looks at all the schema components.

Schema abstractions include examination of domain knowledge, and the most general form of schemas look at knowledge in long-term memory without looking at a particular domain. This study looked at schema components within a subject domain, Earth science, during an authentic crime scene investigation using digital multimedia resources.

For the purposes of this study the definition of a schema is abstracted from Bartlett's (1932) theory of remembering:

> 'Schema' refers to an active organisation of past reactions, or of past experiences, which must always be supposed to be operating in any well-adapted organic response. That is, whenever there is any order or regularity of behavior, a particular response is possible only because it is related to other similar responses which have been serially organized, yet which operate, not simply as individual members coming one after another, but as a unitary mass. Determination by schemata is the most fundamental of all the ways in which we can be influenced by reactions and experiences which occurred sometime in the past. (Bartlett, 1932, p. 201; also cited in Marshall, 1995, p. 12)

According to Bartlett (1932), all of an individual's "experiences are connected by a common interest" (p. 201) that is built upon by past experiences. Even as these new experiences are organized unconsciously, the connection to an individual's past is important. Bartlett noted that there is no reason to consider each new experience as isolated and emphasized the notion of belongingness to the individual. Therefore, appropriating new experiences is an "active organization of past reactions" and requires appropriation, whether consciously or unconsciously, because information isolated from the individual is easily forgotten, such as when science is taught as isolated facts. This reductionist approach to science that isolates it from the individual can be equated to the use of algorithms in math, which Marshall (1995) noted do not carry over from one situation to another.

Marshall's Knowledge Types as Schema Components

Marshall's (1995) knowledge types were derived from exploring the problem solving and strategies used by students in mathematics. Marshall found that individuals solving math problems displayed four types of knowledge: Identification Knowledge (IDK), Elaboration Knowledge (ELK), Planning Knowledge (PLK), and Execution Knowledge (EXK).

IDK usually occurs briefly and is consistent with a search for a schema or schema activation or recognition, which can take on various forms. ELK is the individual's attempt to fit the details of the current experience or situation into a schema template. PLK is more indicative of the development of a working schema and "refers to the way in which the schema can be used to make plans, create expectations, and set up goals and subgoals" (p. 41). Finally, EXK is "knowledge that allows the individual to carry out the steps of the plans. It consists of techniques that lead to action, such as performing a skill or following an algorithm" (p. 41).

Schema Theory as an Analytic and Explanatory Framework

The schema theory framework allows researchers to ask questions about what develops and why. Moreover, one can ask to what extent the nature of the task was congruent with the nature of students' knowledge. To what extent were the expectations of task outcomes reasonable? For example, in Kuhn and Udell's (2003) study of thirty-four 13- and 14-year-old students (14 Hispanics, 19 African-American, and one Ethiopian) from an inner city, the author noted that the goal was to develop argument skills or argument schema using a topic toward which students were not oriented. Using schema theory as a guide supports Kuhn and Udell's (2003) suggestion that the topic was of no interest to the students, and therefore, the development of argument skills could not be attributed to interest.

While the intervention was scaffolded to make sure that students attended to the other side's opposing arguments, assessment of the development of argument skills was noted by increased generation of counterarguments and rebuttals and by whether or not the argument was functional or nonjustificatory, for example. Using schema theory to explain this study, one can conclude that the changes in knowledge base and argument quality observed in the study are not surprising. If students attend to information through the use of a newspaper for stories or statistics, as this study utilized, or if they practiced writing counterarguments, then increased pattern recognition or recognition of the situation (IDK) accompanied by increased elaborations (ELK) should occur.

However, using schema theory leaves open the question of to what extent an argument schema has developed. Schema is indicative of planning knowledge and the ability to set up goals and subgoals and to execute those plans (EXK; Marshall, 1995). Boykin (2000) said that development connotes

> multiple processes of student change. It refers to cultivating, fostering, and bringing talent to fruition. It refers to sustaining talent, keeping it from fading out . . . and enhancing talent, taking it to ever higher levels. It means promoting talent, which necessitates providing many opportunities for its expression. (p. 8)

Therefore, schema development would be akin to talent development that is sustained and becomes a working schema that students could retrieve and apply to other situations, assuming that an argument schema was not preexistent. In Kuhn and Udell's study (2003) the development of argument skills was scaffolded to train students to realize the importance of attending to the opponents' claims. This study did not report whether students would have attended to counterarguments if given a topic of interest, or if they might attend to counterarguments without a prompt if given a similar task later on.

Schema theory also allows the researcher to attend to prior learning, or schema, and to the congruence between task and prior experiences. In Xie and So's (2012) pilot study the preservice teachers were familiar with argumentation in other areas such as philosophy but were not familiar with the idea of argumentation in science. Argumentation in the field of science education is new to both students and educators, yet, students may have engaged in an argument or debate around a topic or issue.

The extent to which engagement in argumentation leads to a developed argument schema is still an open question. Sakamoto and Love (2004) noted that "social schemas are proposed to function as filtering devices for inconsistent information that lead to inconsistent information being ignored and discounted during the encoding process" (p. 535). This phenomenon could also explain achievement and the degree of success in terms of facilitating and encouraging retrieval while minimizing filtering.

Offredy and Meerabeau (2005) used schema theory and think-aloud protocols to explain the correct and incorrect responses of nurse practitioners and general practitioners in diagnosing scenarios of patients' conditions. Likewise (Quinlan, 2012) used schema theory to explore the knowledge progressions of high school students' learning of issues relevant to biology, technology, and Western society. Complex approaches such as argumentation and other issues in learning that perplex our society may require complex methods and not ones easily understood. Possibly, by combining complex methods that have social and cultural implications, research could provide new perspectives.

Schema theory takes many intersecting factors into consideration. It allows researchers to question the extent to which a task is a schema-based instruction that facilitates the development of certain schemas. Schema-based instruction results in the "creation and expansion of students' schemas for the domain in which instruction occurs" (Marshall, 1995, p. 119).

According to Boykin and Noguera (2011) schema-based instruction can lead to increased information processing and student performance, such as "discerning regularities, patterns, and typologies" in problem-solving (Boykin & Noguera, 2011, p. 118). Schema theory addresses the learner and the impact of the social and cultural structure of learning and the effectiveness of the instructional technology curriculum, as well as the extent to which technology use facilitates talent.

In this study students were given access to technology as needed to build on their pre-existing schemas. Students were expected to use their pre-existing schemas and pre-existing cognitive resources to determine when and if specific digital technology and supporting information were needed to reason with the evidence. This access to digital multimedia technology data meant that students could engage in higher order thinking even if they did not have the pre-existing understandings of Earth science concepts and Earth systems. This study explored students' cognitive resources using the schema theory framework and sought to understand how these cognitive resources can be used to inform the integration of instructional technology with three-dimensional science learning.

Research Questions

The research questions that guided this research were as follows:

1. What can be learned about students' cognitive resources if Marshall's (1995) knowledge types are used as an exploratory and explanatory framework for analysis?
2. How can students' cognitive resources be used to inform the integration of technology and three-dimensional science learning promoted in the NGSS?

Methodology

Participants

Participants were five African American female preservice graduate students in a master's degree program in elementary education at an institution identified in the category of historically black college and university. Students were enrolled in a required science and mathematics methods course that was team taught. The researcher (author) was the science methods instructor for the first 8 weeks, or first half of the semester. The class met once weekly for 4 hours. The students agreed to participate and be audiotaped and they signed consent forms.

Timeline

During the first 6 weeks, the students were introduced to argumentation using segments from the Ideas, Evidence, and Argument in Science (IDEAS) Project (Osborne et al., 2004) for the first 2 hours of each class. Exposure to the IDEAS project is believed to be beneficial in teacher training because it looks at the epistemology of argumentation (Simon & Maloney, 2006). Video clips from the IDEAS project were used to train the students in argumentation. These training resources were made available to me by Dr. Jonathan Osborne, first author of the IDEAS project. Afterwards, I implemented the Crime Scene Investigation Toolkit (CSIT) in Earth Science, created by NYSCI for 2 remaining weeks. Table 1 summarizes the digital multimedia resources made available incrementally to students during Week 1 as students engaged in dialogues. In Week 2 students presented their findings.

Table 1
Digital Multimedia Resources Used. Curriculum Source: "CSIT: Circa Unknown, a High School Earth Science Exploration." NYSCI

Resources
PowerPoint Slide 1
• Digital first email to CSIT Team from Detective Barbrady • 2 digital unknown maps • Introduction to digital portfolio sources
PowerPoint Slide 2
• The two maps in question • Digital colored and black and white maps from 1848 • Digital colored and black and white maps from 1966 • Youtube video clip on making a topographic profile. • Digital article of event that occurred in 1895 titled: "Spring storms bring about landslide."
PowerPoint Slide 3
• Digital (repeated resources from last PowerPoint Slide 1) • Digital copy of newspaper clipping by reporter: "Flood devastates town, Wednesday, July 17, 1901" • Google Earth link to Download and Explore https://www.google.com/earth/explore/products/desktop.html
PowerPoint Slide 4
• Radio broadcast of the 1921 forest fire. This audio recording was played for the students. • "Radio News Broadcast transcript, Friday, April 8th 1921" • Final email to the CSIT team from Detective Barbrady • Newspaper article titled: "Flood devastates town, Wednesday July 17, 1901 by Charles Rock" • Final presentation rubric. • Repeated digital resources on maps and Earth Science

Data Collection

Students' dialogues were recorded for 4 hours during the first week of CSIT using a Livescribe Echo Smartpen. These verbal reports are advantageous in accessing students' prior knowledge, in displaying the sequence in which students retrieved information from long-term and short-term memory, and in showing the conscious and cognitive processes that students use to recall and retrieve information (Ericsson & Simon, 1993). They are also indicative of students' sense-making and information they attended to from the tasks.

Students were asked to talk out what they were thinking as they did the tasks and to verbalize as much as they could. Initially, students seemed aware that they were being recorded, then they appeared to have forgotten as indicated by their comments: One student reminded the group they were being recorded. The students then spent time outside of class preparing for their presentation the following week. This portion of students' sense-making was not captured. However, students mentioned getting together for hours to talk over information and indicated that they enjoyed the process. Artifacts from the second week's presentation were collected from students.

Data Analysis

Students' dialogues were transcribed and analyzed, and their narratives are reported in the findings. Analysis began with coding for emergent themes and patterns. This initial analysis showed that a hypothesis and theoretically defined codes would shed light on students' cognitive resources. Thus, analysis was guided by the assumption that Marshall's (1995) knowledge types used to code the data could reveal more about what resources students used in discussion.

Codes were generated using the research literature on Marshall's (1995) knowledge types. Care was taken to make sure that each code was specifically defined to minimize overlap between codes and to highlight the distinguishing features of each code. For example, what distinguished IDK (patterns students recognized) from ELK is that the elaborations were derived from specific details, examples, and abstractions from individual experiences and were consistent with students' generated hypotheses or their evaluation of hypotheses. The research literature was also used to distinguish PLK from EXK. The questions that guided analysis are shown in Table 2. Conceptually ordered tables (Miles & Huberman, 1994) were created for further analysis.

Addressing Validity and Reliability

I limited interruptions of students' dialogues mainly to introduce segments of the CSIT. The constant comparison method of analysis (Corbin & Strauss, 2008) was used continuously to guide this research. Rich supporting narratives are provided as exemplars. A task analysis was performed using the same guiding questions for triangulation and to check for internal consistency between task goals and task outcomes. Student artifacts during Week 2 were also analyzed to better distinguish planning knowledge from execution knowledge. Since these artifacts constituted students' final presentation, they were analyzed for patterns in EXK.

Table 2
Guiding Questions From Marshall's (1995) Schema Depiction and Knowledge Types

Identification Knowledge (IDK)	Elaboration Knowledge (ELK)	Planning Knowledge (PLK)	Execution Knowledge (EXK)
What type of IDK do students exhibit? What patterns do students recognize? What schemas are activated? What is the evidence that this particular schema is activated? What did students have to identify in the task? What is the situation, event, or experience? What are the main features of the situation or event?	What declarations were made? What specific examples of individual's experiences were made? What general abstractions were described from these experiences? What verbal and visual information is retained? (What is the evidence of retention?) What details from current experiences were fit into a template about the situation? What template was created about the situation? What hypotheses were formed through application of IDK? How do students evaluate hypothesis to determine if sufficient evidence exists to warrant recognition? What new verbal and visual details were students expected to learn? How do students acquire both aspects of ELK? What situations were drawn on/heeded to be elaborated?	How can a schema be used to make plans and create expectations? How can the schema be used to set up goals and subgoals? What knowledge is acquired from experiences in using each schema? What necessary knowledge did students develop to help them examine and understand the problem? To what extent did students gain a perspective i.e. broad perspective of making plans that took them from the beginning to the end? What is the evidence that students have PLK and not just IDK and PLK?	What knowledge is required for students to carry out the final steps of the plan? What techniques led to actions such as performing the final skills required of the end goal /end task? To what extent did students understand when and why to carry out various plans?

Findings

Schema theory is used to explain the findings. The language indicative of abstractions from schema theory are shown in italics in the following sections. The language is derived from descriptors provided in Marshall's (1995) book, *Schemas in Problem Solving*. The findings are organized according to the knowledge types.

Identification Knowledge Themes

Task analysis. The findings show that the introduction to the task was designed to elicit students' identification knowledge. Students were first asked to distinguish between facts and inferences and between inferences and assumptions and then to identify the facts in the case. The discussion began with students providing their own definitions; for example, Faith said, "A fact is supported by evidence, and an assumption is to assume something without having substantial evidence or knowledge about it." However, the conversation continued with students using *analogical reasoning* to *abstract* from *personal experiences*.

Students' identification knowledge was characterized by their tendencies to make *associations,* to *classify* and *distinguish*,to *discover,* and to *identify* and *recognize*. When distinguishing between *inference* and *assumption,* words such as *facts* became associated with "information" and seemed to take on new and more tentative meaning:

> I think that assumptions can also be based on facts. For example if you know someone's character you can say they're going to do something even if they don't actually do what you assume they would do. I think it can be based on facts, as well, So, so, I'm thinking assumption is more your opinion from what you gather from facts and facts are just what happen . . . (Joy)

This response calls into question what it means to "know" someone or something. This identification with knowing carried over to their distinction between inference and assumption.

The conversation continued with students' recognition that their use of the word *assumption* depended on their view and everyday use of it.

There was a great deal of *connectivity* in the conversations. Faith said, "Inference you form from information and an assumption, like Joy was saying, you could be going off information you already know," to which Joy added, "I like filling in the gaps, right, because did it happen or you don't know for sure it happened, but you inferred well based on . . ."

This train of thought then led them explicitly to identify assumption as something negative and to indicate that they can be based on a pattern, which led to an available *analogy*: "Because I know that person X is a constant liar if he tells me something, I'm going to assume he's lying to me" (speaker unidentified).

Students then turned their *attention* to the facts in the email provided in the NYSCI curriculum, as required by the task. Their identification of the events that took place was characterized by *connectivity*, *identification, and discovery*.

> Althea: So, we have, um, broken display cases and an overturned book shelf—
>
> Rhonda: Plus the damage.
>
> Althea: Damage to series of maps.
>
> Dani: Damage to—sorry?
>
> Althea: Damage to a series of maps, and this is one map in particular, had a large piece torn map, which include the date and other hard to find information.

Amidst the *repetitions* in conversation, they seemed to question the legitimacy of the facts and the source of the facts during their identification, as indicated in their repetitious attempts to assert what the facts were and why it was a fact as they moved from situation to situation:

> Joy: Facts, those are facts.
>
> Dani: Well some. It's a fact that he reported. Well, I'm assuming since it's in the email and it's from detective Barbrady that this is legit. So, he filed a report 2 days ago.

When it came to identifying the scientific facts, their attention was drawn to the technology resources they were provided.

Role of digital resources. The task required pattern recognition between the Earth systems and the case. Students *recalled* the information they viewed in the video clip on topographic maps and even *revisited* the various multimedia at will. They *abstracted* from the video clips and other technology content resources to connect ideas about Earth systems with the maps: "Alright what are some forces that change landforms . . . chemical and mechanical" (Faith). They also identified what the highest point on the map was, the bodies of water, and additional features:

> Faith: I would say that the highest point on the map which looks like, this one — I would say that whatever is the highest is the mountain.
>
> Joy: But there is the — do you see how this one has two bodies of water side by side? How that happens over time —
>
> Dani: Oxbow, oxbow —
>
> Althea: Yeah, oxbow, it turned into sloping water.
>
> Joy: You're right. It's a meander.

As they identified features and facts, they prompted each other for identification knowledge through questions that elicited *distinctions* and *discovery*: "Do you guys see any difference between 1848 and 1966?" (Joy); "Why is it changed? . . . .I would question though why this is. If this is the same map in 1966, why?" (Rhonda). Students also *recognized* and *identified* chemical and physical processes.

Elaboration Knowledge Themes

Task analysis. The tasks required students to make comparisons between the maps, the information in the video clips on weathering and erosion, and the investigation into changes in the slope over time. The various multimedia files provided students with news articles, equation, guidelines, and maps so that they could attend to the details. Students' ELK indicated that they abstracted information in an attempt to address the details. In this process they generated claims, hypotheses, or predictions and continued to make inferences. They also used their prior experiences in analogical reasoning and attended to the meanings in their language engagement. Their ELK reflected their use of the multimedia resources and each other's cognitive resources.

Students' ELK was best indicated by their (a) actual or inferred hypotheses (or predictions) based on personal experiences and on information from the task; (b) prior knowledge and personal experiences; and (c) use of language. In addition, their retained visual and verbal information were integrated into and reported with these three indicators. Their use of multimedia resources was also integrated into all of the findings even though a separate section is provided for emphasis.

The students generated claims as they attempted to fit the details into their pattern recognition: "You need cold hard facts to convict someone," said Danielle, to which Joy responded, "Or you can use those inferences, but you have to make sure that they are proven by facts." Faith demonstrated awareness about the patterns they were using as they continued to fit the details into a template that distinguished facts, assumptions, and inferences:

> So wait, it wouldn't be an assumption because the fact of the matter is that Mr. Filch said that his intern had been telling him to put those files online, and now all of a sudden. So we have an inference because we made a statement based on a fact.

Shortly afterwards, Danielle responded, "So we're inferring that [the intern] did it just cause he told him to back it up?" The discussion shows that students were aware of the structure provided, defining the terms fact, inference, and assumption:

> Dani: So we're inferring that he did it just 'cause he told him to back it up?
>
> Joy: If there's no other people coming in and out.
>
> Rhonda: But we don't know who came in. We don't know because he said he's normally.
>
> Dani: You' all about to put the brother out. He's not going to have no job [laughs].

If hypotheses are identified by the "If . . .. then . . ." statements, then one could infer that students were hypothesizing the following: If a possible solution to the event is forecasted and that event suddenly happens, then the party that forecasted it might be guilty. Another inferred hypothesis could be the following: If no other people were coming in and out, then the intern must be the one.

While some of the hypotheses can be inferred from their conversations, others were explicit. The hypotheses generated on the Earth science content were more explicit, even though some could be inferred: “If the contour lines are close together, it’s steep, and if they’re further apart, it means that they are flat,” and “It was for the contour interval, so if the number is not on the topographic map itself, you just do basic addition or subtraction” (Faith). Later, the students reiterated the information by repeating their conclusions when Joy stated, “When the lines are close together, that is steep.” They generated hypotheses and made predictions from information they retained from watching the video clips.

Use of digital technology. The videos were instrumental in helping students to obtain general Earth science understandings as they worked to fit details into their template, as illustrated in the following dialogue:

> Faith: Actually hold on, in 1848, there were more plains. The more plains you have, is that as a result of um? What did they say in the video, irrigate? Was it irrigation? You mentioned it in your, um, prose about how farmers relied on, um—
>
> Joy: Less farming.
>
> Faith: There is less farming and less water, so I think maybe we could focus on erosion.
>
> Dani: But how you guys know this though?
>
> Joy: From the videos.

Here, their hypothesis can be inferred from the dialogue: Less plains meant less farming and less water, and therefore, the focus had to be on erosion as the main agent of change. Again, they also demonstrated awareness of their source of support – namely the videos.

Prior knowledge and experiences. Students also abstracted from personal experiences and prior knowledge as they attended to the details. They remembered and related experiences watching television shows such as *Magic Schoolbus*, *Zoom*, and *Cyberchase*, even as they demonstrated awareness of their feelings about knowing, which they attributed to watching these television series: “This is why our room is smart,” Joy said.

They tapped into prior experiences, which they used to create analogies: “I saw that . . . . where they live or the actual school setting, like how its changed over, how things growing was impacted” (Joy). The conversation then segued into gentrification.

> Althea: Changes in DC.
>
> Faith: That’s gentrification.
>
> Rhonda: Now, you’ll say that [Laughs].
>
> Faith: Gentrification [Laughs].

Here students are seen making *connections* between the abstract concepts in Earth science and a more concrete example from their daily lives. Their repetitious return to their technology resources seemed to assist them in heuristic discussions where they themselves were each other's resource: "How do you know it's steeper though?" (speaker unknown, either Althea or Rhonda) They prodded each other with questions as they continued to construct their own knowledge and schema for the situation.

Role of language. During their knowledge construction, their individual characterization became important. They attended to each other's descriptors of the river and river flow in their explanations as the meaning of words and defining words became important. It seems that each of them attributed different meanings to the same words or situations.

> Faith: Okay, so this river is becoming steep because of the landslide —
>
> Dani: To me, I would say that the 1848 river was stronger, and it kind of, I guess, maybe had uh —
>
> Joy: Subsided.
>
> Dani: Yes, slowed on down.
>
> Faith: I won't say more stronger. I would say more steep. Oh wait.
>
> Dani: But it won't move like its location. Oh, oh, you mean like maybe from a starting point?
>
> Rhonda: Wait, wait, what are we saying? What did you say?
>
> Dani: Um, Faith said that the river would have been more steep. It won't have.
>
> Faith: Actually, I am a little confused. Sorry you guys.
>
> Faith: Oh, wait, the wider the river is, the less steep it is, so it's more steep in 1848, so in 1966 because of the landslide it was less steep.
>
> Dani: Do we apply steep slopes to the rivers?

This dialogue revisited a previous debate that seemed to hinge on whether or not they were describing the physical characteristics of the river versus the water flow. The same words whether "stronger" or "steep" were used by the same person. Each individual seemed clear about her own usage until the issue came up again as they worked together and tried to make sure they were in agreement and were discussing the same variables and concepts. The idea was revisited, sometimes with further abstractions and more details or additional questions, depending on the persistence of individuals, for resolution.

Planning Knowledge Themes

Task analysis. Task analysis showed that most of the CSIT required planning knowledge. Students were expected to combine various situations, use different types of information, predict how changes in Earth systems (information about which was made available in the technology resources) were reflected in changes in the maps. They also created a digital portfolio (which was not emphasized in this study). To determine the connection between the equation and the map, students needed to devise a plan. Their PLK required them to create claims, use different ways to find supporting evidence, then choose what information would be important in an argument presentation.

Students' PLK was indicated by their questions, metalevel thinking, and gain in perspectives. Students used questions to set up goals, generate plans or intentions, for clarifications, affirmation, to question the questions, as prompts, or to generate hypotheses or conclusions. They displayed awareness of each other, for the type of knowledge framework they were generating and for their own feelings about the tasks as they evaluated the information.

Though there were many indications of students' gain in perspectives, the gains were difficult to determine, especially when students revisited ideas later on. The evidence provided on student gains in perspectives was limited to students' explicit "aha" moments, that is, when students came to a new understanding or realization. The impact of the technology resources is infused into the narratives that follow.

Questions. Questions were pervasive throughout students' dialogue. When students began to plan, they asked, "So what is the first thing that we need to figure out?" or "How do you guys want to split up responsibilities?" Further along in the tasks, Joy asked, "What have we learned ladies?" They used questions to help them get started: "What's our plan, like, how are we going to do this? (Faith); "What's our mission?" (Danielle); and "Our goal is to help him put the records back together. Is that not right?" (Althea). They asked questions about the guiding questions or appropriated the questions into their own dialogues.

Metalevel thinking. Students seemed continuously aware of the task's impact and often expressed their feelings about performing the tasks or their own feelings about knowing, as seen in Danielle's recurring comments: "Observation is using your own eyes. Oh boy, this is too deep," or "This seems more complicated," or "I have no idea," or "Is that what you're talking about?" Faith added, "I think we're doing well." She reflected on her own learning: "I think I just learned my content. I think I learned a lot more so in this class by watching videos than just reading the text alone" (Faith).

While the first comment about observation was prompted by my question to distinguish between observation and inference, the remainder were not. The remaining comments came up in the middle of participants' conversations as they were making sense of the information. Later on, she stated, "I feel like I've been able to contribute more to the conversation after watching videos and just reading." Others joined in:

> Dani: Yeah. I feel like videos reinforce.
>
> Joy: Yeah, every time we had an assignment to do where we had to argue, we weren't just like reading, and now that we're arguing based on this.
>
> Instructor: You remember them more.
>
> Faith: Yeah.
>
> Dani: I like both. I like being able to see the textbook and, like, we talk too.
>
> Someone: Talk through it.

> Faith: Our conversations have not been choppy.
>
> Joy: But now we're all experts [laughs].

They were aware of the impact of their technology resources and of the task demands to choose what to attend to and then put them into words:

> Dani: I think you're right though. I think that several things could be taking place, because, um, I was trying to figure out I guess how to put it in words, um, but like you were saying, we definitely see that this oxbow was formed. Wow, meander first and then that turns into an oxbow —
>
> Faith: Oxbow, yeah.
>
> Dani: And then that turns into this swamp that's now. So we can tell that that series has happened as well.

This dialogue led to the introduction and identification of a new feature for discussion, which temporarily suspended sense-making as they drew conclusions. Other feelings were expressed, such as, "I really love this lesson," or feelings of confusion.

Gain in perspectives – aha moments. In one instance a confusion was followed by continued observation then to an aha moment that led to a prediction or hypothesis. Determining gain in perspectives was challenging because students repetitiously revisited ideas for clarity. Thus, only explicit aha moments are reported here:

> Faith: Aha.
>
> Instructor: So you have it?
>
> Faith: I have an aha moment.
>
> Instructor: You have an aha moment.
>
> Rhonda: It's supposed to be 12 slides?
>
> Joy: Nobody broke into any of the—
>
> Dani: It was the river.
>
> Joy: It was the shift in the ground.
>
> Faith: How do we, um, account for the vandalism?
>
> Joy: The ground moved and thus all the [unclear word] in the place moved.
>
> Althea: Earthquake.

There were examples to suggest that the students were seeking their own aha moments through their use of questions. For example, one student wanted to know how another knew what she knew. Thus, the process of knowing was important to her even as her task was writing:

> Dani: Okay, someone said flooding, sorry, [writing]. Did you say more than that? I know you explained it, but we're just putting flooding.
>
> Faith: No, no. I was saying that maybe we can imply that there was more than one kind of force that happened.
>
> Dani: So we're saying flooding, erosion. Okay. Flooding would come from three, so then erosion [writing], so then —
>
> Faith: Actually hold on. In 1848, there were more plains. Plains. The more plains you have is that as a result of, um — What did they say in the video, irrigate. Was it irrigation? You mentioned it in your, um, prose about how farmers relied on, um—
>
> Joy: Oh yeah flooding —
>
> Faith: To water their —
>
> Joy: To water their ground, their fields.
>
> Faith: Okay. If there were less plains in 1966 —
>
> Joy: Less farming.
>
> Faith: There is less farming and less water, so I think maybe we could focus on erosion.
>
> Dani: But how you guys know this though?
>
> Joy: From the videos.
>
> Dani: But I'm saying, like, how do you know there is plains here?
>
> Faith: The points are further apart.
>
> Joy: Yeah, when the lines are further apart —
>
> Joy: We're assuming that they were plains.
>
> Dani: Okay.
>
> Joy: We don't know for sure, but we know not hills.
>
> Dani: Right. Oh, I see what you mean. So, that could be farmland, you're saying? Or some type of ah —
>
> Faith: Yes, hold on. [someone chuckles]. Yeah, let's just stick with erosion

While different conclusions can be made from this dialogue, it is important to note again the importance of the technology resources in helping students gain knowledge. Repetitious revisiting of ideas was important in creating and setting up plans.

Execution Knowledge Themes

Task analysis. The execution knowledge tasks required students to create a final report and presentation. They were to evaluate their findings and create claims and defend them using the evidence generated. Unlike the IDK, ELK, and PLK, the EXK was also derived from students' writings and artifacts, and not from their dialogues. Students' dialogues during their presentations were not captured during the second week. Therefore, their artifacts are used to describe their EXK.

Putting it all together. The transcripts focused on students' sense-making dialogues, as students were given additional time on their own to get together to create a report on their findings. However, throughout the dialogues students were performing some execution and making sense of execution. For example, as students made sense of the information, they tried to determine if they should create a timeline or a bar graph. This dialogue was not the first one of this kind:

> Dani: Are you really doing a bar graph or a timeline?
>
> Faith: I think Joy's idea is better, but I was thinking about a bar graph in terms of tracking the slope. Right. So let's say we do find a slope.
>
> Dani: Yes
>
> Faith: How are we going to keep track of this? Like, are we just going to have a slope and just look at it on paper? Like how are we going to graph it?
>
> Joy: But we don't have a starting point. We don't have a, an initial value.

Then later, the following dialogue ensued that showed that final execution was foremost on their minds:

> Faith: You guys, I think we might have to break up some of this information between us instead of looking at all of it at the same time cause, like, I'm starting to put things together but I'm having —
>
> Dani: It's just a lot to put together.
>
> Faith: Yeah, I'm overwhelmed with all the information, and if I could just focus on one piece.
>
> Researcher: And don't forget that you have, you're going to work on this during the week, um, so, because you're presenting it next week. So, you'll have some time to play with this.

They proceeded without much guidance except for the rubric on how to create a report of what they found. The students went back to the drawing board to look at everything they had and the electronic slides they began with, though they did not explicitly state that they were going back to the drawing board. They did this to create their timeline and to make sense of how to put it all together in report form.

Gradient calculations. Students repeatedly revisited the use of the mathematical formulas for calculating the gradient of the slope. At times the conversation was steered toward performing this task, and at times it seemed to be steered away from this task. One or two of the students may have attempted to or did calculate the gradient, but they debated about whether or not it was actually necessary, and this discussion was not as fully developed.

EXK. Students divided their PowerPoint presentation into three sections: “Claim,” “Evidence,” and “Reasoning.” However, while students’ reasoning about their claim and evidence were sound, their artifacts called into question how they defined claim and evidence:

> Claim: The map in question most resembles the map from 1966. The range of the map in question would be from 1933 to 1966. There’s gradual change between the fire and the flood in 1921 to 1966. In the black and white map in question photo shows a swamp that formed as a result of the 1901 flood.
>
> Evidence: Based on careful analysis of the maps, we concluded that there has been no evident change between the 1966 map and the map in question. Therefore, we concluded that the map in question must be dated in the years after the natural disasters, the flood of 1901 and fire of 1921.

The evidence seemed to include information that might best be characterized as their claim, and the claim seemed more indicative of their evidence.

For Reasoning, the participants noted on their electronic slide, “see chart paper,” then presented the various charts, calculations, and timelines that they generated during sense making. The students indicated that they met for a few hours outside of class time. They labeled their reasoning according to the days that corresponded with the evidence provided.

Thus, in the Day 1 chart they presented the facts they generated and indicated which was a fact or an assumption. Here, they included the contour lines and the gradient of a slope equation. Their Day 2 chart showed a comparison between the maps and the difference in contour intervals between the two. They noted changes and changes inferred, such as “flooding, erosion, meander to ox-bow to swamp, the river has expanded due to natural causes over time.”

Day 3 listed a series of events according to the days reported. Day 4 showed an incomplete chart that indicated information and changes inferred, as derived from the forest fire. A fifth chart provided a timeline with all the events. A sixth incomplete chart displayed an argument outline with the labels, Claim, Evidence, and Reasoning but not filled out.

Organization of the rubrics was different from students’ presentation outline, even though the introductory sentence above the rubric stated, “Students who demonstrate understanding will be able to: Present a claim for what range of years the unknown map most likely represents, backed by evidence and reasoning.”

Discussion and Conclusion

Marshall's (1995) knowledge types was used to determine the cognitive resources preservice graduate students brought to the table during a discussion that integrated technology with the three dimensions of science learning. Students used their IDK for pattern recognition and abstracted from prior experiences and specific examples in their ELK. Their PLK is not only indicative of more permanent knowledge structures used to create plans, but also indicated the cognitive resources that students used during the tasks. They used their metalevel thinking, questioning, repetitions, and connectivity to gain new perspectives and other features of schemata and to carry out their EXK.

Connection to Technology and Three-Dimensional Science

When it comes to preservice elementary education majors with little to no science background, it is important to consider how they engage with science and technology. The preservice graduate master's degree students in this study were nonscience majors as undergraduates. Marshall (1995) found that when learning new concepts, students should have the choice to learn from both abstract elements, such as definitions, and from specific examples.

In this study, the preservice students explored the abstract definitions, generated their own examples, and sought examples from the data. Access to additional multimedia technology resources was important in helping students to construct their science ideas. Students repetitiously returned to the simulations and video clips showing different landforms, landform changes, and contour maps to extract specific and abstract information.

Thus, these digital resources were not only important in helping students in their own pattern recognition but also in allowing them to use the scientific information to fill in the blanks. The digital maps presented changes in landforms using contour lines which the students were unfamiliar with. Students used the multimedia technology to determine what kind of landform change was represented, to access the scientific processes and descriptors, and for visualizations. They needed to understand what Earth systems might indicate what contour lines and how the information in the news article could be substantiated.

Marshall (1995) noted that the presence of only one kind of information, whether abstract or specific, often leads to confusion, to students' filling in the missing information, and to less articulation among students. Marshall's finding is interesting considering that one or more of the students in this study expressed awareness of the flow in their conversations, as well as their need to fill in any missing information. In this case, their use of the multimedia technology resources encouraged them to fill in the missing information with the science information they identified. Thus, multimedia resources can be used to present the same information to students in different ways and, thus, facilitate the development of IDK and ELK for concepts students do not know.

Identification Knowledge and Pattern Recognition

Students used pattern recognition to make sense of information, and they used repetition and connectivity for pattern recognition. Once students recognized a pattern, they engaged in repetition to understand these various patterns and to generate their own definitions and meanings. This type of engagement is different from providing students with definitions, as seen in learning hierarchies in science: "An additional problem with the learning hierarchy approach is that it may emphasize the learning of algorithms at the expense of conceptual knowledge" (Marshall, 1995, p. 116). Students needed to conceptually understand what a fact and an assumption was in order to determine what patterns to seek from the scientific and nonscientific evidence.

Their questioning of the source of information was consistent with Lin, Horng, and Anderson's (2014) study, which showed that source credibility is a more important evaluative tool of text when students are engaged in more surface level evaluation. Source credibility becomes less important as an evaluative tool as students engage in deeper levels of evaluation indicative of increased text comprehension. In this study comprehension was aided by discussions and by revisiting available digital information.

Elaboration Knowledge and Connection to Technology

Students' ELK was indicative of general abstractions from experiences that fit into a template and were indicated by their use of hypotheses and inferences. The hypotheses generated from examining science concepts were more explicitly stated and more indicative of observed phenomenon. However, the characterizations of nonscience concepts were mainly derived from inferences generated from their discussion and can be likened to claims made without proof. This finding could mean that it is easier to generate nonscientific claims than it is to generate scientific claims. Scientific claims that involve science concepts might require additional processing and additional proof in order for preservice students to make a connection to the science or feel comfortable about stating a scientific claim.

The use and access to multimedia resources provided students with additional information to build descriptive components or representations. They used these components heuristically as their investigation proceeded. They made references to prior experiences in science, analogies to changes in urban areas or gentrification, or everyday sense making analogies, such as, "If you hit something hard, you're gonna eat away at it." The use of language and vocabulary of choice was also elaborated upon. The impact of combining these varied multimedia resources is indicated by their metalevel awareness.

Planning Knowledge

PLK most indicated students' cognitive resources and how they use these resources to set up plans. According to Marshall (1995) PLK "refers to the way in which the schema could be used to make plans, create expectations, and set up goals and subgoals" (p. 41). Marshall noted that acquiring PLK is difficult, and it is not uncommon for students to have IDK and ELK but no PLK or working schema to carry out specific plans. Furthermore, students' PLK in one area does not mean that this working schema can be used elsewhere.

In this study, preservice students use questions, metalevel thinking, their new gains in perspective, and repetitious revisiting of concepts to set up subgoals and create plans. The importance of metalevel thinking in procedural transfer of argumentation skills is supported by Iordanou's (2010) study that show increased transfer of argumentation skills from the science domain to the social domain rather than vice versa. Iordanou concluded that the development of metalevel awareness might have contributed to the "execution of argument skills at the procedural level across domains of application" (p. 315).

The challenge to develop procedural and execution knowledge in science possibly facilitates the development of increased metalevel awareness. Alternatively, the development of scientific skills might require the use of metalevel cognitive skills to attain procedural knowledge. The importance of metalevel awareness in developing argumentation skills is supported by Kuhn's (2010) finding that students develop more counterarguments as they develop more metalevel thinking. The graduate students' awareness of each other's position is indicated by their use of questions to understand how each other knew and for clarification, explanation, and evidence from each other.

Students' extensive engagement in planning knowledge before knowledge acquisition goes against learning hierarchies. This approach is supported by the Talent Quest Model (TQM) or Talent Development Model, which "seeks to overdetermine success for student[s] through implementing multiple, evidence-based activities and programs" (LaPoint, Ellison, & Boykin, 2006, p. 373). The four features of TQM are overdetermination of success, use of integrity-based ethos, multiple expected outcomes, and coconstruction (LaPoint et al., 2006). In this study, preservice graduate students coconstructed knowledge using multimodal forms of technology and dialogues.

Execution Knowledge

According to Marshall (1995) EXK follows through with students' PLK after learners scan for pertinent information. In this study, the dialogues became the means to an end and, thus, the reasoning that supported students' final claim and evidence. More time was spent in PLK than in EXK. In students' final executions they presented a great deal of information from planning as their reasoning behind their claims. Embedded in their reasoning, however, was the evidence for their claims, even though the information was not labeled as their evidence. What they characterized as evidence read more like their overall conclusion. However, one can assume that correcting misidentification of knowledge is much easier to do than developing and implementing planning knowledge.

EXK should not always be given priority over PLK, as is regularly done in the science classroom. This focus can be equated with a heightened concern for final answers rather than for the process of getting there. Similarly, Marshall (1995) indicated that in solving some mathematical problems teachers usually have less concern about whether students can execute certain skills because they already knew the appropriate algorithms to do so.

Greater concern should be given to whether or not students understand when and why to perform specific operations; that is, to whether or not they acquired the appropriate PLK that would facilitate transfer (Marshall, 1995). Science should focus less on generating final answers and more on the nature of PLK. Various types of digital multimedia technology resources can be used to facilitate a focus on planning and development when students have little to no prior knowledge in science.

Implications for Argumentation

This study requires consideration for distinguishing explanations and arguments. While students' dialogues went back and forth, they seemed to exhibit counterarguments or disagreements as they attempted to understand and determine how best to identify and describe the nature of a phenomenon.

While research has shown that argumentation is eventually characterized by counterarguments and rebuttals with some training, the actual nature of these counterarguments and rebuttals, especially when dealing specifically with the science content, needs to be further explored. In distinguishing facts, inferences, and assumptions, students' disagreements were minor and best characterized as sense making. It is also possible that to disagree one must first get to a place of understanding or one must first go through the process of sense making. This explanation would support the increased rebuttals and increased attention to the opponent's counterarguments that accompanies training.

Conclusion

In this study, multimedia technology resources were instrumental in students' engagement in higher order evaluative thinking. A great deal of time and opportunity was provided for PLK, which is indicative of students' cognitive resources, schema development, and higher order evaluative thinking in science, even without a science content background. Tasks such as labeling and identification, which are lower on the taxonomy of learning objectives, can be integrated alongside sense making to build understanding even as students abstract from repetitions and personal experiences.

Even though the results of this study are consistent with prior research, the outcomes have limited generalizability because of several variables. In addition to the small size of the study sample, the study did not collect data on students' preexisting schema or cognitive resources. Other unexplored factors that may have influenced the outcomes include the institutional environment, the instructor, and the nature of scaffolding provided. Students' cognitive resources along with available digital resources vary from situation to situation. However, the study framework, methods, and guidelines are generalizable and can be used to explore students' cognitive resources and to check for consistency between task goals and outcomes.

Overall, this study showed that tasks that allow students to use their PLK extensively can engage their cognitive resources. It is expected that different studies will display different degrees of PLK. However, schema theory is important in considering the role that different variables play in producing diverse outcomes.

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