An Analysis of Science Teachers’ Perceptions of Graphical Literacy within the Context of the Secondary Science Classroom

Pete Marsh
University of Nebraska at Omaha

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AN ANALYSIS OF SCIENCE TEACHERS’ PERCEPTIONS OF GRAPHICAL LITERACY WITHIN THE CONTEXT OF THE SECONDARY SCIENCE CLASSROOM

by

Pete Marsh

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Supervisory Committee:

C. Elliott Ostler, Ed.D

Jeanne L. Surface, Ed.D

Tamara Williams, Ed.D

Sheryl L. McGlamery, Ph.D
The topic of graphical literacy is considered to be an important aspect of a student’s science education. Skills related to the construction and interpretation of graphs are well documented in science education literature as well as instructional strategies meant to help develop a student’s graphical literacy in science. Absent in the literature is how science teachers address skills related to graphical literacy with their students. The purpose of this study is to provide some insight into how secondary science teachers devote instruction to address graphical literacy with their students in the context of their classroom. Eight secondary science teachers from two school districts in a Midwestern city completed a pre-interview survey and then participated in a semi-structured interview. The quantitative and qualitative instruments used in this study asked participants to respond to survey statements and open-ended interview questions related to their instruction of graphing skills within the context of their classroom. Participants also responded to open-ended questions about how they addressed their students’ deficiencies with graphing and instructional strategies used to address those deficiencies. The results of this study demonstrate that the participants were familiar with specific
graphing skills and various instructional strategies to address graphing skills identified in the literature. The results further demonstrate that the secondary science teachers who participated in this study addressed graphical literacy in ways that helped their students learn content, promoted graphical literacy as a life-skill, and allowed students opportunities to make connections between math and science.
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Chapter 1: Introduction

Introduction to the Problem

Students’ ability to work with graphs and develop their graphical literacy is a skill which extends beyond the typical science classroom and likely to be useful in a students’ future academic work as well as their daily life (Glazer, 2011; Harsh & Schmitt-Harsh, 2016; McDermott, Rosenquist, & van Zee, 1987; Taylor, 2010). Graphical literacy is not a skill that develops spontaneously, but one which requires some form of direct instruction (Arons, 1983; Glazer, 2011; McDermott et al., 1987). An opportunity for direct instruction to occur is available in secondary science courses such as physics, chemistry, and biology.

The science education literature has documented specific confusions, and errors related to graphing that is demonstrated by students when developing and interpreting graphs (Arons, 1983; R. Beichner, 1994; Glazer, 2011; McDermott et al., 1987). For example, these student deficiencies typically arise in secondary physics course during the study of kinematics. The topic of kinematics is concerned with describing the linear motion of an object. Student development and interpretation of graphs which represent linear motion are critical to their understanding of kinematics. Furthermore, kinematics is usually the first major topic introduced in a typical physics course, and it sets the foundation for other topics to come as students continue their study of physics.

In a typical secondary chemistry course, students may be required to develop and interpret graphs representing pressure versus volume, mass versus volume, moles of solute versus volume of solvent, and or pH titration curves (Arons, 1983; Dori & Sasson, 2008). Students in a secondary biology course are typically asked to develop graphs from
data related to some factor that changes over a period of time, such as plant growth, population growth, or the production of carbon dioxide and draw conclusions based on the relationships depicted in the graph. They may even be asked to interpret graphs during a lab activity, an assessment, and quite possibly during a lecture when presented with new information (Harsh & Schmitt-Harsh, 2016; Taylor, 2010).

Much of the research in science education related to the topic of graphing and graphical literacy demonstrates that the deficiencies associated with learning to develop and interpret graphs is a common issue for students at all academic levels and nationalities (Dori & Sasson, 2008; Harsh & Schmitt-Harsh, 2016; McDermott et al., 1987; Phage, Lemmer, & Hitge, 2017). Given the ubiquitous nature of student difficulties with graphing and graphing skills, secondary science teachers need to provide instruction to address graphical literacy in a typical secondary science course. Teachers need to have developed specific knowledge bases and knowledge of specific instructional strategies and representations that relate to student deficiencies associated with graphing and graphical literacy (Glazer, 2011).

**Purpose Statement**

The purpose of this mixed-methods study was to document conversations with secondary science teachers and collect survey data from those same individuals; the goal is to determine how secondary science teachers devote instruction to address graphing literacy with their students in the context of their classroom.

**Purpose of the Study**

There is a significant amount of research in the field of science education related to the importance of graphical literacy and student deficiencies associated with the
construction and interpretation of graphs in science courses (R. Beichner, 1994; Dori & Sasson, 2008; Glazer, 2011; McDermott et al., 1987). Being able to interpret and construct graphs is considered crucial and foundational to a student’s understanding of scientific concepts. Even though most high school students do not pursue a science-related career, graphing literacy is considered a valuable life skill that is applicable in many career fields (Arons, 1983; Glazer, 2011; Harsh & Schmitt-Harsh, 2016; Taylor, 2010). How secondary science teachers address the skills related to graphing as well as the student deficiencies associated with graphing within the context of a secondary science course has the potential to set their students up for academic success in not only science and mathematics but other disciplines as well (Glazer, 2011).

The literature identifies as many as twelve student deficiencies or issues related to graphical literacy in science and mathematics curricula (Arons, 1983; Glazer, 2011; Rosenquist & McDermott, 1987). The academic benefits, skills, and the increase in graphing competency acquired when students work with graphs in combination with the ubiquitous nature of the student deficiencies associated with the learning, understanding, construction, and interpretation of graphs begs the question: how is the topic of graphing literacy bring addressed in the secondary science classroom?

There are several studies and articles in the area science education lauding the benefits of students being able to interpret and develop graphs as well as the instructional strategies science teachers should use to assist their students in the development of their graphing skills of the topic (Harsh & Schmitt-Harsh, 2016; McDermott et al., 1987; Rosenquist & McDermott, 1987; Taylor, 2010). However, there seems to be very little research in the area of science education that explores how secondary science teachers
provide instruction on skills related to graphing with their students, their familiarity with
the student deficiencies associated with graphing, and the instructional strategies science
teachers use to address those deficiencies. How secondary science teachers articulate and
identify specific student deficiencies associated with graphing and graphical literacy in
addition to the instructional strategies they use to help their students overcome those
deficiencies was the focus of this study.

Research Questions

The central research question that guided this study was to how do secondary science
teachers devote instruction to address graphical literacy with their students in the context
of their classroom? The following research sub-questions informed the central question.

1) How did secondary science teachers’ beliefs about science teaching and learning
in combination with their topic-specific professional knowledge inform their
instruction as they addressed their students’ graphical literacy within the context
of their classroom?

2) What were the specific student deficiencies in graphical literacy that secondary
science teachers addressed within the context of their classroom?

3) What were the specific instructional strategies or representations used by
secondary science teachers to address their students’ deficiencies associated with
graphical literacy in the context of their classrooms and the rationale for their use?

Operational Definitions

Topic-Specific Professional Knowledge (TSPK): TSPK is considered static,
canonical, and recognized by experts. It represents a teacher’s knowledge that is specific
to the topic of instruction and the development level of the student. Examples of
knowledge within this construct are, determining effective instructional strategies or representations, organizing content, building overarching ideas, recognition of student difficulties, and knowing how to integrate science and engineering practices associated with the topic (Gess-Newsome, 2015).

Science teaching beliefs: A set of beliefs a teacher has about the goals and purposes for science teaching, the beliefs about the nature of science teaching, and beliefs about science teaching and learning which can act as amplifiers and filters for instruction (Friedrichsen, Driel, & Abell, 2011). For this study, only a science teacher’s beliefs concerning science teaching and learning were considered.

Teacher Beliefs Interview (TBI): A qualitative instrument developed to capture a science teacher’s epistemological beliefs (Luft & Roehrig, 2007).

Teacher Beliefs about Effective Science Teaching (TBEST): The TBEST is a quantitative instrument designed to provide a method to gauge teacher beliefs related to classroom practice and student learning (Smith, Smith, & Banilower, 2014).

Graphical literacy: A set of skills concerned with an individual’s ability to utilize, develop, and interpret graphs that represent quantitative relationships regardless of the subject matter (Arons, 1983; Glazer, 2011; McDermott et al., 1987).

Student deficiencies: For this study, student deficiencies are those associated with the topic of graphical literacy and other skills related to the interpretation and construction of graphs. The literature defines many deficiencies related to graphical literacy in the context of science and mathematics curricula such as graph as a picture, slope/height confusion, variable confusion, non-origin slope errors, area/slope/height confusion, confusing an interval with a point, and conceiving a graph as constructed of
discrete points (R. Beichner, 1994; Glazer, 2011; McDermott et al., 1987). The literature supporting and defining student deficiencies concerning graphical literacy are explored further in Chapter 2.

**Instruction or instructional strategies and or representations:** Representations or instructional strategies consist of illustrations, analogies, explanations, and or demonstrations used by a teacher to make content knowledge related to a specific topic or subject comprehensible to their students (Kind, 2015).

**Conceptual Framework**

The model of teacher professional knowledge and skill, shown in figure 1, helped to define the framework for this mixed-methods study as it examined the extent to which secondary science teachers devote instruction to address graphical literacy with their students within the context of their classrooms. Within this model, the central research question and research sub-questions lean heavily on the model’s representation of a science teacher’s topic-specific professional knowledge (TSPK). The teacher’s beliefs about science teaching and learning as they address graphical literacy with their students. This model of teacher professional knowledge and skill and how it demonstrates the interaction between TSPK and the beliefs of the science teacher served as the conceptual framework for this mixed-methods study and as it attempted to examine graphical literacy in the context of a typical science classroom.
Figure 1.

Model of teacher professional knowledge and skill, including influences on classroom practices and student outcomes. Gess-Newsome, J. (2015).

Topic-specific professional knowledge (TSPK) is, as the name implies, specific to the topic being taught, such as linear motion, the model of the atom, or photosynthesis. TSPK informs a teacher's knowledge of a specific topic within their domain or subject area, such as biology, physics, or chemistry. The blend of subject matter, pedagogy, and context recognized as knowledge held by the teaching profession. TSPK also includes knowledge of instructional strategies, the selection of representations, and an understanding of incoming student difficulties, preconceptions, and or misconceptions concerning a specific topic (Gess-Newsome, 2015).

Science teachers’ TSPK is amplified and filtered by their beliefs about teaching science. A teacher’s instructional choices are constantly being affected by their beliefs
and orientations (Friedrichsen et al., 2011; Gess-Newsome, 2015; Pajares, 1992). What information will they choose to include, omit, reject, or change when teaching a specific topic? This study was not attempting to demonstrate a connection between science teachers’ TSPK and their beliefs about science teaching and learning as they addressed graphical literacy in their classroom. This study examined the perceptions of secondary science teachers as to how they addressed graphical literacy within the context of their classrooms and how their beliefs about science teaching and learning and TSPK informed their instructional decisions regarding the topic of graphical literacy.

Secondary science teachers - and teachers in general - are constantly faced with making instructional decisions when teaching a specific topic. Their TSPK informs their decisions as to which instructional strategy to use for a specific topic, the amount of instructional time to devote to a specific topic, and the depth of instruction for a specific topic. The science teacher’s individual beliefs and attitudes towards a topic’s instruction and its implementation, prior knowledge of the topic, and its relationship within the subject drive the content delivery for that science teacher (Jones, M. G., Carter, 2007). The topic of graphical literacy is no exception.

TSPK and teacher beliefs framework for graphical literacy shown in Figure 2 provided a more concise model to represent this study and was adapted from the model of teacher professional knowledge and skill. Within the realm of TSPK and teacher beliefs framework, are the four elements which guided this study: teacher’s beliefs, TSPK, instructional strategies for developing and interpreting graphs, and student deficiencies with graphing. These elements are connected to graphical literacy in the secondary
classroom through the central research question and the research sub-questions that guided the study.

Figure 2.

*TSPK and Teacher Beliefs framework for graphical literacy. Adapted from the model of teacher professional knowledge and skill, including influences on classroom practices and student outcomes. Gess-Newsome, J. (2015).*

These four elements are represented in the survey instruments and interview questions that were used in this study and guided their development as well. These survey instruments and semi-structured interviews were used to collect the data on how these elements inform instruction of graphical literacy by secondary science teachers within the context of their classroom. Furthermore, these elements guided the analysis of the data and helped to merge the qualitative themes and quantitative data generated by this study.
and, in the process, provided some insight into how graphical literacy was being addressed in the secondary science classroom.

No formal classroom observations were conducted of the science teachers who participated in this study as they conducted lessons to address graphical literacy with their students. This absence of classroom observations serves as a limitation for this study. As a result, the teacher’s classroom practice, student amplifiers, and filters, and student outcomes within the model of teacher professional knowledge and skill, shown in Figure 1, and their possible influence on instruction related to graphical literacy were not explored in this study. TSPK and science teaching beliefs and orientations, as well as the remaining constructs within the model of teacher professional knowledge and skill, are explored further in Chapter 2.

Conclusion

The effective instruction of any topic requires the teacher to understand the content and be able to recognize student deficiencies and preconceptions associated with a particular topic. Additionally, the teacher needs to be able to identify and implement specific instructional strategies that lead to outcomes in which the students learn the content. Graphical literacy within the context of a specific science classroom is no exception. However, what makes this particular topic’s academic merit and social impact standout is graphical literacy’s foundational nature, and the skills necessary to interpret and develop graphs are of value not only in science-related disciplines but non-science related disciplines as well. Being able to interpret and develop graphs is considered by many to be a life skill.
There were a great many aspects to explore within the realm of this study’s central research question, and its examination to the extent secondary science teachers addressed graphical literacy with their students. These might include but may not be limited to a science teacher’s topic-specific professional knowledge, knowledge of students’ graphing deficiencies associated with graphs and graphing, choice of instructional strategies for addressing those student deficiencies, and the importance of graphical literacy in the learning of science and graphical literacy as a life skill. These various constructs and concepts represent an interconnected and complex tapestry of ideas within the field of science education. This complex tapestry of ideas which helped to define this study’s academic merit and social impact.
Chapter 2: Review of the Literature

The central question which guided this mixed-methods study is what extent do secondary science teachers devote instruction to address graphical literacy with their students within the context of their classroom. This study addressed this central question by examining how a science teacher’s beliefs about teaching and learning science and their topic-specific professional knowledge (TSPK) informed their instructional decisions related to addressing graphical literacy with their students. Additionally, the study examined how secondary science teachers identified and addressed common student deficiencies associated with graphing. As well as the specific instructional strategies they used to help their students overcome their deficiencies with graphing within the context of their classroom. Secondary science teachers’ TSPK and their beliefs about science teaching and learning, their knowledge of students’ deficiencies with graphing and instructional strategies addressing student deficiencies with graphing, outline the major categories for this literature review.

Contemporary Findings and Justifications

Graphical Literacy

Students’ graphical literacy and their ability to interpret and develop graphs representing a variety of relationships are considered by some to be one of the most important skills to be taught in science-related courses. Also important is a student’s ability to apply graphical analysis regardless of the subject or topic (Arons, 1983; Glazer, 2011; McDermott et al., 1987). The literature identifies nine major deficiencies students have regarding graphical literacy within the context of graph interpretation and
development and with graphs in general (R. Beichner, 1994; Glazer, 2011; McDermott et al., 1987).

1. **Graphs as Picture Errors**: The graph is considered by the student to be a picture of the event or situation and is not seen as a mathematical representation but as a concrete duplication of the object’s motion.

2. **Slope/Height Confusion**: Students read axes values and assign them to the slope.

3. **Variable Confusion**: Students are unable to relate one type of graph to another. For example, students not being able to distinguish between variables of distance, velocity, and acceleration when working with kinematic graphs. The students believe that graphs of these variables should be identical to one another without the realization that the graphed line should change as well.

4. **Non-origin Slope Errors**: Students can determine the slope of a graph successfully but will often have trouble determining the slope of a line or tangent line if it does not go through the origin.

5. **Area Ignorance**: Students are not able to interpret areas under the curve for graphs.

6. **Area/Slope/Height Confusion**: Students will often perform slope calculations or use inappropriate axis values when area calculations are required.

7. **Confusing an Interval with a Point**: Occurs when students focus on a particular point rather than an interval.
8. Conceiving a graph as constructed of discrete points: Students interpret graph as a series of data points rather than a continuous graph.

9. Student difficulties with graph construction that result from students’ choice of graph format or visual features such as color, size, aspect ratio, scale, and legend/labels.

Furthermore, teachers themselves can be a primary cause for student deficiencies with graphing and lack of student improvement with graphical literacy simply because the teachers are unable to identify student deficiencies with graphs and graphing, or they are simply unaware of their student's difficulty with the topic (Glazer, 2011). A study involving pre-service science teachers found that they not only had serious difficulties in determining if a graph should be used to represent data but also how to work with the data to address a specific question regarding the data. A significant number of the pre-service science teachers in the study exhibited a common misconception that all data points used to generate a graph needed to align to claim that a relationship might exist between variables (Bowen & Roth, 2005).

Teachers often assume that their students possess the requisite math skills and knowledge required to develop and interpret graphs. Many times students are then expected to be able to transfer their prior knowledge of math and math skills to the study of physics, biology, and chemistry by themselves (Meredith & Marrongelle, 2008). Students must be familiar with the mathematical and physical concepts related to graphing and how to combine them while keeping in mind the context. They need to be guided and given direction as they work towards improving their comprehension of
graphs and graphical literacy (Phage et al., 2017). Students need examples of graphs that represent different relationships but are mathematically identical (Arons, 1983).

A primary goal of this study was the collection of data related to the participants’ instructional decisions within the context of their classrooms to address graphing deficiencies exhibited by their students. This study also examined the instructional strategies chosen by the participants to address these graphing deficiencies and the rationale for their specific use.

**Instructional Strategies for the Teaching of Graphs**

The general purpose of any instructional strategy is for the teacher to develop illustrations, analogies, explanations, and demonstrations in anticipation of student difficulties or preconceptions surrounding a particular topic (Kind, 2015). A compelling aspect of this study is the instructional strategies secondary science teachers utilize as they address their students’ graphical literacy and graphing skills. The rationale provided for a specific instructional strategy or strategies used by the teacher to address graphing and improve graphical literacy among their students is important as well (Rosenquist & McDermott, 1987; Taylor, 2010)

A search of the literature yielded many articles and research studies related to the various instructional strategies that teachers could use to help students learn to develop and interpret graphs and improve their overall graphing skills. These studies and articles typically offered evidence as to why a particular instructional strategy was beneficial and should be used in the science classroom to teach graphs.

Many studies advocated students using real-time data to generate graphs for examination and interpretation (Dori & Sasson, 2008; Harsh & Schmitt-Harsh, 2016;
Lapp & Cyrus, 2000; Oakes, 1997; Riley & Biernat, 2018). Some of the studies focused on strategies specific to graphs representing linear motion. One example are graphs of linear motion generated from real-time data through the use of video analysis (R.J. Beichner, 1996; Robert J Beichner & Abbott, 1999; Brungardt & Zollman, 1995; Eshach, 2010; Rosenquist & McDermott, 1987) and ultrasonic motion sensors (Testa, Monroy, & Sassi, 2002) or GPS (Wood & Romero, 2010). A few studies examined the collection of real-time data using motion detectors mounted on robot cars (Brockington, Schivani, Barscevicius, Raquel, & Pietrocola, 2018; Mitnik, Recabarren, Nussbaum, & Soto, 2009). Another study explored the use of the video game Angry Birds, in which students would collect real-time data through the use of video analysis (Rodrigues & Simeão Carvalho, 2013). The common theme examined in each of these studies was the necessity for the data to be collected in real-time or as a part of a lab activity.

Some studies examined the use of software programs that generated specific kinematic graphs, graphs of linear motion, that were examined and interpreted by students individually or collaboratively. Students would also use a software program to generate graphs to complete homework assignments or would share their designed graphs with other students (Araujo, Veit, & Moreira, 2008; Cataloglu, 2007; Laverty & Kortemeyer, 2012; Simpson, Hoyles, & Noss, 2006). There were a few unique studies and articles which examined other various strategies. One is a particularly math-intensive strategy in which the author made a case for the importance of connecting algebraic functions using a vertical line test (Sokolowski, 2017). Another examined the use of a flipped classroom or blended learning approach through the use of e-learning and online multimedia as an instructional strategy for improving graphing skills (Watson &
Brathwaite, 2013). As well as the specific use of graphs to help explain concepts during biology lecture presentations (Taylor, 2010).

This study is not trying to determine what instructional strategies are considered most effective; rather, this study is trying to present what instructional strategies secondary science teachers use to address their students’ deficiencies with graphing and the rationale for their use. Therefore, familiarity with various graphing deficiencies held by students and instructional strategies related to the teaching of graphs is an important aspect of this literature review. The review of the literature related to instructional strategies for teaching graphs and the improvement of student graphical literacy, in general, was beneficial in the development of interview and survey questions and in preparation for the interviews conducted by the researcher to collect data relevant to the central research question and sub-questions.

**Professional Teacher Knowledge and Skill**

Within recent years there has been a restructuring of the pedagogical content knowledge (PCK) construct (Shulman, 1986, 1987) within science education (Carlson, Stokes, Helms, Gess-Newsome, & Gardner, 2015). The paradigm of PCK was put forth as a way to describe the profession of a teacher. Shulman suggested that the act of teaching required more than being a pedagogical expert, training in the knowledge of general instructional strategies and classroom management, or simply being a content expert in a specific subject area (Shulman, 1986, 1987). Shulman considered the profession of teaching to be a blend of content, knowledge of students, and pedagogical knowledge. He considered this blend of knowledge bases as the essential factor distinguished which teachers from other professions.
An implication that developed as a result of Shulman’s PCK model is that teachers must be able to choose or implement instructional strategies to make specific content knowledge and topics accessible to their students. As a result, the teacher needs to acquire knowledge of instructional strategies for a specific content area or topic as well as any information regarding any student difficulties associated with that topic (Kind, 2015). In learning to teach, Shulman’s PCK model makes no connections between teachers’ knowledge of instructional strategies and their knowledge of student difficulties. The implication is that the two could be learned independently. In practice, teachers’ knowledge of their students’ difficulties with a particular topic informs the creation of a specific instructional strategy and exactly how to use and implement that specific instructional strategy, which is why the PCK model offers a way to examine and identify various aspects of a teacher’s knowledge (Kind, 2015). However, the PCK model is by no means perfect and has its flaws.

Kind (2015) identifies what she calls operational flaws, which develop from Shulman’s PCK model. One, a teacher’s PCK, is static and unchanging. Two, no requirement exists in Shulman’s model to consider student learning, only that the teacher learns instructional strategies that have a positive impact on student learning. Three, many factors play a role in the overall success of a teacher’s efforts, such as context, environment, curriculum, student preferences, abilities, behaviors, and motivations. Kind (2015) sums up Shulman’s original model as such, “PCK could be all things to all people or mean nothing to anyone” (p. 180). Therefore, the idea that PCK could mean all things to all people mean nothing to anyone, or something in between makes PCK a difficult model to evaluate and or identify the relevant aspects a teacher’s knowledge and practice.
The elusive nature of a science teachers’ PCK is one of many reasons science education researchers came together in 2012 for a PCK summit. Their goal was to bring about some clarification of this construct (Berry, Friedrichsen, & Loughran, 2015). The participants of the summit brought with them various models and philosophies regarding the PCK construct, and each needed to be considered as they worked towards developing a better construct for PCK. For starters, should PCK be considered integrative where the content, context, and pedagogical knowledge of a teacher becomes an amalgam that creates a teacher’s PCK? Is PCK transformative, and the content, context, and pedagogical knowledge of a teacher are distinct and inform one another (Gess-Newsome, 1999)? Is it even important to define PCK as integrative or transformative (Kind, 2015)? Others took the view that PCK was topic-specific (Cochran, DeRuiter, & King, 1993; Rollnick & Mavhunga, 2015). Some looked at PCK as hierarchical, and they examined how a teacher’s PCK develops. The lowest level of development being general pedagogical knowledge as it relates to a wide range of science subjects, then subject-specific PCK strategies, followed by domain-specific PCK strategies within a specific subject area, and topic-specific PCK strategies at the highest level of the PCK hierarchy (R. M. Schneider & Plasman, 2011; Rebecca M. Schneider, 2015). The goal of this summit was to marry these different ideas and philosophies into a new comprehensive model of the PCK construct. Through discussion and consensus, the model of teacher professional knowledge and skill was developed and shown in Figure 3.
Figure 3.

Model of teacher professional knowledge and skill, including influences on classroom practices and student outcomes. Gess-Newsome, J. (2015).

The move to distinguish within the model the construct of topic-specific professional knowledge was an important one. Moving TSPK from a dominating generalized PCK implies that teachers are professionals and their decisions to use specific instructional strategies within the context of their environment to help their students learn is what defines them as a teacher (Kind, 2015). The new model also recognized the effect that a science teacher’s beliefs and orientations have on their knowledge, skill, and practice and how these beliefs and orientations act as filters and amplifiers for their learning and practice (Gess-Newsome, 2015). Additionally, PCK is defined to have two
roles with this model. First, as a knowledge base used for the planning and implementation of topic-specific instruction in a specific classroom context, and second, PCK is considered a skill applied during the act of teaching and identified within the model as pedagogical content knowledge and skill. The model of teacher professional knowledge and skill accounts for student outcomes, which were lacking in the original PCK model. These student outcomes act as amplifiers and filters and can inform and alter teacher knowledge and practice (Gess-Newsome, 2015). Teacher professional knowledge and skill required for the act of teaching and its representation of the various constructs and philosophies developed by the participants of the summit still lack a theoretical basis. However, the new construct developed during the summit does make available a way for researchers to study PCK and the various constructs within the model (Kind, 2015).

**Professional Teacher Knowledge**

Science teachers’ knowledge of student difficulties associated with the specific content and instructional strategies necessary to address those student difficulties is a direct result of secondary science teachers’ preparation. It is this preparation and knowledge base that builds and reinforces a science teachers’ topic-specific professional knowledge. The secondary science teachers’ topic-specific professional knowledge is then further amplified and filtered by their science teaching orientations (Friedrichsen et al., 2011; Gess-Newsome, 2015).

The preparation of secondary science teachers is one of the key indicators of student success in science (Hill, Rowan, & Ball, 2005; Keller, Neumann, & Fischer, 2017; McDermott, Heron, Shaffer, & Stetzer, 2006; Meltzer & Otero, 2014; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013). For secondary science teachers to assist
their students and address their deficiencies with graphical literacy within the context of
their classroom, they must be able to not only recognize their students’ deficiencies but
also be able to employ effective instructional strategies geared towards addressing those
deficiencies. A specific issue cited in the literature as a barrier to graphical literacy is the
teacher (Glazer, 2011). Bowen & Roth (2005) demonstrated that pre-service science
teachers do not have the necessary skills to adequately address the issue of graphing
deficiencies considering they exhibited many of the same deficiencies with graphing
identified in most secondary science students. However, there appears to be an absence in
the literature that examines in-service science teachers’ ability to address their students
graphing deficiencies apart from studies examining strategies for teaching graphing
skills. Nor do there appear to be studies that examine how to improve in-service teachers’
abilities to address graphical literacy with their students through professional
development opportunities.

Professional development and teacher preparation concerned with helping
secondary science teachers address graphical literacy with their students was not an area
addressed in this study. However, with the central question being how secondary science
teachers address graphical literacy with their students within the context of their
classroom, there was the possibility that professional development related to graphical
literacy for in-service science teachers might be a theme that emerged from this study.

**Topic-Specific Professional Knowledge**

Shulman (1986, 1987) recognized that teaching was more than just pedagogy and
content knowledge and that what made the act of teaching unique from other professions
was the ability of teachers to transform their content knowledge in a way that was
accessible by their students. Other researchers in education quickly realized that Shulman’s pedagogical content knowledge (PCK) model was also subject or domain-specific (Grossman, 1990; Hashweh, 1987; Loewenberg Ball, 1990). This realization would eventually result in the culmination of the topic-specific content knowledge (TSPK) construct within the model of teacher professional knowledge and skill (Gess-Newsome, 2015).

Hashweh (1987) described four categories of knowledge associated with a science teacher’s subject-matter knowledge; knowledge of topics, knowledge of other discipline concepts and principles, knowledge of conceptual schemes within a discipline, and knowledge of approaches or strategies for relating the topic to other disciplines. This theme of PCK being subject-specific continued within fields of mathematics (Loewenberg Ball, 1990) and literature education (Grossman, 1990). Others further distinguished PCK as being more subject-specific in nature and described this form of PCK as pedagogical content knowing (Cochran et al., 1993). The construct of pedagogical content knowing is defined as a teacher’s combined understanding of pedagogy, subject matter, student characteristics, and the environment. Teachers demonstrating a high level of pedagogical content knowing can “create teaching strategies for teaching specific content in a discipline” (Cochran et al., 1993, p. 266).

While these particular studies did not explicitly define the topic-specificity of PCK, they did lay the foundation in that “PCK helps us recognize that the knowledge needed for teaching science is different from knowledge to teach literature” (Abell, 2008, p. 1414).

The literature begins to recognize further the topic-specific nature of PCK with the development of a PCK taxonomy that is hierarchical with three distinct levels (Veal
& Makinster, 1999). Level one, general PCK, implies that an experienced teacher would possess a good understanding of the pedagogical concepts related to their specific disciplines such as science, math, or English. Level two, domain-specific PCK, is concerned with a particular subject in a specific discipline. For example, the subject of chemistry is in the discipline of science. Level three, topic-specific PCK, is at the highest level within the hierarchy. Every subject of science has its specific vocabulary, concepts, and topics. Some of these ideas or concepts may or may not overlap between subjects or domains. Ideas that intersect subjects or domains are usually addressed differently by the domain-specific teacher teaching the content and exhibiting topic-specific PCK (Veal & Makinster, 1999).

In 1997 Geddes and Wood essentially laid the foundation for the elements that would eventually be used to describe a teacher’s topic-specific professional knowledge in the model teacher professional knowledge and skill. These elements, of which there were five, were adapted from Shulman’s (1986, 1987) original PCK construct and are considered to represent knowledge a teacher must possess for the transformation of content knowledge from teacher to student (Geddis & Wood, 1997). These identified knowledge elements are learners’ prior concepts, subject representations, instructional strategies, curriculum materials, and curricular saliency. Curricular saliency is concerned with the depth and breadth given to a specific topic of instruction by the teacher (Geddis & Wood, 1997).

In 2012 Mavhunga developed an instrument using these five knowsledges to measure what she called a teacher’s topic-specific PCK. The study was concerned with the topic of chemical equilibrium within the domain of chemistry and demonstrated that
topic-specific PCK could be developed in pre-service teachers for a specific topic of instruction (Mavhunga, 2015; Rollnick & Mavhunga, 2015). The combined work of Mavhunga (2012) and Geddis and Wood (1997) helped to distinguish the topic-specific professional knowledge (TSPK) construct within the model of teacher professional knowledge and skill and eventually separate it from the PCK construct (Gess-Newsome, 2015).

This TSPK construct helped guide this study and validated the themes that emerged from the data collected from the participants regarding their instructional approaches to the topic of graphical literacy within the context of their classroom. How participants’ beliefs about teaching and learning and their TSPK informed their instructional decisions as they focused on graphical literacy with their students was of paramount importance for this study.

**Science Teaching Beliefs**

Within the broad realm of research related to science education, there is a significant number of studies and articles addressing science teachers’ orientations and beliefs towards the teaching of science. Additionally, science teaching orientations have been an aspect of pedagogical content knowledge (PCK) since Shulman first introduced the paradigm (Shulman, 1986, 1987). Defining a science teacher’s orientations and establishing those orientations within the PCK model has been identified as crucial when defining the PCK of a science teacher (Abell, 2007; Boesdorfer, 2015; Friedrichsen et al., 2011; Jones, M. G., Carter, 2007; Luft & Roehrig, 2007; Magnusson, Krajcik, & Borko, 1999; R. M. Schneider & Plasman, 2011). An attempt was made to identify various science teaching orientations and embed them within the model of PCK. The result of
this effort was the identification of nine different science teaching orientations
(Magnusson et al., 1999). Subsequently, this position paper is often cited in science
education as the seminal work connecting science teaching orientations to PCK.

Another position paper related to science teaching orientations examined the
broad and often ambiguous nature of science teaching orientations within the realm of
PCK literature (Friedrichsen et al., 2011). The authors of the paper conducted a review of
literature related to science teaching beliefs and orientations and how the literature
characterized connections between those beliefs and orientations to the PCK construct.
They identified four issues with science teacher beliefs and orientations depicted in the
literature and their connection to the PCK construct. The first was the use of orientations
in ways that differed or were unclear. Second, the relationships between orientations and
other components within the model of PCK were absent or unclear. Third, researchers
were trying to assign science teachers to one of the nine orientations described by
Magnusson et al. (1999). Fourth, some researchers were ignoring the orientations
component of PCK altogether and instead focusing on only one or two components of the
PCK model (Friedrichsen et al., 2011).

There are many difficulties when trying to define teacher beliefs and orientations,
and the research literature on topics related to PCK and teacher orientations in the field of
science education had become too diverse and vague (Friedrichsen et al., 2011). Instead
of nine science teaching orientations (Magnusson et al., 1999), a redefined construct of
science teaching orientations comprised of three specific sets of beliefs and attitudes
towards science teaching; purposes and goals of science teaching, views of science, and
beliefs about learning and teaching science (Friedrichsen et al., 2011). The redefined
construct for science teaching orientations was meant to provide a common language to be used in science education research related to PCK and science teaching orientations. This redefined construction, which defines a teacher’s beliefs and orientations towards the teaching of science, is part of the conceptual framework for this study.

- Conceptions of science teaching and learning are concerned with how the teachers teach students science, how students learn science, and the best way to teach science in a way that makes science concepts more accessible to the students learning those concepts.

- Conceptions about the nature of science are divided into the ontological and the epistemological. The ontological nature of science helps to define the beliefs about the reality of a scientific concept and how different ontologies for a particular concept such as scientific laws, models, phenomena, and objects related to that concept are distinguished from one another. The epistemological nature of science is concerned with the value that a specific concept adds to the predictive and interpretive power of science (Papadouris & Constantinou, 2017).

- Conceptions about the goals or functions of science education are divided into learning science, learning to do science, learning about science, or the teaching of science for the broader social impact.

The examination of teachers’ science teaching orientations can help to provide an understanding of the teachers’ practice and how those orientations inform their instructional decisions. An instrument, the Teacher Beliefs Interview (TBI), was developed to capture a science teacher’s epistemological beliefs (Luft & Roehrig, 2007).
Seven questions comprise this instrument. These questions are designed to elicit responses during a semi-structured interview and would allow the interviewer to capture a science teacher’s epistemological beliefs.

- How do you maximize student learning in your classroom? (learning)
- How do you describe your role as a teacher? (knowledge)
- How do you know when your students understand? (learning)
- In the school setting, how do you decide what to teach and what not to teach? (knowledge)
- How do you decide when to move on to a new topic in your classroom? (knowledge)
- How do your students learn science best? (learning)
- How do you know when learning is occurring in your classroom? (learning)

Considering that this study’s first research sub-question is epistemological, the TBI questions were modified—through the use of a focus group—to assist in answering how secondary science teachers’ beliefs about teaching and learning informed their instructional decisions when addressing graphical literacy with their students and the difficulties that might arise when providing instruction on this topic. The modification of these interview questions with the help of a focus group and the administration of these questions within this mixed-methods study is explored further in chapter 3.

**Conclusion**

The literature places a great deal of importance on the skills associated with graphical literacy and the quality of instruction designed to address a student’s
deficiencies with graphing to improve a student’s graphical literacy. The literature
documents and identifies specific student deficiencies associated with graphing in
general. The literature identifies specific instructional strategies designed to help students
improve students' graphical literacy as well as skills related to the development and
interpretation of graphs. There is also a significant number of studies and position papers
addressing the interconnection between science teaching orientations and beliefs and
topic-specific professional knowledge and how those two constructs influence a science
teacher’s instructional decisions for a specific topic.
Chapter 3: Methodology and Method

A Convergent Mixed-Methods Design

This study was conducted using the fully integrated variant of a convergent mixed-methods design (J. W. Creswell & Plano Clark, 2018). This study attempted to examine how the topic of graphical literacy is addressed in the secondary science classroom by answering the following central research question: how do secondary science teachers address graphical literacy with their students in the context of their classroom? Data for this study was collected through the use of qualitative and quantitative methods. Quantitative data was collected using closed-ended questions posed on a survey instrument that participants completed before participating in a semi-structured interview. Quantitative data were also collected using closed-ended questions asked during a semi-structured interview of secondary science teachers participating in the study. Qualitative data was collected using open-ended questions during a semi-structured interview with the same participants (except for one individual) who completed the pre-interview survey.

The fully integrated convergent mixed-methods design was appropriate for this study as it addressed the central research questions and research sub-questions outlined earlier. A fully integrated convergent mixed-method design makes it possible for the researcher to compare or combine the results from the qualitative and quantitative data, which has been collected simultaneously. By collecting the data simultaneously, the researcher can obtain a better understanding of the problem, validate one set of data with the other, or determine if the participants respond similarly to closed-ended questioning versus open-ended questioning (J. W. Creswell & Plano Clark, 2018). This fully
integrated convergent mixed methods approach is also beneficial when the researcher is planning on collecting both qualitative and quantitative information by having each participant in the study complete the same qualitative and quantitative instruments (J. W. Creswell & Plano Clark, 2018). The fully integrated variant is used by the researcher when keeping the quantitative and qualitative aspects of the study separated is not feasible or if the quantitative and qualitative instruments interact as they are implemented during data collection. For example, the researcher may ask open-ended questions based on a response to a closed-ended survey question which will be the case for this mixed methods study. The flow chart in figure 4 represents the basic procedural outline used for this fully integrated convergent mixed methods study and was adapted from Creswell, J. W. (2018).
Fully Integrated Mixed-Methods Design

Quantitative Strand
Secondary Science Teachers
- Survey instrument sample, n=9
- Interviews, n=8

Instruments
- Pre-Interview Survey
  - Teacher Beliefs about Effective Science Teaching (TBEST)
  - Survey of Graphical Skill Importance
- Interview
  - TSPK in Graphical Literacy - Closed-Ended Interview Questions

Qualitative Strand
Secondary Science Teachers
- Sample, n=8

Instruments
- Interview
  - Teacher Beliefs Interview (TBI) for Graphical Literacy: Open-Ended Interview Questions
  - TSPK in Graphical Literacy: Open-Ended Interview Questions

Analyze Quantitative Data:
- Pre-Interview Survey: TBEST and Survey of Graphical Skill Importance
  - Screen Likert scale survey data
  - Apply descriptive statistics for ordinal data
  - Analysis of non-parametric data, both nominal and ordinal, using descriptive statistics.
- Interview: TSPK in Graphical Literacy
  - Screen nominal data collected from closed-ended interview questions

Analyze Qualitative Data:
- Analysis of the responses from the open-ended interview questions using classical content analysis as the analytical strategy

Merge Quantitative and Qualitative Data:
- With use of fully integrated variant, quantitative and qualitative data has already been merged during data collection
- Draw distinctions between how the collection of quantitative data informed or influenced the collection of qualitative data
- Identify differences and similarities in the emerging themes regarding participants approach to graphical literacy within the context of their classroom and subject areas that emerge from both data sets

Interpret results to gauge how participants approached graphical literacy within the context of their classroom and subject areas.

Figure 4.

Role of the Researcher

With the design of this study being mixed-methods, which utilizes both qualitative and quantitative instruments, realizing the researcher is the instrument is important in qualitative research. The researcher’s perceptions, approach, the method of data collection, and interpretation provide the level of validity or trustworthiness for the study. The researcher has been a secondary physics/science teacher for almost two decades, taught physics at a variety of levels from sophomore physical science, general and honors physics and advanced placement physics, and honors chemistry. The researcher has mentored eight different science student teachers, earned their National Board Certification in science—adolescence and young adult with a specialty in physics in 2012, written curriculum guides and common summative assessments for various levels of secondary physics courses for two different school districts.

The researcher’s experiences related to physics and science education provide valuable insight into this topic of students’ graphical literacy. The researcher's experience as a secondary science teacher, review of the literature, and focus group feedback resulted in the generation of survey instruments and interview questions relevant to the topic of graphical literacy. These instruments described how the secondary science teachers, who participated in this study, addressed graphical literacy with their students.

The researcher’s interest in the subject of physics, the topic of graphical literacy, and personal approach to improving graphical literacy with students by addressing their deficiencies constitute particularly strong biases that were difficult to overcome. Those factors had the potential to contribute to bias regarding this topic of graphical literacy but also helped to define the researcher’s expertise in this area. This expertise provided the
necessary background and knowledge, which gave the researcher the ability to analyze and interpret the data and construct a narrative that represents the perceptions of other secondary science teachers’ successes and struggles with their approach to graphical literacy within the context of their classroom.

**Participant Selection and Sampling**

Nine secondary science teachers participated in this study from various schools in a Midwestern city in the United States. The participants were chosen through purposeful sampling using the strategy of concept sampling (J. Creswell, 2015). The idea behind concept sampling is for the researcher to select a pool of participants for a study who may have the requisite knowledge to answer the central research posed by the study. In this case, to what extent do secondary science teachers devote instruction to address graphical literacy with their students within the context of their classroom. Participants in the study were chosen based on two criteria: one, the science teachers participating in the study had taught more than five years, and two, the participants in the study taught in a single content area such as biology, chemistry, or physics. Many secondary science teachers teach a variety of science content, which may include all the content areas listed above; however, only secondary science teachers who had more than five years of teaching experience and taught primarily in a single content area were chosen to participate in this study. The researcher attempted, through the use of concept sampling, to keep an even balance of participants who specifically taught in one of the three content areas of biology, chemistry, or physics. Of the nine participants in the study, four participants taught biology-related courses such as anatomy and freshman biology. The other five participants taught physical science-related content, such as chemistry and physics. This
balance of content area teachers allowed for the comparison of the data collected from the participants by content area.

**Focus Group**

The generation of interview questions for a semi-structured interview and the review of a survey instrument is crucial to the success of the interviews conducted, and the collection of qualitative and quantitative data during a mixed-methods study. If the interview questions are too specific for the qualitative piece, the interviewer and interviewee have little chance for a dialogue to occur. If the questions are too vague, then the interview will lack structure and direction (Savin-Baden & Major, 2013). The use of a focus group to assist with the generation, development, and review of interview questions was crucial to the success of the interviews conducted during this study. Additionally, the focus group provided feedback on each survey instrument used in this mixed-methods study, which helped refine and clarify the instruments and statements presented in each instrument and their connection to the study’s central research question and research sub-questions.

The focus group consisted of five current or former secondary teachers, a veteran freshman biology teacher and instructional coach, veteran AP biology teacher with a doctorate in curriculum and instruction, an assistant principal and former AP biology teacher with a doctorate in educational leadership, a veteran physics teacher, and veteran AP calculus teacher. Before the meeting, each group member was provided a brief synopsis of the study, the central research question, and research sub-questions. Also, each member of the focus group was provided a rough draft of interview questions and
survey instruments designed by the researcher or adapted from instruments based on a review of the literature.

During the session, the group reviewed the survey instruments and interview questions and provided input on individual interview questions and survey statements regarding vocabulary, clarity, and ability to address the central research question and research sub-questions. Group members also provided feedback concerning the survey instructions, the order of the interview questions, and offered suggestions for potential follow up questions to be used during the interviews. Based on feedback from the focus group, interview questions and survey instruments were revised to reflect that feedback. The members of the focus group were given a revised copy of the interview questions for a second review. The second round of feedback from the focus group offered no significant changes to the wording or order of the questions.

**Qualitative Approach**

**Instrumentation: A Semi-Structured Interview**

A semi-structured interview was conducted after participants completed a pre-interview survey. The semi-structured interview not only allows the use of a list of specific open-ended questions during the interview but also provides flexibility for the inclusion of additional follow-up questions based on a participant's response to a particular question or survey response (Savin-Baden & Major, 2013). The instrument designed for conducting the semi-structured interview consisted of two sections. The first section consisted of questions adapted from the instrument, teacher beliefs interview (TBI) (Luft & Roehrig, 2007). The second section of the interview consisted of questions adapted from the content representation framework developed by Hume and Berry.
The researcher developed the remaining open-ended interview questions after a review of the literature specific to instructional strategies and representations used to address graphical literacy, which was addressed in chapter 2.

**Teacher Beliefs Interview (TBI) for Graphical Literacy**

Nine open-ended questions were developed for TBI for graphical literacy from the original TBI instrument, which consisted of seven open-ended interview questions. The seven questions from the original TBI instrument were separated into two categories, knowledge and learning. The response to each question in the TBI then being differentiated through the use of a rubric and placed in one of five epistemological domains in science teaching, traditional, instructive, transitional, responsive, and reform-based (Luft & Roehrig, 2007). The seven questions of the TBI instrument are listed below.

1. How do you maximize student learning in your classroom? (learning)
2. How do you describe your role as a teacher? (knowledge)
3. How do you know when your students understand? (learning)
4. In the school setting, how do you decide what to teach and what not to teach? (knowledge)
5. How do you decide when to move on to a new topic in your classroom? (knowledge)
6. How do your students learn science best? (learning)
7. How do you know when learning is occurring in your classroom? (learning)

Each of the seven questions developed for the TBI was reworded specifically to address graphical literacy to create the TBI for graphical literacy but keeping the same categories
of knowledge and learning. Questions six and seven were each divided into two separate questions and reworded to address student graph interpretation and development, as suggested by the focus group assisting the researcher with the development of this interview instrument. Additionally, the order of the questions was changed on the suggestion of the focus group. See table 1 for the final version of the TBI for Graphical Literacy.

**Table 1**

**TBI for Graphical Literacy**

<table>
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<th>Knowledge</th>
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<tbody>
<tr>
<td>1</td>
<td>How do you describe your role as a teacher when teaching graphs and other skills related to graphing?</td>
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<td>2</td>
<td>In the school setting, how do you decide what to teach and what not to teach about the topic of graphs and other skills related to graphing?</td>
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<td>3</td>
<td>How do you decide when to end your instruction on a concept which requires students to interpret and construct graphs and move on to a new topic in your classroom?</td>
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<td>Learning</td>
<td>4</td>
<td>How do you maximize student learning related to content which requires the interpretation and construction of graphs in your classroom to promote skills related to graphing?</td>
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<td>5</td>
<td>How do your students best learn graphing skills through the development of graphs?</td>
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<td>6</td>
<td>How do your students best learn graphing skills through the interpretation of graphs?</td>
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<td>7</td>
<td>How do you know when your students are understanding content which requires the interpretation and construction of graphs?</td>
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<td>8</td>
<td>How do you know when students are learning to construct graphs in your classroom?</td>
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<td>9</td>
<td>How do you know when students are learning to interpret graphs in your classroom?</td>
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Instrument for Topic-Specific Professional Knowledge in Graphical Literacy

The researcher developed a series of open-ended and closed-end questions. They were designed to capture the topic-specific professional knowledge (TSPK) in graphical literacy of the participants by addressing four aspects of a science teacher’s TSPK, curricular saliency, student difficulties with a topic, students’ prior knowledge of a topic, and instructional strategies and representations for a specific topic (Geddis & Wood, 1997; Gess-Newsome, 2015; Rollnick & Mavhunga, 2015). With the use of a fully integrated mixed-methods design, responses from the pre-interview surveys and the closed-ended questions asked during the interview informed many of the open-ended interview questions. This merger of the qualitative and quantitative strands during data collection provided a complete picture of the participants’ TSPK and how it informed their instruction as they addressed graphical literacy within the context of their classrooms.

Six open-ended interview questions were adapted for this instrument from the content representation framework developed by Hume and Berry (Hume & Berry, 2011, 2013). The content representation framework was designed as a method of lesson planning for pre-service chemistry teachers and to help develop their pedagogical content knowledge (PCK) in the process (Hume & Berry, 2013). The six interview questions target participants’ curricular saliency and understanding of students’ prior knowledge, and difficulties with graphs and graphing are illustrated in table 2.
Table 2.

Knowledge and difficulties with graphs and graphing

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<table>
<thead>
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<tbody>
<tr>
<td>1</td>
<td>What would you consider as the big ideas when teaching content that requires the construction and interpretation of graphs?</td>
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<tr>
<td>2</td>
<td>What do you intend for your students to know about the construction and interpretation graphs?</td>
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<tr>
<td>3</td>
<td>Why is it important for your students to know how to construct and interpret graphs?</td>
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<tr>
<td>4</td>
<td>What concepts need to be taught before teaching graphs?</td>
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<tr>
<td>5</td>
<td>What else do you know about graphs and graphing skills that you do not intend your students to know when you address this graphing in your classroom?</td>
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<tr>
<td>6</td>
<td>What do you consider easy or difficult in teaching graphs? And why?</td>
</tr>
</tbody>
</table>

In addition to questions outlined in table 2, a series of three open-ended questions were developed by the researcher and helped build upon responses by the participants to the pre-interview survey of graphical skill importance.

1. On the pre-interview survey, you identified the following graphing skills as important for your students when developing and interpreting graphs.
   - Why are these specific graphing skills important for your students to be proficient within the context of your classroom?

2. On the pre-interview survey, you identified the following graphing skills as important for your students when developing and interpreting graphs.
   - Why are these specific graphing skills important for your students to be proficient within the context of your classroom?

3. On the pre-interview survey, you identified the following graphing skills as important for your students when developing and interpreting graphs.
   - Why are these specific graphing skills important for your students to be proficient within the context of your classroom?
These open-ended questions further addressed the participant’s TSPK in graphical literacy within the context of the participant’s classroom and helped to provide additional insight to the participant’s responses to the statements on the survey of graphical skill importance. The final questions of the instrument consisted of a series of closed-ended and open-ended questions designed by the researcher to address the participants' knowledge and use of instructional strategies and representations to address graphical literacy within the context of their classrooms. The interview questions required the participants to list specific instructional representations and strategies they have used or abandoned and the rationale for their use or abandonment.

The interview questions generated by the researcher from the teacher beliefs interview and the content representation framework were further developed with the help of a focus group. These interview questions acted as a roadmap for interviewing the participants in this study. This semi-structured interview format provided flexibility and structure during the interview process and built upon the participants’ responses to the pre-interview survey. The interviews generated data in which the themes that emerged were compared and combined with responses to closed-ended questions posed on a pre-interview survey instrument. As well as the closed-ended questions asked as part of the semi-structured interview with open-ended follow up questions based on the participant’s response. The order of the interview questions and how they were asked during the semi-structured interview was in response to the participant’s pre-interview survey results. This questioning strategy aligned well with the fully integrated variant of the convergent mixed methods design.
Qualitative Data Analysis

The application of content analysis as an analytical strategy was used to examine the data collected from the text of the interviews. Specifically, classical content analysis, which strives to make replicable and valid inferences from the data and to make objective, systematic, and quantitative descriptions of the data. Classical content analysis allows the researcher to make inferences through the systematic and objective identification of specific characteristics in a text using the following generic steps (Savin-Baden & Major, 2013):

- examine the text
- peruse it in its entirety
- determine the properties of the text
- examine overt and latent emphases
- determine the rules for categorizing
  - how much data will be analyzed at any one time: a line, a phrase, a sentence
  - determine categories
  - the categories must be inclusive, in that all examples fit in that one category
  - the categories must be mutually exclusive, in that no examples fit within more than one category
  - determine the themes that emerge
Quantitative Approach

Non-parametric data in both nominal and ordinal forms were collected through the use of a pre-interview survey instrument and closed-ended questions posed during the semi-structured interview. The responses provided by participants as a part of the pre-interview survey and responses to closed-end interview questions from the interviews were collected, combined, and compared through the application of a fully integrated mixed-methods design. With this design, the researcher can obtain a better understanding of the problem and validate one set of data with the other. The designed used allows for the opportunity to ask qualitative questions in response to quantitative data or results, get additional information in response to or determine if the participants respond similarly to closed-ended questioning versus open-ended questioning and (J. W. Creswell & Plano Clark, 2018).

For this study, the responses from the pre-interview survey instrument were used to inform the questions asked during the interview. The results from the pre-interview survey helped focus the interview questions and allowed the participant to provide information regarding their specific beliefs about science teaching and learning and topic-specific knowledge with regards to graphical literacy and what that looks like in their classroom — the pre-interview survey instrument allowed for a more efficient and direct interview. The closed-ended interview questions asked of each participant related to representations and instructional strategies for graphing. The responses from these closed-ended questions informed and drove the open-ended questioning during the interview regarding instructional strategies for graphing. With all but one participant in this study completing the same pre-interview instrument and sitting for an interview, it
was possible to identify differences and similarities in the themes that emerged from the quantitative and qualitative data regarding each participant’s approach to graphical literacy in their classroom.

**Instrument: Pre-Interview Survey**

A pre-interview survey with closed-ended questions was given to the participants of the study before a semi-structured interview. The pre-interview survey allowed for the collection of quantitative data by the researcher and allowed the researcher to tailor the interview questions based on the participant’s responses to the pre-interview survey. There were two sections to the pre-interview survey. The first was a survey consisting of 21 statements, named the teacher beliefs about effective science teaching (TBEST). The survey is designed to gauge a science teacher’s beliefs toward teaching and learning (Smith et al., 2014). The second section of the pre-interview survey had participants consider the importance of 12 statements within the context of their classroom. Each statement represented either a common student error or confusion that has been attributed to graphical literacy identified in the literature (Glazer, 2011).

**Teacher Beliefs about Effective Science Teaching (TBEST) Instrument**

The teachers’ beliefs about effective science teaching (TBEST) survey instrument was used to gauge participants’ beliefs of effective science teaching based on their ranked responses to 21 statements using a six-point Likert scale. The TBEST instrument was designed to provide researchers with a method to gauge teacher beliefs related to classroom practice and student learning (Smith et al., 2014). In this study, results from the TBEST instrument was compared to themes generated from the responses to the open-ended interview questions from the teacher beliefs interview (TBI) for graphical
literacy in an attempt to examine how teacher beliefs about teaching and learning informs secondary science teachers’ instruction as they address their students’ graphical literacy within the context of their classrooms. The results of the TBEST were also compared to the results and themes generated by the open-ended questions asked during the interview. Comparisons were also made between participants by the subject the participants teach.

Since Likert scale data is a form of ordinal data, measures of variance can be determined by examining the range of scores between participants for the responses to the statements on the TBEST. The data collected from the TBEST instrument could be analyzed using a Kruskal-Wallis test for a difference between biology, chemistry, and physics teachers and their responses on this instrument.

The TBEST consists of 21 statements in which respondents were asked to rate each statement on a six-point Likert scale, 1- strongly disagree to 6 – strongly agree. A confirmatory factor analysis was used to confirm a three-factor solution for the questionnaire. The three factors were labeled as learning theory aligned science instruction, confirmatory science instruction, and all hands-on all the time. The TBEST scored greater than 0.9 on both the comparative fit index, CFI, and the Tucker-Lewis index, TLI, and less than 0.08 on the root mean square error of approximation, RMSEA. The TBEST also scored greater than 0.7 (Cronbach’s Alpha) on reliability for elementary, middle, and high school science teachers in each of the three factors.

Survey of Graphical Skill Importance

The survey of graphical skill importance was modeled after a survey format used for assessing the teaching efficacy of science teachers (Lekhu, 2013). The primary purpose of this survey was to give the researcher some perspective as to the level of
importance a participant placed on various skills attributed to graphs and graphing before the interview. The responses to this particular survey allowed the researcher to tailor interview questions, which helped to expand on those responses and provide a complete picture of how participants’ topic-specific professional knowledge informed their instruction related to graphical literacy with their students. The survey instrument provided the researcher with some insight into the ability of the participant to recognize student deficiencies associated with graphing within the context of their classroom.

The survey of graphical skill importance asked the participants to consider 12 statements with each statement representing student deficiencies or confusion related to graphical literacy, as identified in the literature (Glazer, 2011). The participant was asked to consider each statement and rank the statement on three levels of importance: not important, slightly important, or important. Another option for each statement was made available for the participant to consider: not applicable within the context of their classroom. Since participants were asked to rank the level importance of each statement within the context of their classroom, the not applicable category helps prevent the possibility of the participants selecting not important as a response when the skill may not be applicable within the context of their curriculum. For example, a participant may have believed a student should possess a specific skill related to graphing, but their students are not being asked to demonstrate that specific skill within the context their classroom and the subject they teach. This additional option for the participants allowed the researcher to determine better if a participant truly thought a specific graphing skill was important or not. The skills which received a response of not applicable were examined further by the researcher during the semi-structured interview.
Since Likert scale data is ordinal data, measures of variance can be determined by examining the range, high to low, for the responses to the statements on the survey of graphical skill importance. The data collected from the survey of graphical skill importance could be analyzed using a Kruskal-Wallis test for a difference between biology, chemistry, and physics teachers.

**Interview: Instructional Strategies for Graphical Literacy**

The semi-structured interview contained two closed-ended questions related to the topic of instructional strategies for developing and interpreting graphs. These closed-ended interview questions were developed by the researcher based on a review of the literature specific to instructional strategies and representations used to address graphical literacy in secondary science classrooms and feedback from the focus group. The first question asked participants to list as many specific instructional representations or strategies with which they were familiar and that they believed helped students develop their graphical literacy whether or not they specifically use that strategy or representation in their classroom. Examples that might have been mentioned but were not limited to illustrations, models, analogies, simulations, or activities which incorporate graphing or graphing related skills. The second question asked participants to list, in order of most to least frequency of use, any specific representations such as illustrations, models, analogies, simulations, or activities they have utilized in their classroom when teaching students about a science concept that incorporates graphing and graphing related skills.

These closed-ended interview questions informed the open-ended questions asked during the interview related to instructional strategies for graphical literacy. These questions collected nominal data, so measures of variance could be made based on the
number of strategies listed by each participant and comparisons made between groups based on subject taught and beliefs about teaching and learning with regards to graphical literacy.

**Analysis by Research Question**

**Research Sub-Question 1 (RSQ1)**

*How do secondary science teachers’ beliefs about science teaching and learning together with their topic-specific professional knowledge inform their instruction as they address their students’ graphical literacy within the context of their classroom?*

Both qualitative and quantitative data were collected during this study to answer RSQ1. The quantitative data were collected using the teacher beliefs about effective science teaching (TBEST) survey instrument and the survey of graphical skill importance. Both instruments were a part of a pre-interview survey given to each participant. The results from the pre-interview surveys were used to inform and help guide the semi-structured interview by allowing for targeted interview questions and follow up questions based on participants’ responses to the survey of graphical skill importance.

Qualitative data was collected during the semi-structured interview using the open-ended questions designed for the teacher beliefs interview (TBI) for graphical literacy and topic-specific professional knowledge (TSPK) in graphical literacy. The responses to the interview questions were analyzed using classical content analysis. The themes which emerged from the analysis were used to help identify the differences and similarities in how participants’ beliefs and their TSPK informed their instruction of graphical literacy in their classroom.
Research Sub-Question 2 (RSQ2)

What are specific student deficiencies in graphical literacy that secondary science teachers address within the context of their classroom?

Both qualitative and quantitative data were collected during this study to answer RSQ2. Participants’ responses to the survey of graphical skill importance, a segment of the pre-interview survey, were used to inform open-ended interview questions that related to what specific graphing skills participants address with their students and allowed them an opportunity to provide a rationale for their responses on the survey.

The pre-interview survey asked participants to rank specific graphing skills on the importance or not applicable within the context of their classroom. During the interview, follow-up questions were asked of the participants. These questions had the participants clarify their responses as to why they felt a specific graphing skill was important, not important, or not applicable for students to demonstrate proficiency within the context of their classroom and the subject they teach.

The responses to the interview questions were analyzed using classical content analysis. The themes which emerged from the analysis of both the quantitative and qualitative data helped identify the differences and similarities in how the participants addressed specific graphing skills for the interpretation and development of graphs in their classroom.

Research Sub-Question 3 (RSQ3)

What are some specific instructional strategies or representations used by secondary science teachers to address their students’ deficiencies associated with graphical literacy in the context of their classrooms and the rationale for their use?
Both qualitative and quantitative data was collected during this study to answer RSQ3. During the semi-structured interview, participants were asked to respond to two closed-ended interview questions that were related to instructional strategies or representations for graphing. Then a series of open-ended follow-up questions were asked during the interview. These questions allowed participants to provide a rationale for their responses to the closed-ended questions that addressed graphing strategies or representations.

The first of the two closed-ended questions had participants list instructional strategies or representations for graphing with which they are familiar and not necessarily strategies or representations they have personally used in their classroom. The second closed-ended interview question had participants rank the frequency of use, specific strategies, or representations that they do use in their classroom. The open-ended follow-up questions had participants distinguish between strategies used for developing graphs versus those strategies used for the interpretation of graphs. Participants were also asked to identify any instructional strategies for graphing that they have used in the past or have considered using to address graphical literacy in their classroom.

The responses to the closed-ended interview questions requiring participants list and rank instructional strategies for graphing were analyzed using descriptive and inferential statistics for the nominal data generated by the closed-end questions. The responses to the open-ended interview questions were analyzed using classical content analysis. The results and themes which emerged from the analysis of both the quantitative and qualitative data were used to help identify the differences and similarities in what
specific instructional strategies or representations were being used by the participants to address graphical literacy within the context of their classroom.

The interview questions designed for the TBI for graphical literacy and TSPK in graphical literacy helped to provide some perspective into the representations and instructional strategies the participants used to address their students’ deficiencies related to graphical literacy.

**Ethical Procedures**

This study was conducted ethically and observed IRB and CITI protocols for ethical research. The following procedural steps were carried out to the best of the researcher’s ability. Information was obtained, from the various school districts where the participants taught, regarding permission to conduct research. All necessary information was provided to the target school districts to secure approval to research before inviting teachers who worked in the district to participate in this study. The principals of the buildings where prospective participants taught were also contacted and informed about the possibility of their teachers participating in this study after receiving district approval. Potential participants were contacted through email following district approval. Informed consent was then obtained from those individuals willing to participate in this study. Participants in this study were kept anonymous through the use of teacher codes assigned by the researcher. Digital copies of recorded interviews, interview transcripts, survey responses, and all analysis of the data was stored on a password-protected computer maintained at the researcher’s private residence.

Any digital copies of recorded interviews, interview transcripts, survey responses, and all analysis of the data was stored on a password-protected cloud service platform.
Any physical paper copies of interview transcripts, survey responses, and all analyses of the data were stored and secured at the researcher’s private residence. Participants in the study were made aware, as a condition of informed consent, that they have access to their responses to both the pre-interview survey and their interview transcript. Participants were also made aware that they may opt-out of the study at any time.
Chapter 4: Results

For this mixed-methods study, nine individuals chose to complete two Likert scale surveys, which generated a portion of the quantitative data used in this mixed-methods survey. The surveys were administered online by emailing a link to the survey to each of the participants. The survey responses were collected electronically in an online spreadsheet.

Of the nine participants who completed the survey, eight were interviewed in-person after the completion of the survey instruments. The researcher transcribed the results by using a speech to text application. The responses to the interview questions were analyzed and coded based on the themes that emerged from the participants’ responses. Responses to selected interview questions were used to generate the remaining quantitative data for this study.

**Demographics of Participants**

All participants were secondary science teachers with five or more years of teaching experience and taught in school districts located in a midwestern city. See table 3.
Table 3.

Participant Demographics

<table>
<thead>
<tr>
<th>Participants</th>
<th>Years of teaching experience</th>
<th>Primary Subject Area Taught</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant #1</td>
<td>More than 15</td>
<td>Primarily Biology or Biology related courses</td>
</tr>
<tr>
<td>Participant #2</td>
<td>Between 5 and 10</td>
<td>Primarily Biology or Biology related courses</td>
</tr>
<tr>
<td>Participant #3</td>
<td>Between 5 and 10</td>
<td>Medical Science</td>
</tr>
<tr>
<td>Participant #4</td>
<td>Between 5 and 10</td>
<td>Primarily Biology or Biology related courses</td>
</tr>
<tr>
<td>Participant #5</td>
<td>Between 10 and 15</td>
<td>Primarily Physics or Physics-related courses</td>
</tr>
<tr>
<td>Participant #6</td>
<td>Between 10 and 15</td>
<td>Primarily Chemistry or Chemistry related courses</td>
</tr>
<tr>
<td>Participant #7</td>
<td>Between 5 and 10</td>
<td>Physical Science (Chem &amp; Physics)</td>
</tr>
<tr>
<td>Participant #8</td>
<td>More than 15</td>
<td>Primarily Physics or Physics-related courses</td>
</tr>
<tr>
<td>Participant #9</td>
<td>More than 15</td>
<td>Primarily Chemistry or Chemistry related courses</td>
</tr>
</tbody>
</table>

General Quantitative Survey Results

Before the interview, each participant completed a pre-interview survey with closed-ended questions. There were two sections to the pre-interview survey. The first section was the teacher beliefs about effective science teaching (TBEST) survey, consisting of 21 statements. The survey was designed to gauge a science teacher’s beliefs toward science teaching and learning (Smith et al., 2014). The second section of the pre-interview survey had the participants consider the importance of 12 graphing skills identified in the literature within the context of their classroom. Each statement represented either a common student error or confusion that has been attributed to graphical literacy identified in the literature (Glazer, 2011). The second section of the pre-interview survey was designed to provide some insight into the importance the participants placed on graphing literacy and graphing skills within the context of their classroom.
Teachers Beliefs about Effective Science Teaching (TBEST) Results

Participants’ Responses

The participants were asked to respond to the 21 statements by indicating how much they agreed or disagreed with the following statements on a 1 to 6 Likert scale from strongly disagree to strongly agree, respectively. Tables 4, 5, and 6 show the average of the participants’ responses to the 21 statements regarding their beliefs about effective science teaching. The 21 statements were separated into three belief categories, learning-theory aligned science instruction (Table 4), confirmatory science instruction (Table 5), and all hands-on all the time science instruction (Table 6).
Table 4

*Average of participants’ responses to statements regarding learning-theory aligned science instruction.*

<table>
<thead>
<tr>
<th>Statement</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.) Students should rely on evidence from classroom activities, labs, or observations to form conclusions about the science concept they are studying.</td>
<td>5</td>
</tr>
<tr>
<td>6.) Teachers should provide students with opportunities to connect the science they learn in the classroom to what they experience outside of the classroom.</td>
<td>6</td>
</tr>
<tr>
<td>7.) Teachers should ask students to support their conclusions about a science concept with evidence.</td>
<td>6</td>
</tr>
<tr>
<td>9.) At the beginning of instruction on a science concept, students should have the opportunity to consider what they already know about the concept.</td>
<td>4.9</td>
</tr>
<tr>
<td>11.) Teachers should provide students with opportunities to apply the concepts they have learned in new or different contexts.</td>
<td>5.7</td>
</tr>
<tr>
<td>12.) Students should use evidence to evaluate claims about a science concept made by other students.</td>
<td>5.3</td>
</tr>
<tr>
<td>14.) At the beginning of lessons, teachers should 'hook' students with stories, video clips, demonstrations, or other concrete events/activities in order to focus student attention.</td>
<td>5.3</td>
</tr>
<tr>
<td>15.) Students’ ideas about a science concept should be deliberately brought to the surface prior to a lesson or unit so that students are aware of their own thinking.</td>
<td>5.1</td>
</tr>
<tr>
<td>17.) Students should have opportunities to connect the concept they are studying to other concepts.</td>
<td>5.8</td>
</tr>
<tr>
<td>18.) Students should consider evidence that relates to the science concept they are studying.</td>
<td>5.7</td>
</tr>
<tr>
<td>21.) Students should consider evidence for the concept they are studying, even if they do not do a hands-on or laboratory activity related to the concept.</td>
<td>5.6</td>
</tr>
</tbody>
</table>
Table 5

Average of participants’ responses to statements regarding confirmatory science instruction

<table>
<thead>
<tr>
<th>Statement</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.) At the beginning of instruction on a science concept, students should be provided with definitions for new scientific vocabulary that will be used.</td>
<td>3.3</td>
</tr>
<tr>
<td>2.) Hands-on activities and/or laboratory activities should be used primarily to reinforce a science concept that the students have already learned.</td>
<td>2.9</td>
</tr>
<tr>
<td>5.) Teachers should explain a concept to students before having them consider evidence that relates to the concept.</td>
<td>2.7</td>
</tr>
<tr>
<td>10.) Students should do hands-on activities after they have learned related science concepts.</td>
<td>3.9</td>
</tr>
<tr>
<td>16.) Teachers should provide students with the outcome of an activity in advance, so students know they are on the right track as they do the activity.</td>
<td>2.2</td>
</tr>
<tr>
<td>19.) When students do a hands-on activity, and the data don't come out right, teachers should tell students what they should have found.</td>
<td>3.3</td>
</tr>
<tr>
<td>20.) Students should know what the results of an experiment are supposed to be before they carry it out.</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Table 6

Average of participants’ responses to statements regarding all hands-on all the time science instruction.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.) Teachers should have students do hands-on activities, even if the data they collect are not closely related to the concept they are studying.</td>
<td>3.1</td>
</tr>
<tr>
<td>8.) Students should do hands-on or laboratory activities, even if they do not have opportunities to reflect on what they learned by doing the activities.</td>
<td>3.2</td>
</tr>
<tr>
<td>13.) Teachers should have students do interesting hands-on activities, even if the activities do not relate closely to the concept being studied.</td>
<td>3.8</td>
</tr>
</tbody>
</table>
The average of the responses by teachers participating in this study ranged moderately to strongly agree with belief statements, which corresponded to learning-theory aligned instruction. The average response to statements that corresponded to confirmatory science instruction and all hands-on all the time were comparatively lower to the average response for statements corresponding to learning-theory aligned instruction. The average responses to statements to all hands-on all the time and confirmatory science instruction ranged from moderately disagree to slightly agree with the average response for the majority of the statements in the two categories was slightly disagree.

**Participant Scores**

Tables 7, 8, and 9 show the participants’ scores for each category on the TBEST survey. The participants’ scores were determined by averaging their Likert scale responses to each statement in their respective categories.

**Table 7**

*Individual participant’s score on the learning-theory aligned science instruction.*

<table>
<thead>
<tr>
<th>Participant #</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant #1</td>
<td>5.1</td>
</tr>
<tr>
<td>Participant #2</td>
<td>4.8</td>
</tr>
<tr>
<td>Participant #3</td>
<td>5.9</td>
</tr>
<tr>
<td>Participant #4</td>
<td>5.5</td>
</tr>
<tr>
<td>Participant #5</td>
<td>5.5</td>
</tr>
<tr>
<td>Participant #6</td>
<td>5.8</td>
</tr>
<tr>
<td>Participant #7</td>
<td>5.5</td>
</tr>
<tr>
<td>Participant #8</td>
<td>5.8</td>
</tr>
<tr>
<td>Participant #9</td>
<td>5.2</td>
</tr>
</tbody>
</table>
Table 8

*Individual participant’s score on the confirmatory science instruction.*

<table>
<thead>
<tr>
<th>Participant #</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant #1</td>
<td>3.3</td>
</tr>
<tr>
<td>Participant #2</td>
<td>2.0</td>
</tr>
<tr>
<td>Participant #3</td>
<td>3.1</td>
</tr>
<tr>
<td>Participant #4</td>
<td>3.9</td>
</tr>
<tr>
<td>Participant #5</td>
<td>2.7</td>
</tr>
<tr>
<td>Participant #6</td>
<td>2.6</td>
</tr>
<tr>
<td>Participant #7</td>
<td>2.4</td>
</tr>
<tr>
<td>Participant #8</td>
<td>2.0</td>
</tr>
<tr>
<td>Participant #9</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Table 9

*Individual participant’s score on all hands-on all the time science instruction.*

<table>
<thead>
<tr>
<th>Participant #</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant #1</td>
<td>3.7</td>
</tr>
<tr>
<td>Participant #2</td>
<td>3.7</td>
</tr>
<tr>
<td>Participant #3</td>
<td>4.3</td>
</tr>
<tr>
<td>Participant #4</td>
<td>4.3</td>
</tr>
<tr>
<td>Participant #5</td>
<td>2.0</td>
</tr>
<tr>
<td>Participant #6</td>
<td>2.7</td>
</tr>
<tr>
<td>Participant #7</td>
<td>4.3</td>
</tr>
<tr>
<td>Participant #8</td>
<td>5.0</td>
</tr>
<tr>
<td>Participant #9</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The participants' scores were the highest for learning-theory aligned science instruction. The participants' scores were much lower for the other two categories, with the exception of participant #8. Their score was a 5.0 on all hands-on all the time compared with a 5.8 for learning-theory aligned science instruction. Much like the averages for the individual belief statements within confirmatory science instruction and all hands-on all the time science instruction, the participants’ scores in those two categories were low as well. Scores on the all hands-on all the time, science instruction were slightly higher than confirmatory science instruction. The exception was participant...
#5, whose confirmatory science instruction score was slightly higher than their score for all hands-on all the time.

Of possible interest, there is no clear distinction when comparing the average participant scores from the learning theory-aligned and the confirmatory science instruction of those participants whose content area is the biological sciences with the scores of those participants whose content area is the physical sciences. Scores from all hands-on all the time show the participants whose primary content area is biology having an average response near 4.0 and most of the physical science content area participants scoring below 3.0. However, with such a small sample size, these results may not be an indication of anything significant.

**Topic-Specific Professional Knowledge (TSPK) Survey Results**

Table 10 shows a count of the participants’ responses to the importance of each graphing related skill statement within the context of their classroom and the content area they teach.
Table 10

*A count of all participants' responses to the graphical skills survey.*

<table>
<thead>
<tr>
<th></th>
<th>Not Important</th>
<th>Slightly Important</th>
<th>Important</th>
<th>Not Applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.) Students being able to distinguish the slope of a graph from the height of a graph</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>2.) Students being able to distinguish between an interval on a graph versus a point on the same graph</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>3.) Students not treating a graph as a picture or a map.</td>
<td>0</td>
<td>3</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>4.) Students not conceiving a graph as constructed of discrete points, e.g., students connecting data points instead of drawing a line of best fit.</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>5.) Students being able to construct an understanding of graphs presented during lectures</td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>6.) Students being able to match narrative information from a passage to a graphical representation</td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>7.) Students being able to translate an algebraic equation to a graphical representation and a graphical representation to an algebraic equation</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>8.) Students being able to interpret what the slope of a graph represents</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>9.) Students being able to interpret what the area under a graph represents</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>10.) Students being able to recognize when it is appropriate to sketch a graph that passes through the origin or (0,0) point</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>11.) Students being able to interpret graphs based on the format of the visual features such as color, size, aspect ratio, scale and legend/labels</td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>12.) Students being able to construct graphs with appropriate choice of graph format or visual features such as color, size, aspect ratio, scale and legend/labels</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
Only one participant marked one skill as not important, skill statement seven. Of particular interest is the number of participants indicating the importance of skill statements 5, 6, and 8, which correspond to students being able to derive meaning from a graph correctly. Students being able to derive meaning from a graph through interpretation was a theme that was pervasive throughout the qualitative portion of this study. Statement 12, students being able to construct graphs with appropriate choice of graph format or visual features such as color, size, aspect ratio, scale and legend/labels, is a bit of mystery because many of the participants during the interview stage of this study discuss the importance of students being able to choose the correct graph to represent the data, construct, label, and scale graphs correctly.

**Survey of graphical skill importance - biology content area participants results**

Table 11 shows a count of the biology teachers’ responses to the importance of each graphing related skill statement within the context of their classroom and the content area they teach.
Table 11

*Count of secondary biology participants’ responses - graphical skills survey.*

<table>
<thead>
<tr>
<th></th>
<th>Not Important</th>
<th>Slightly Important</th>
<th>Important</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Students being able to distinguish the slope of a graph from the height of a graph.</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Students being able to distinguish between an interval on a graph versus a point on the same graph</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Students are not treating a graph as a picture or a map.</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Students not conceiving a graph as constructed of discrete points, e.g., students connecting data points instead of drawing a line of best fit</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Students being able to construct an understanding of graphs presented during lectures</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Students being able to match narrative information from a passage to a graphical representation</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Students being able to translate an algebraic equation to a graphical representation and a graphical representation to an algebraic equation</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>Students being able to interpret what the slope of a graph represents</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Students being able to interpret what the area under a graph represents</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Students being able to recognize when it is appropriate to sketch a graph that passes through the origin or (0,0) point</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Students being able to interpret graphs based on the format of the visual features such as color, size, aspect ratio, scale and legend/labels</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>Students being able to construct graphs with appropriate choice of graph format or visual features such as color, size, aspect ratio, scale and legend/labels</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
The participants who indicated their primary content area was biology ranked most skills as slightly important or N/A, not applicable. However, only one teacher marked one skill statement, number 7, as not important. Only graphing skills 5 and 6 were ranked important at a higher count than all the other skills. The other skills were ranked either slightly important or N/A.

**Survey of graphical skill importance physical science content area results**

Table 12 shows a count of the physical science teachers’ responses to the importance of each graphing related skill statement within the context of their classroom and the content area they teach.
### Table 12

**Count of secondary physical science participants’ responses - graphical skills survey.**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Not Important</th>
<th>Slightly Important</th>
<th>Important</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Students being able to distinguish the slope of a graph from the height of a graph.</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Students being able to distinguish between an interval on a graph versus a point on the same graph</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Students are not treating a graph as a picture or a map.</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Students not conceiving a graph as constructed of discrete points, e.g., students connecting data points instead of drawing a line of best fit</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Students being able to construct an understanding of graphs presented during lectures</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Students being able to match narrative information from a passage to a graphical representation</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Students being able to translate an algebraic equation to a graphical representation and a graphical representation to an algebraic equation</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>Students being able to interpret what the slope of a graph represents</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>Students being able to interpret what the area under a graph represents</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Students being able to recognize when it is appropriate to sketch a graph that passes through the origin or (0,0) point</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>Students being able to interpret graphs based on the format of the visual features such as color, size, aspect ratio, scale and legend/labels</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>Students being able to construct graphs with appropriate choice of graph format or visual features such as color, size, aspect ratio, scale and legend/labels</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>
The participants who indicated their primary content area was in the physical sciences ranked most skills as important within the context of their classroom. The exceptions were graphing skill statements 7 and 10, which were marked as slightly important with a greater frequency than important. Additionally, only one participant marked one graphing skill statement as N/A, skill statement 9.

**Topic-Specific Professional Knowledge (TSPK) Results from Interviews**

**Section 3 Interview Questions: TSPK – Strategies and Representations**

For this section of the interview, participants were asked to list as many specific representations, such as illustrations, models, analogies, simulations, or activities, with which they were familiar whether or not they utilized those representations in the classroom when teaching students about a science concept which incorporates graphing. The researcher categorized all the participants’ responses regarding instructional representations and strategies shown in table 13.

**Table 13**

*Response rate for instructional strategies and representations for graphical literacy.*

<table>
<thead>
<tr>
<th>Representation</th>
<th>Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Class Examples</td>
<td>10</td>
</tr>
<tr>
<td>Assessment</td>
<td>9</td>
</tr>
<tr>
<td>Lab Activity</td>
<td>7</td>
</tr>
<tr>
<td>Student Feedback</td>
<td>7</td>
</tr>
<tr>
<td>Practice Graphs</td>
<td>6</td>
</tr>
<tr>
<td>Online Computer Simulations</td>
<td>5</td>
</tr>
<tr>
<td>Data sets (Student or Teacher Generated)</td>
<td>5</td>
</tr>
<tr>
<td>Software Interfaces</td>
<td>5</td>
</tr>
<tr>
<td>Student Groups</td>
<td>4</td>
</tr>
<tr>
<td>Outside source material</td>
<td>2</td>
</tr>
<tr>
<td>Use of a spreadsheet program</td>
<td>1</td>
</tr>
<tr>
<td>Application of Statistics</td>
<td>1</td>
</tr>
<tr>
<td>Video Analysis</td>
<td>1</td>
</tr>
<tr>
<td>Develop Equations</td>
<td>1</td>
</tr>
</tbody>
</table>
Next, the participants were asked to rank, from most to least frequency of use, the specific representations or instructional strategies they were currently utilizing in their classrooms when teaching students about a science concept that incorporated graphing which is shown in Table 14

**Table 14**

*Instruction strategies and representations ranked and counted ranks*

<table>
<thead>
<tr>
<th>Strategy or Representation</th>
<th>Ranking and Counted Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data sets (Student or Teacher Generated)</td>
<td>#1, #3</td>
</tr>
<tr>
<td>Lab Activity</td>
<td>#1, #2, #3</td>
</tr>
<tr>
<td>Practice Graphs</td>
<td>#1, #2 #2 #2 #2 #2 #3</td>
</tr>
<tr>
<td>In-Class Example</td>
<td>#1 #1, #3 #3</td>
</tr>
<tr>
<td>Software Interfaces</td>
<td>#1 #1, #2</td>
</tr>
<tr>
<td>Online Computer Simulations</td>
<td>#3</td>
</tr>
<tr>
<td>Student Feedback</td>
<td>#1</td>
</tr>
</tbody>
</table>

**Summary of Participants’ Interviews**

The interviews conducted for this study consisted of three sections and occurred after the participants completed the pre-interview survey. The first section included questions from the Teacher Beliefs Interview for graphing literacy adapted from the instrument, teacher beliefs interview (TBI) (Luft & Roehrig, 2007). The research classified the participants' responses into three categories, teacher-focused, transitional, and student-focused (Luft & Roehrig, 2007).

In the second section of the interview, Topic-Specific Professional Knowledge of graphical literacy consisted of questions adapted from the content representation framework developed by Hume and Berry (Hume & Berry, 2011, 2013). The third section of the interview consisted of questions developed by the researcher with the help of a focus group. This third section of the interview asked the participants to list instructional strategies and representations with which they were familiar and indicate
which strategies or representations they used in their classrooms to address their students’ deficiencies with skills related to the construction or interpretation of graphs.

Participant #1

**Teacher Beliefs: Teacher Knowledge**

Participant #1’s responses to the interview questions regarding teacher knowledge demonstrated a teacher-centered approach when addressing concepts and content, which required students to apply skills related to graphing. When asked how they decided when to end instruction on content related to graphing and graphing skills, they responded that students were given two days to do the lab activity. The curriculum and the pacing of the course dictated the decisions made by this teacher on whether to teach graphing and graphing skills. This teacher does not specifically design activities that require the use of graphing and graphing-related skills by the students. If data is collected during a lab activity, the construction of a graph from the data is optional and is a student choice. If graphing skills are required of the student, those are typically skills related to the interpretation of graphs presented during the lecture and are content-specific.

**Teacher Beliefs: Student Learning**

Participant #1’s responses to interview questions related to student learning were primarily teacher-focused and instructive with the teacher using basic questioning, observations of student work, and formative assessments to determine how well students were learning how to interpret and construct graphs. To help the students learn to interpret and construct graphs, they provided remediation and opportunities to practice graphing. Some of their responses showed a measure of being student-focused and
responsive to students, with the teacher observing students teaching other students how to construct graphs as a way to determine if students were learning to construct graphs.

**Graphical Literacy: Curricular Saliency**

Participant #1 considered themselves to be weak at graphing and graphing related skills, but their responses to questions regarding graphical literacy’s curricular saliency and what is important for students to know and be able to do when it comes to graphing were not all that different than the other participants. Participant #1’s perceptions were that students need to be able to correctly label, scale, and plot data on a graph and recognize trends in the data through the correct interpretation of a graph. Participant #1’s perception was graphing literacy was an important skill set for all students, and they needed to have opportunities to apply those skills to real-life situations. Also, the teacher felt that graph interpretation skills were more important than skills related to the construction of graphs.

On the pre-interview survey of graphical skill importance, participant #1 stated that none of the skills related to graphical literacy on the survey were important within the context of their classroom. Participant #1 explained that they have the students complete very few activities throughout the school year, which requires graphing. For the activities which do generate data and could be represented graphically, students are not required to generate a graph to represent their collected data; nonetheless, some students do choose to represent their collected data graphically. Participant #1 did state that graphing skills 3, 5, 6, 11, and 12 from Table 10 were slightly important because they considered those specific graphing skills as basic and are familiar to most students. Participant #1 identified the following graphing skills from Table 10 as not applicable; 1,
2, 4, 7, 8, and 9 because of the few activities in the curriculum which require graphing data and the few that do represent trends over time. None of the course requirements require the calculation of slope, area-under-the-curve, or best fit line for students to interpret the graph and make a connection to the concept or content.

**Graphical Literacy: Student Difficulties and Prior Knowledge**

Participant #1 felt that it was easier to teach students to interpret graphs than construct. Their perception that it was easier to teach graph interpretation compared with graph construction was the opposite of the other participants. Their rationale was that students in the class have the requisite math skills, which makes interpretation of graphs easier, but the teacher commented, “I know the content.” Therefore, it was somewhat unclear whether it is easier for the teacher to teach graph interpretation because they, as the teacher, are the content expert and know how to interpret the graphs correctly, or it is easier for them to teach graph interpretation because they feel the students can learn skills related to graph interpretation easier compared to the skills required for graph construction. Participant #1 added that it was more difficult to teach students how to set up a graph because it requires higher-order thinking by the students to set up a graph from a given data set properly.

**Graphical Literacy: Instructional Strategies and Representations**

Participant #1’s instructional strategies for graph construction and interpretation were the same. The teacher acts as a model or guide, designs lab activities, asks questions, and provides student feedback. The teacher feels these instructional strategies help the students generate conclusions and recognize their mistakes when working with graphs. Participant #1 has used graphing software connected to some sensor interface in
the past and is considering whether or not to use graphing software in connection with probe-ware as a future instructional strategy to address students’ deficiencies with graphing.

Participant #2

Teacher Beliefs: Teacher Knowledge

Most of the responses to the interview questions related to teacher knowledge by participant #2 were teacher-centered. Time and pacing dictated participant #2’s decision to end instruction related to content requiring graphing and graphing skills. This teacher will set-up the x and y-axes and scaling for students before a graphing activity for the sake of time and efficiency. For participant #2, skills related to the interpretation of graphs and looking for trends depicted by a graph are more important when teaching biology than the construction of graphs and plotting data from a lab activity, which was supported by participant #1. Participant #2 typically gave students a variety of teacher constructed graphs or data sets for extra practice related to graph interpretation skills and walked around and observed the student responses to check for understanding.

Teacher Beliefs: Student Learning

Participant #2’s responses were exclusively teacher-centered and instructive in response to how their students learn to construct and interpret graphs. Participant #2’s perception is that the best way to learn skills related to the construction and interpretation of graphs is through practice, connections to skills learned in math class, teacher-led examples, and connecting the graphs generated in labs back to the content discussed in class. Participant #2 typically makes informal observations of student work and gives
formative assessments to determine if students are learning to interpret and construct graphs.

**Graphical Literacy: Curricular Saliency**

For participant #2, students being able to recognize trends through the interpretation of a line graph was important as well as their students developing skills related to graphing literacy and be able to apply those skills to real-world experiences. The examples given by participant #2 indicated the desire that their students be able to interpret graphs for themselves on topics such as climate change, information related to vaccination, and antibiotic resistance rather than rely on interpretations from other individuals. The teacher felt it was important to help students recognize when a bar graph was appropriate, and when a line graph was appropriate. This teacher felt that students were good at making bar graphs but lacked the skills necessary to know when a bar graph was appropriate versus a line graph. They also felt students struggled to interpret the trends depicted in a line graph based on whether the slope was positive or negative.

Participant #2 uses very little math with their students and feels most of the math associated with line graphs, such as slope and area-under-curve, is more applicable to the physical sciences.

Participant #2 identified graphing skills 5 and 6 on the survey of graphical skill importance in Table 10 as important in the context of their classroom. Participant #2 felt that these skills were important for practical application and would be used by the students outside the classroom in everyday situations. These skills were important for student success in the class, with the students needing to be able to construct graphs,
notice general trends in data, and interpret graphs to be able to engage with the content presented in participant #2’s class.

Skills 2, 4, 7, 9, and 10 from Table 10 were identified by participant #2 as not applicable in the context of their classroom. Their perception was that these skills were too math-intensive, and the graphing skills required in this biology course did not require the use of calculus-based concepts or skills. The students typically examined and graphed data collected from a lab activity to observe trends in the data. The students were not calculating slopes or rates of change; they were only examining the data for general trends to make their conclusions.

**Graphical Literacy: Student Difficulties and Prior Knowledge**

Participant #2’s perceptions about what is easy to teach about graphing mirror most of the other participants’ perceptions. Most students have the prerequisite knowledge about how to set-up a graph from their math classes, and this teacher feels that they only have to provide some simple reminders to students related to graph set-up and plotting data points. In the context of their classroom, they felt it was more difficult for students to scale and interpret graphs correctly. For many of their students, this is the first time the students have been required to examine data and graphs, make conclusions, and recognize any trends presented in the graph. Since skills related to graph interpretation are a new skill for most students, participant #2 feels teaching graph interpretation is particularly difficult.

**Graphical Literacy: Instructional Strategies and Representations**

Participant #2 uses lab activities, formative assessment, and small groups as their instructional strategies to address student deficiencies with interpreting graphs. Their
rationale is that it is easy to walk around the small groups to observe and give feedback. This teacher has made use of formal lab reports in the past but discontinued their use because they felt the lab reports were not beneficial in helping students learn to interpret graphs. The teacher found that students’ conclusions did not correspond with the data depicted in the graphs. Participant #2 uses in-class examples and guided practice to address student deficiencies with graph construction. With the students having a wide range of math abilities, the teacher feels these instructional strategies work best to help address students’ troubles with constructing graphs.

**Participant #3**

**Teacher Beliefs: Teacher Knowledge**

Participant #3 is more transitional with their approach to the instruction of graphing skills. Student feedback and student explanations inform the teacher’s instructional decisions regarding graphical literacy in their classroom. Participant #3 acts as a guide to help students make connections between math and science and does very little formal instruction on graphing and graphing related skills. They assume students have already learned skills related to graphing in their math classes. The teacher will, based on student feedback, provide remediation, and review graphing skills if necessary. The participant’s experience as a high school and college student drives their instruction related to graphing skills by helping students see that graphing and other math-related skills are necessary for doing science. Participant #3 is “not going to let math in a biology or ecology class be a surprise.”
Teacher Beliefs: Student Learning

The responses by participant #3 demonstrated a student-center approach to helping their students learn to interpret and construct graphs. This teacher encourages and provides opportunities for students to take on the mindset of a researcher to help them learn to construct and interpret graphs. Students have to decide the best way to make a graph and how best to represent their data in a graph for their research projects rather than the teacher providing a set model or an example. Participant #3 offered teacher-centered responses to how they recognized that their students were learning to construct and interpret graphs. The teacher relies upon direct questioning, formative assessment, and observations of student work as evidence of students learning to construct and interpret graphs.

Graphical Literacy: Curricular Saliency

Participant #3’s perceptions regarding graphing literacy were that students need to be able to represent data graphically and identify relationships between the dependent and independent variables. This teacher does not focus much instruction on graph set-up. They operate with the understanding that their students have prior knowledge from their math classes, but the teacher will provide remediation if they notice students are struggling with the set-up of a graph. Participant #3 is familiar with various statistical tools available in typical spreadsheet programs but does not intend for their students to apply these statistical tools in their classroom.

Participant #3 was similar to participant #2 with wanting their students to be able to critically review and examine data presented in graphs from real-life situations and not only in the classroom. Participant #3’s perception was that if an individual were unable to
critique information, then that individual must accept the information given and another individual’s interpretation as is. As a result, students are unable to make any personal connection with the information presented. This teacher feels that students being able to interpret and construct graphs is a form of academic literacy and is of important value.

Participant #3 identified a large majority of the graphing skills, 1, 2, 3, 5, 6, 8, 9, 10, 11, 12, in Table 10 as important in the context of their classroom. Participant #3 felt that proficiency in these graphing skills and other math-related skills were necessary for interpreting research and doing basic science. Participant #3 has the students read a variety of research articles and conduct research projects as part of the course requirements. So, to be successful in the course, participant #3 felt that students needed to able to correctly construct data tables and graphs, properly express quantified data, and identify and interpret the relationships between the variables presented. Participant #3 identified the remaining skills as only slightly important in the context of their classroom.

**Graphical Literacy: Student Difficulties and Prior Knowledge**

Again participant #3 affirms the responses given by most participants, that teaching graph set-up and plotting data points is easier due to the students’ prior knowledge. Participant #3’s perceptions are that it is more difficult to teach graph interpretation and help students make the connection between math and science. This teacher’s perception is that it is difficult for students to see the relationship between variables after the data is graphed. The students have the math skills but have difficulty transferring those skills to a science class or other novel situations, which makes teaching graph interpretation particularly difficult.
Graphical Literacy: Instructional Strategies and Representations

To address their students’ deficiencies with interpreting graphs, participant #3 uses assessments, research activities, small group work, questions students, and provides opportunities for in-class practice. Through the use of the research activities, the teacher is wanting to convey to the students that someone is going to read the conclusions they have drawn from the data they have collected. The questioning and in-class practice help students think about how to represent a particular relationship correctly on a graph. When addressing the construction of graphs, the teacher uses whole-class discussion. Participant #3 likes this instructional strategy because it gets students actively engaged and does not allow students to “hang back.”

Participant #4

Teacher Beliefs: Teacher Knowledge

Participant #4 has a very teacher-centered approach when deciding what to teach about the topic of graphing and graphing-related skills. District curriculum and ACT preparation dictate this participant’s decisions on what to teach related to graphing and graphing skills. However, the teacher’s responses to their perceived role and when it is time to move onto a different topic were more transitional. Participant #4 sees instruction related to graphing and graphing related skills as an ongoing process. They are building on those graphing skills, which were first introduced in elementary school then continued through middle school and into high school with this teacher’s class being another opportunity for students to improve and build upon their graphing skills. Participant #4 assesses students’ graphing skills by having students show the teacher their finished
graphs, which is an example by this teacher of taking a more transitional approach as compared to a more teacher-centered approach for assessment.

**Teacher Beliefs: Student Learning**

Participant #4 was teacher-focused regarding how students best learn skills related to graphing and how they knew their students were learning those graphing skills. Participant #4 relies heavily on helping students build upon graphing skills through practice, exposure to different example graphs, and providing feedback to the students about their graphing skills. The teacher was also provided teacher-centered responses as to how they knew when students had learned how to construct and interpret graphs. Their responses to interview questions related to student understanding and learning typically included some reference to the students’ performance on a formative or summative assessment of graphing skills.

**Graphical Literacy: Curricular Saliency**

Being a biology teacher, participant #4 had many of the same responses as participant #2 regarding the curricular saliency of graphical literacy. They place a lot of emphasis on students being able to recognize when to use a bar graph or line graph and students being able to recognize trends through the interpretation of graphs. This teacher also places a great deal of importance on students being able to set up a graph correctly through scaling, titles, units, and plotting of data. Similar to participant #3, this teacher is familiar with statistical and calculus concepts commonly associated with graphing but does not have students apply those concepts in the classroom.

Like most participants in this study, having students able to apply skills related to graphical literacy outside the classroom to real-life situations and experiences and draw
conclusions for themselves was important to participant #4. They also mentioned graphing skills as being important for ACT preparation and preparation for college since most college instructors expect students will have and can perform skills related to the interpretation and construction of graphs.

Participant #4 identified half of the graphing skills, 5, 6, 8, 10, 11, and 12 from Table 10 as important in the context of their classroom. Participant #4 mentioned these skills would help prepare students for the ACT. Participant #4 felt that these graphing skills were good to learn and fell under the realm of general practical knowledge useful for everyday life. These skills related to graphing literacy allow students to examine data in a study for themselves. “They can see for themselves what the data is telling them.” With participant #4 teaching the same subject as participant #2, many of the comments made by participant #4 were similar to those made by participant #2.

Participant #4 identified graphing skill 7 as not important and graphing skill 2 and not applicable. The explanation for both rankings by participant #4 was similar: biology is not a math-intensive course, and students are examining trends and not representing those trends as algebraic equations. Participant #4 felt these skills were more applicable to chemistry and physics courses than biology.

**Graphical Literacy: Student Difficulties and Prior Knowledge**

Participant #4 finds it easier to teach students how to set-up a graph and plot data points because of the students’ math background. Occasionally, the teacher needs to provide a quick refresher to get the students on track with how to set-up and create a graph. Participant #4 finds it difficult to teach students how to graph multiple variables versus time. The example given by the teacher was deer and wolf populations, wherein
students confuse the multiple variables changing over the same time interval. Teaching this skill to students requires a lot of one-on-one intervention and teacher assistance. All the students struggle at first, so for them to learn how to graph multiple variables versus time and examine the trends, take time and practice.

**Graphical Literacy: Instructional Strategies and Representations**

Participant #4 uses similar instructional strategies as the other participants to help students with the interpretation and construction of graphs. This teacher uses a blend of cooperative learning, direct instruction, and student feedback to help their students learn graphing skills. Participant #4 feels these strategies lend themselves well to promoting student discussion and allows opportunities for students to help other students with the construction and interpretation of graphs.

**Participant #5**

**Teacher Beliefs: Teacher Knowledge**

Participant #5’s responses to the interview questions regarding teacher knowledge were teacher-centered. The teacher defines their role as instructive by teaching students three basic algebraic relationships, their graphical equivalents, and equations associated with each relationship. The teacher provides opportunities through the use of practice exams for students to link a specific equation type to the appropriate graph for that equation and vice-a-versa. Much of what drives the instruction of graphing skills for participant #5 is the curriculum and the content. With the amount of content covered in a typical school year, the teacher relies on a pacing guide, so time is the deciding factor as to when to continue with a different topic rather than student feedback. The curriculum and preparation for the AP Physics exam also drive the instruction related to graphing
skills. Aside from preparing students for the AP exam, participant #5 feels that to learn science, students need to know how to read and interpret graphs and for students to learn the physics content and they need to be able to make connections to the physics concepts through the use of graphs and graphing skills.

**Teacher Beliefs: Student Learning**

Many of the responses by Participant #5 were again teacher-center concerning how their students best learned graphing skills. The teacher’s responses indicated the importance of giving students multiple opportunities to practice the interpretation and construction of graphs. Participant #5 places emphasis on students being able to match graphs to a particular scenario or provide a correct written description of a graph to help students learn graphing skills. This teacher frequently mentioned student assessments when asked how they knew students were learning to construct and interpret graphs.

**Graphical Literacy: Curricular Saliency**

Participant #5 places a great deal of emphasis on students being able to apply the mathematical skills of slope and area-under-the-curve when students are interpreting and constructing graphs. Similar to the other participants, this teacher places little emphasis on statistical analysis. Rather, the teacher values the importance of students correctly scaling, labeling, and applying units that allow students to interpret graphs.

Participant #5’s response was very content-oriented as to why students being able to interpret and construct graphs was important. This teacher wants their students to recognize that graphing is a useful mathematical tool for problem-solving in physics and is beneficial in helping students better understand physics-related concepts.
Participant #5 identified all 12 graphing skills in Table 10 as important in the context of their classroom. Participant #5 stated that these skills are used during the entirety of the school year and related to every topic in physics. Different topics have different units of measurement, and those measurements exhibit different relationships based on the comparison of the variables or measurements. As a result, the students’ ability to determine the slope, interpret the slope, distinguish between x and y-intercepts, and identify the units of a graph are important to their success in physics. Of all the 12 graphing skills, participant #5 identified graphing skill 7—students being able to translate an algebraic equation to graphical representation and a graphical representation into an algebraic equation—as the most important skill for their students and graphing skill 8—students being able to interpret what the slope of a graph represents—as their number two skill for students to be able to perform.

**Graphical Literacy: Student Difficulties and Prior Knowledge**

Participant #5 finds that overall, it is easy to teach graphing in physics because it is visual, and students can see the data as a picture. Additionally, there are only three basic graphical relationships students will be exposed to in physics; linear, inverse, and quadratic. This teacher finds it is easy to teach these different relationships, but that it can be difficult for students to learn. They find it is difficult to teach graphing skills related to slope and area under the curve because students who have trouble keeping the units straight are inconsistent with showing the proper units on a graph. Teaching graphing can also be difficult because the students need constant reminders to pay attention to the units.
Graphical Literacy: Instructional Strategies and Representations

Participant #5 employs an algorithmic approach to address graph interpretation and construction with students in addition to student questioning, modeling, and providing student feedback. With many graphs looking similar, participant #5 feels that having the students follow a set of rules helps them properly interpret and construct graphs. This teacher has also used video analysis in the past as an instructional strategy for graphical interpretation but no longer uses that strategy for the sake of time and the need to cover the curriculum by the time the AP Physics test is to be administered.

Participant #6

Teacher Beliefs: Teacher Knowledge

Participant #6’s responses to the interview questions related to teacher knowledge of graphing skills were teacher-centered and virtually identical to those of participant #5. The pace of the course, the course content, and the chemistry curriculum were the responses provided as to when the teacher makes the decision to continue to a new topic and decides what to teach related to graphing and graphing related skills. This teacher finds that the graphing skills taught are influenced by the chemistry content and used to help students learn the chemistry concepts. Much like with physics, participant #6 stated that graphs and graphing skills are used repeatedly by the students throughout the course and that students cannot do chemistry if they are unable to graph data and are not proficient with graphing skills. Participant #6 sees their role in teaching graphing skills as being no different from teaching the chemistry content. The teacher is going to model the skills and provide guidance in terms of how the students are practicing those graphing skills.
Teacher Beliefs: Student Learning

Participant #6 had very teacher-centered responses to the interview questions related to student learning of graphing skills. They help students learn to construct graphs by modeling the skills and making use of graphing software to generate graphs from data collected during a teacher-assigned activity through the use of electronic probes to help maximize the available instruction time. The teacher places more emphasis on how students connect concepts and content through the interpretation of graphs, class discussions, and the observations of student work.

When responding to questions about how they knew if students were learning and understanding how to construct and interpret graphs, participant #6’s responses indicated an approach to student learning and understanding that was between transitional and student-focused. The teacher still relies on formative and summative assessments to gauge student learning. However, the teacher also assesses students’ graphical literacy in the students’ abilities to ask more complex questions, spot discrepancies in the data on their own, recognize when the software has not scaled the graph correctly, and connect relationships generated through graphing data to the content without prompting.

Graphical Literacy: Curricular Saliency

Graph format and scaling are important skills for students to know for participant #6. Participant #6 also makes mention that students knowing how to construct and interpret graphs are important (skills) for ACT preparation. This teacher feels that it is important for students to be proficient with graphing because a graph is an easy way to summarize large amounts of data, and it is easier to describe a relationship between variables using a graph than explaining the relationship in words. This teacher, like the
others, is familiar with the various forms of statistical analysis but does not have the students apply those tools when developing and interpreting graphs.

Participant #6 identified just over half of the graphing skills, 2, 3, 4, 5, 8, 11, and 12 from table 10 as important in the context of their classroom and identified the remaining skills as slightly important. Many of participant #6’s comments related to the importance of these skills were associated with students recognizing that graphs are models and convey information. “Graphs are not just a nice thing to have,” said the teacher. Students need to know how to construct a graph, understand what the graph is communicating and that graphs “contain a wealth of information” and are not always going to be “pretty.” Participant #6’s perception was similar to participant #5 regarding the slope of a graph, that correct interpretation of the slope of a graph is a very important skill for students. Students who were able to use graph interpretation had a better understanding of the content.

**Graphical Literacy: Student Difficulties and Prior Knowledge**

Participant #6 agreed with participant #1 that graph interpretation is easy to teach for simple graphs such as temperature versus time. If students need to find a temperature that corresponds to a specific time, that skill is very concrete and is easy to teach. This teacher felt that teaching students how to see the connections expressed in the graph to the content in the chemistry course is more difficult. Participant #6’s perception was that students have a difficult time connecting mathematical concepts, such as slope, to the investigation of a science concept in a lab activity.
Graphical Literacy: Instructional Strategies and Representations

Participant #6 utilizes formative assessments, in-class questioning intertwined with the chemistry content to help students with interpreting graphs. They feel that since the chemistry content and graph interpretation are so connected, the skill will help the students make a connection with the content through in-class questioning will help with graph interpretation as well. To help students with learning how to construct graphs, participant #6 uses several online simulations and graphing software. For this teacher, the skill is about connecting the content to the graph. With the online simulations, the students can see the change in the variables immediately, and the software combined with a sensor interface provides students the opportunity for real-time data collection. Participant #6 used to have students graph data by hand but no longer does so for the sake of time. The teacher is considering adding, as an instructional strategy, a collection of premade data sets which are designed to guide students through the construction and interpretation of graphs while helping them connect the content to the graph.

Participant #7

Teacher Beliefs: Teacher Knowledge

Participant #7’s responses to the teacher knowledge interview questions were more transitional but still leaned mostly towards being teacher-centered, especially when asked how they decided on instruction related to graphing. The state standards and district curriculum guide participant #7 on what to teach related to graphing skills. As far as deciding when to continue with another topic, like the other participants, time is a major influence. Ideally, participant #7 uses student feedback through the use of assessments to decide when it is best to continue to a new topic. If students are struggling
with specific graphing skills, the teacher will reteach or form small student groups to provide remediation for struggling students, which is more student-centered.

**Teacher Beliefs: Student Learning**

Participant #7 provides students multiple scenarios to practice when helping them learn graphing skills. The teacher has students focus on creating a story that would match a particular motion graph rather than the collection of quantitative data, which is a more teacher-centered approach than student-centered. Participant #7’s responses on how they knew students demonstrated understanding and learning exhibited instruction that was a more transitional approach. Participant #7 was one of the few participants who did not provide a response relating to some form of assessment of student learning. Rather, the teacher related student learning to a student’s “look of puzzlement or of struggle” and if students were engaged with the activity and not completely withdrawn.

**Graphical Literacy: Curricular Saliency**

Participant #7 matched many of the other participants’ responses as to why students knowing how to interpret and construct graphs is important. Graphs are a way to relate and communicate information to others. If an individual is deficient in those skills, they will have to rely on others for the interpretation when exposed to data in a graphical format in magazines, newspapers, online, and other forms of media. Participant #7 places much more emphasis on the interpretation of graphs rather than construction as important skills for students to be able to know and do—students being able to recognize where the graph hits zero, changes in slope, important points along the line of the graph, and being able to differentiate similar-looking graphs from each other. The teacher also agrees with
the other participants that basic algebra skills are fundamentally important for students being able to construct and interpret proficiently.

Participant #7 identified half the graphing skills, 1, 2, 3, 6, 8, and 11 from table 10 as important in the context of their classroom and identified the remaining skills as slightly important. Through the use of stories, participant #7 helps students interpret graphs depicting the motion of objects rather than equations and mathematical relationships. The use of stories as an instructional strategy by this teacher is primarily due to the students’ weak background in math. Participant #7 considered students’ proper interpretation of the slope of a graph an important skill but not to the degree where the students need to determine an equation that represents the relationship depicted by the graph. Participant #7’s goal for students was an understanding of what the steepness of slope for a particular graph depicting motion represented versus a single data point on the graph.

Graphical Literacy: Student Difficulties and Prior Knowledge

Participant #7’s response to what was easy about teaching graphs was similar to participant #5’s response. Since graphs are visual and hands-on, it makes teaching graphing skills easier. The teacher’s rationale was that students like to draw and that it is different than just taking notes. Participant #7 said that the scaling of graphs was very difficult to teach due to the varied math background of the students and how time intensive it was to teach students how to scale a graph properly, so much so, that this teacher felt it was not worth the time required to teach scaling compared to other skills related to graphing.
Graphical Literacy: Instructional Strategies and Representations

Participant #7 uses many of the same instructional strategies as the other participants to help students with the interpretation of graphs. The teacher models, asks questions, and provides student feedback. The teacher wants the students to be able to compare their interpretation with the teacher’s interpretation. Participant #7 has made use of online computer simulations and software connected to a sensor interface in the past but not anymore because they feel the opportunities are lacking with the current curriculum. To address student deficiencies with the construction of graphs, the teacher utilizes small group work and will pair strong students with weak students. With students helping other students, participant #7 feels that working on the construction of a graph as a team allows the struggling student a better opportunity to recognize their mistakes.

Participant #8

Teacher Beliefs: Teacher Knowledge

Participant #8 has a more transitional approach when providing students with lab activities that involve graphs and graphing skills. They act as a facilitator and have students explain their thoughts during lab activities when students are collecting data and utilizing graphing skills to construct and interpret graphs. However, their role is more teacher-centered when it comes to providing practice graphs in preparation for the AP Physics test by providing practice test problems that involve graphing.

Time and curriculum drive the decision making when continuing with a new topic or concept which requires instruction related to graphing skills for participant #8, which is similar to the other participants. Participant #8 views graphing skills as fundamental to the understanding of physics. From this teacher’s perspective, if students do not
immediately have success with graphing, there will be plenty more opportunities for students to improve their graphing skills with future concepts.

**Teacher Beliefs: Student Learning**

Participant #8’s responses to interview questions related to student learning were a blend of transitional and student-focused. For this teacher, “it’s all about the labs.” The majority of responses to how their students best learn to construct and interpret graphs had some connection to a lab activity based on a teacher-designed question. Students were expected to work together in small groups to develop a procedure to collect and analyze data that would answer the question posed by the teacher. Participant #8 recognizes when student understanding and learning are occurring through quick informal observations, and when students are helping each other with the construction and interpretation of graphs, which is a student-focused approach. The teacher is looking for an increase in complexity in the students’ questions, responses, and artifacts. A graphing skill that was difficult for the students at the start of the school year is easier even though the task the teacher is asking the students to perform is more difficult.

**Graphical Literacy: Curricular Saliency**

Participant #8, like the others, places emphasis on the labeling and appropriate scaling. If the labels and scale are incorrect, the student interpretation of slope and area-under-curve will be incorrect. While this teacher recognizes the importance of students’ algebra skills to be able to construct and interpret graphs, most of their students have the requisite skills and only need reminders. Participant #8 also mentioned ACT preparation as a rationale for students learning to interpret and construct graphs. They also mentioned how important graphing skills are to help students make a cross-curricular connection
between math and science. Participant #8’s perception is that graphing validates the use of math and is not just something done in a math class. Even though this teacher sees the importance of statistical analysis, they forgo its application for the sake of time. They will make mention of various calculus concepts when providing instruction related to graphing but will not perform actual calculations or assign problems that would require the students to make use of calculus.

Participant #8 identified all graphing skills as important from table 10, except for number 10, that students being able to recognize when it is appropriate to sketch a graph that passes through the origin or (0,0) point, which they ranked as slightly important in the context of their class. Their perception was that skill number 10 was not on the same level of importance as the other eleven graphing skills. With participant #8 teaching the same subject as participant #5, many of participant #8’s comments as to why skills they deemed as important were similar to participant #5. The students’ ability to apply their math skills to derive equations from a graph, calculate the slope of the graph, determine the area-under-the-curve for a graph, are important for students to learn the physics content and fundamental to learning the physics concepts.

Participant #8 made comments similar to participant #6, that graphs have a purpose and act as a visual representation of the data. Graphs are more than something that looks “pretty.” For participant #8, the student experience is very important. Getting students collecting data as soon as possible, graphing that data, recognizing patterns, and making sense of the data through graphing was paramount. Participant #8 has received feedback from students appreciating that they were able to derive many of the equations used throughout the course.
Graphical Literacy: Student Difficulties and Prior Knowledge

With graph set-up having been taught in previous math and science classes, participant #8 finds teaching graph set-up particularly straightforward when the students typically have a strong background in math. What this teacher finds particularly difficult to teach related to graphing is students being able to interpret the relationships presented in a particular graph and being able to derive a physics equation from that relationship presented in that particular graph. Participant #8 felt that being able to derive an equation based on the relationship displayed in a graph requires higher-level thinking by the student, trial and error, a knowledge of the basic mathematical relationships, linear, inverse, and quadratic and what those relationships look like on a graph.

Graphical Literacy: Instructional Strategies and Representations

Participant #8 feels that units are the key to interpreting graphs correctly, so they design activities which force students to examine units. They also ask probing questions of the students and provide student feedback. The teacher feels that the feedback and questioning help students address their misconceptions related to the interpretation of graphs. Participant #8 uses a software interface to help students construct graphs and provides guided practice with proper scaling of graphs through the use of the software. The teacher has used hand graphing in the past, but no longer for the sake of time.

Findings by Research Sub Question

Findings by research question will be addressed through the merger of the quantitative and qualitative pieces. The central research question that guided this study was to how do secondary science teachers devote instruction to address graphical literacy
with their students in the context of their classroom? The following research subquestions inform the central research of this study.

1) How did secondary science teachers’ beliefs about science teaching and learning in combination with their topic-specific professional knowledge inform their instruction as they addressed their students’ graphical literacy within the context of their classroom?

2) What were the specific student deficiencies in graphical literacy that secondary science teachers addressed within the context of their classroom?

3) What were the specific instructional strategies or representations used by secondary science teachers to address their students’ deficiencies associated with graphical literacy in the context of their classrooms and the rationale for their use?

**Research Sub Question #1**

How did secondary science teachers’ beliefs about science teaching and learning in combination with their topic-specific professional knowledge inform their instruction as they addressed their students’ graphical literacy within the context of their classroom?

Several themes emerged through the analysis of the qualitative and quantitative aspects of this study that helped the researcher address RSQ #1. Content and curriculum, time, standardized test preparation, math connections, and students making real-world connections were pervasive throughout the interview. These themes provided some insight into how the participants’ beliefs about science teaching and learning, and their topic-specific professional knowledge (TSPK) informed their instruction as they addressed graphical literacy with their students in the context of their classroom.
On the teacher beliefs about effective science teaching (TBEST) survey, all the participants in this study ranked statements that correlated with learning-theory aligned science instruction much higher than statements that correlated to confirmatory science instruction and all hands-on all the time. Many of the responses to interview questions by the participants in this study corresponded to statements categorized as learning theory aligned instruction. Statements 3, 6, 11, 17, and 18 from the TBEST survey, see Table 15, exhibit characteristics of the themes from the interviews.

**Table 15**

*Average participants’ responses – statements of learning theory aligned science instruction.*

<table>
<thead>
<tr>
<th>TBEST Statement</th>
<th>Average Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.) Students should rely on evidence from classroom activities, labs, or observations to form conclusions about the science concept they are studying.</td>
<td>5</td>
</tr>
<tr>
<td>6.) Teachers should provide students with opportunities to connect the science they learn in the classroom to what they experience outside of the classroom.</td>
<td>6</td>
</tr>
<tr>
<td>11.) Teachers should provide students with opportunities to apply the concepts they have learned in new or different contexts.</td>
<td>5.7</td>
</tr>
<tr>
<td>17.) Students should have opportunities to connect the concept they are studying to other concepts.</td>
<td>5.8</td>
</tr>
<tr>
<td>18.) Students should consider evidence that relates to the science concept they are studying.</td>
<td>5.7</td>
</tr>
</tbody>
</table>

However, many of the participants' responses to interview questions from the teacher beliefs interview (TBI) for graphing literacy exhibited a teacher-focused approach to skills related to graphing. Occasionally some of the participants' statements were transitional and were between teacher and student-focused.
Content and curriculum helped to inform instruction for both the physical science teachers and biology teachers as they addressed graphical literacy and graphing related skills with their students. Many of the participants discussed how the graphing skills taught to the students were used to help students better understand the content or concepts being taught and how the construction and interpretation of graphs helped to facilitate the learning of a particular concept. For example, participant #6 stated that “You can’t do chemistry without graphing.” Many also discussed the pacing and time allotted to curriculum and content as something which influenced their instruction related to graphical literacy.

When the researcher asked participants how they decided when to end instruction on a topic, which required students to interpret or construct graphs, most mentioned some aspect of time or pacing. Participant #1 was most direct “Students have two days to do the lab.” Many of the teachers referenced time or having to follow a pacing guide so that they would be able to cover the required content. Most participants cited time as a primary factor that influenced instructional decisions related to graphing skills. Many participants acknowledged that skills related to the construction and interpretation of graphs were used and expanded throughout the school year when addressing different concepts or content. Therefore, if students were struggling with a particular skill related to graphing, there would be additional opportunities to address that skill later in the course.

Many of the participants mentioned that students being able to demonstrate graphing skills were either written into the district curriculum or was an integral part of the curriculum being taught and would be assessed in some format be it on the ACT, on
formative or summative assessments, or a final content test like an AP content exam. All participants mentioned test preparation in some form as a factor that influenced their instructional approach to graphical literacy with their students. A majority of participants mentioned that graphing skills needed to be addressed with students to help prepare them for the ACT. All participants mentioned some form of summative or formative assessments as a method to gauge student learning related to graph construction and interpretation.

The connection between math and science was a pervasive theme through all the interviews. Participants whose main content area was physical science (except for Participant #7), discussed how vital it was for their students to be able to derive equations from graphs as well as be able to apply the concepts of slope and area under curve to help with the understanding of a particular concept or to correctly interpret a graph. Participants whose content area was the biological sciences focused on a less math centric approach to graph interpretation of slope and by helping students “see trends” in the data through graph construction and interpretation rather than calculating slopes and deriving equations.

Every participant discussed in some fashion how important it was for the students to be able to apply what they have learned in their math classes related to graphing and graph construction to science. The students’ graphical literacy was important to the participants for their students' ability to make the connection that the skills they learned in their math classes had an application outside of math, and students’ graphing skills helped to provide that bridge between math and science. When discussing the realization by a student that the concept of slope has an application outside the math classroom,
participant #8 made the following comment in the character of a student, “Wait, slope means something? It’s not just something my math teacher told me I had to do.”

This theme of math connections was also prevalent when participants mentioned the difficulties students had with graphing skills. Every participant mentioned algebra and algebra-related skills needed to be taught or remediation be provided if students’ math skills were not adequate before or during the instruction of skills related to graph construction and interpretation. The participants' responses to what they knew about graphs and graphing skills and what they did not intend for their students to know about graphing also had a cross-curricular connection with math. Each participant mentioned some form of statistical analysis and or calculus concepts related to graphing as something they knew but did not intend for their students to know.

Having students able to make real-world connections through the use of graphing skills, typically those skills related to graph interpretation, was a common theme. Many participants considered skills related to graph interpretation as a life skill and necessary for their students to be able to make informed decisions about a topic or concept they read about in the media. Many participants talked about not wanting their students to have to rely on interpretations of others and considered the inability to interpret graphs outside the context of the classroom an academic deficiency.

Research Sub Question #2

What were the specific student deficiencies in graphical literacy that secondary science teachers addressed within the context of their classroom?

The results from the survey of graphical skill importance and the themes which emerged from the follow-up interview questions to the survey of graphical skill
importance helped the researcher address RSQ #2. The results from the survey of graphical skill importance and the interviews demonstrated a clear distinction between the participants whose primary content area was biology and those whose primary content area was physical science and the specific deficiencies related to graphical literacy they addressed.

Participants whose primary content area were the physical sciences generally identified either all or most of the skills on the graphing survey and during the interview as important for their students within the context of their classrooms. While those participants whose primary content area was biology identified graphing skill 5: students being able to construct an understanding of graphs presented during lectures, skill 6: students being able to match narrative information from a passage to a graphical representation, and 11: students being able to interpret graphs based on the format of the visual features such as color, size, aspect ratio, scale and legend/labels, as those important for their students based on the results from the survey of graphical skill importance and the interview questions related to student deficiencies in graphing literacy.

The biology instructors were more concerned with their students being able to correctly label, set-up graphs, notice the trends in graphed data collected during a lab activity, and conceptually examine the slope produced by a line graph. The physical science instructors were more concerned with students being able to derive equations that represented the mathematical relationships of the concepts and content being addressed in the course. The physical science teachers expected students to be able to utilize mathematical concepts such as slope and area under the curve to solve problems, interpret graphs, and quantify relationships between the variables shown in a line graph.
Two themes related to students’ deficiencies with graphing emerged from the graphical skill surveys and interviews that were common to each participant in the study: connecting science to math and making connections to the content through the interpretation of graphs. Participants in the study identified math skills and math connections to science as key factors enabling students' proficiency with skills related to graph construction and interpretation. Participants made statements like “students need to know what various mathematical relationships look like on a graph,” “it’s difficult for students to transfer and apply math skills to science,” “students need to be proficient in math,” and “math scares students.” Many of the participants also acknowledged the relationship between a student’s math skills and their ability to interpret and construct graphs. They also perceived that the majority of their students had the requisite math skills to be able to construct and interpret graphs properly. If students did struggle with the math, they would provide the necessary review or remediation.

The majority of participants discussed having to help students connect what they learned in math to what they were doing with graphing in the context of the science course. In response to this issue, Participant #5 stated, “It’s easy to teach but hard for students to learn.” Participant #3 said, “Students have the tools but don’t know how to use them.” Participants’ perceptions were that they were not teaching students math skills so much as they were helping students apply those math skills when addressing graphing.

Students making connections to the content through the interpretation of graphs was another common student deficiency related to graphical literacy mentioned by all the participants. They discussed students making connections to the content through the interpretation of graphs “as being a new skill,” “takes practice and time,” “requires
higher-level thinking,” “does not come quickly,” “fundamental to learning the content,” and “helps students understand the content.” Regardless of content area or grade level, students being able to make connections to the concepts or content was a theme that was pervasive throughout all of the interviews. Participant #6 did not see teaching graphing skills as “being as different than teaching the other content and chemistry.” When referring to teaching chemistry and graphing data, participant #6 also said, “You can’t really do one without the other.” Participant #8 said of students making connections to content through graphing, “graphing was not the end goal of the experience (a lab activity), but it was fundamental to that experience.”

**Research Sub Question #3**

What were the specific instructional strategies or representations used by secondary science teachers to address their students’ deficiencies associated with graphical literacy in the context of their classrooms and the rationale for their use?

Participants were asked to list as many representations or instructional strategies related to teaching skills related to the construction and interpretation of graphs with which they were familiar, regardless if they used them or not. The majority of participants struggled with this question during the interview, even though many had already mentioned several representations or instructional strategies throughout the interview. Their struggle could have been a result of the length of the question or that this question was near the end of the interview. The majority of the interviewed participants listed five different instructional strategies or representations associated with graphical literacy within the context of their classrooms, see Table 16.
Table 16

Number of instructional strategies or representations mentioned per participant

<table>
<thead>
<tr>
<th>Participant</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant #1</td>
<td>5</td>
</tr>
<tr>
<td>Participant #2</td>
<td>5</td>
</tr>
<tr>
<td>Participant #3</td>
<td>8</td>
</tr>
<tr>
<td>Participant #4</td>
<td>8</td>
</tr>
<tr>
<td>Participant #5</td>
<td>10</td>
</tr>
<tr>
<td>Participant #6</td>
<td>6</td>
</tr>
<tr>
<td>Participant #7</td>
<td>5</td>
</tr>
<tr>
<td>Participant #8</td>
<td>7</td>
</tr>
</tbody>
</table>

The majority of participants listed instructional strategies or representations that were related to in-class examples, some form of assessment, student feedback or questioning, or lab activity. Many of the responses had some relationship to the use of technology, online computer simulations, software interfaces, video analysis, and the use of a spreadsheet program, see Table 17.

Table 17

Count of instructional strategies and representations for graphical literacy.

<table>
<thead>
<tr>
<th>Strategy or Representation</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Class Examples</td>
<td>10</td>
</tr>
<tr>
<td>Assessment</td>
<td>9</td>
</tr>
<tr>
<td>Student Feedback</td>
<td>7</td>
</tr>
<tr>
<td>Lab Activity</td>
<td>7</td>
</tr>
<tr>
<td>Practice Graphs</td>
<td>6</td>
</tr>
<tr>
<td>Online Computer Simulations</td>
<td>5</td>
</tr>
<tr>
<td>Data sets (Student or Teacher Generated)</td>
<td>5</td>
</tr>
<tr>
<td>Software Interfaces</td>
<td>5</td>
</tr>
<tr>
<td>Student Groups</td>
<td>4</td>
</tr>
<tr>
<td>Outside source material</td>
<td>2</td>
</tr>
<tr>
<td>Use of a spreadsheet program</td>
<td>1</td>
</tr>
<tr>
<td>Application of Statistics</td>
<td>1</td>
</tr>
<tr>
<td>Video Analysis</td>
<td>1</td>
</tr>
<tr>
<td>Develop Equations</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 18 shows instructional strategies ranked on the frequency of use by the participants and frequency of use by the participants. Practice graphs as an instructional strategy were mentioned most frequently by the participants to address their students’ deficiencies with the construction and interpretation of graphs. Of particular interest is the participants’ response rate for instructional strategies or representations involving the use of technology. The use of some form of technology as a way to address graphical literacy was mentioned twelve times by the participants, but only two of the participants used technology frequently to address graphing skills.

**Table 18**

*Instruction strategies ranked on frequency of use and count of frequency.*

<table>
<thead>
<tr>
<th>Strategy or Representation</th>
<th>Rank and Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data sets (Student or Teacher Generated)</td>
<td>#1, #3</td>
</tr>
<tr>
<td>Lab Activity</td>
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<td>Practice Graphs</td>
<td>#1, #2 #2 #2, #3</td>
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<td>In-Class Examples</td>
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<td>Online Computer Simulations</td>
<td>#3</td>
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<td>Student Feedback</td>
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Many of the instructional strategies used by the participants are used in conjunction with one another. For example, all participants mentioned using a lab activity in which students would collect data and construct a graph to represent that data. However, many of the participants mentioned how they would ask students probing questions and provide students feedback to guide their thinking and help them make connections from their interpretation of the graphs to the content or concept during these lab activities. Many participants had students working in groups during a lab activity, which allowed opportunities for students to help one another with the construction or
interpretation of the graph. The group work also allowed the teachers to move from group to group and provide feedback to help the students make connections to the content or concepts.

The instructional strategy mentioned most often was the use of practice graphs in the form of bell work, homework, or guided practice. Six of the eight participants ranked this instructional strategy as one of their most often used instructional strategies. Participant #2’s perception is that the use of practice graphs helps to address students’ wide range of math abilities. Participant #3 used practice graphs and an in-class activity to help students think about how to represent a specific relationship on a graph. Participant #5 used an algorithmic approach to graph construction and interpretation and provided several practice graphs to their students. Participant #7 used practice graphs as a modeling tool to help students compare their interpretation of the graph with the teacher’s interpretation of the same graph as a strategy to improve student’s graphing skills.

Only two participants in this study regularly used some form of technology in the form of probe-ware and a sensor interface. Their primary rationale for its use was to save time. They each acknowledged that it took the frontloading of instruction on their part to teach the students how to properly use the technology, but saved time in the long run by avoiding the tedious process of graphing by hand. Both participants also mentioned the benefit of real-time data collection by the students and having the sensor interface generate the graphical relationship immediately helped students better interpret relationships between variables. Participant #6 used online simulations as a way for their students to be able to make a change to one variable and observe the immediate change in the dependent variable. While many participants in this study did not use technology as
an instructional strategy for building students’ graphical literacy, they all acknowledged its benefit and expressed a desire to use more technology.

An overarching finding from this study is that there does not appear to be a universally accepted instructional strategy used by these participants, but rather an interconnectedness of several instructional strategies or representations. Each participant seemed to have a favored strategy when providing instruction related to the improvement of students’ graphical literacy. For some participants, it was the use of technology; for others, the strategy of choice was the use of in-class example graphs. Regardless of the favored strategy or representation, virtually all participants mentioned that providing students an opportunity to practice the construction and interpretation of graphs and providing feedback was crucial to the improvement of students’ graphical literacy. This result should not be surprising because practice and student feedback are simply examples of good pedagogy.

**Conclusion**

All the participants in the study responded favorably to statements on the teacher beliefs about effective science teaching (TBEST) surveys that were representative of learning-theory aligned science instruction and responded much less favorably to statements representative of confirmatory science instruction. Responses to statements on the TBEST representative of all hands-on all the time were less favorable than learning-theory aligned but not to the degree as statements related to confirmatory science instruction. Many of the comments made by the participants during the interview process reflected a learning-theory aligned approach to science instruction of skills and content,
which required students to apply or learn skills related to the interpretation or construction of graphs.

The participants whose primary content area was biology placed far more emphasis on their students being able to utilize graphing skills that were not so math centric such as students being able to construct an understanding of graphs presented during class, match a narrative to a graphical representation, and interpret graphs based on the format of the graph. All participants recognized the importance of the skill statements mentioned in the survey of graphical skill importance. Only one individual marked one skill as not important, but their explanation as to why had more to do with the skill not applying to what they taught rather than an unimportant student skill needed for graphical literacy.

All the participants emphasized the importance of students learning and having to apply graphing skills in their classes to become more graphically literate and be able to apply those skills of graphical interpretation to graphs they may encounter outside the classroom and when their formal education has ended. Each participant mentioned how it was important that their students had an opportunity to apply a skill learned in a math class to a situation or application outside of the traditional math class.

The participants’ viewed graphing skills important within the context of their classroom as a way for students to make connections to the content and that the application and learning of skills related to the construction and interpretation of graphs, and improvement in students’ graphical literacy was a by-product of learning the content. Participant #8’s statement when referring to a lab activity best represents this theme,
“graphing was not the end goal of that experience, but it was fundamental to that experience.”
Chapter 5: Discussion and Conclusions

**Introduction**

This mixed-methods study began with the question of how do secondary science teachers address graphical literacy in the context of their classroom. Through the use of topic-specific professional knowledge (TSPK) as the conceptual framework for this study, the researcher developed survey and interview instruments with the help of a focus group to collect data from nine participants with eight being interviewed. These participants were all secondary science teachers. Each teacher taught in a specific content area at a large school in a Midwestern city. The primary themes which emerged from this study related to how these teachers addressed graphical literacy with their students were, helping students make connections with science and math, being able to apply graphing skills to real-world situations outside of the traditional classroom and later in life, and using graphing related skills to help students make connections with the content and concepts being explored.

**Connections to the Literature**

**Research Sub Question #1**

*How did secondary science teachers’ beliefs about science teaching and learning in combination with their topic-specific professional knowledge inform their instruction as they addressed their students’ graphical literacy within the context of their classroom?*

Real-world application by students was a prevalent theme throughout all the interviews, and a theme all participants mentioned when responding to interview questions related to the importance of their students learning graphing-related skills. The importance of students being able to apply skills related to graphical literacy outside the
classroom identified in this study was also identified in the literature (Arons, 1983; Glazer, 2011; McDermott et al., 1987). Students being able to make cross-curricular connections with math skills learned in a traditional math classroom through the application graphing skills was expressed by all participants as being important.

Many of the participants indicated in their responses to interview questions that they felt that their students had the requisite math skills to construct and interpret graphs but, at times, needed remediation. This aspect of teacher-assumed math skills by students was mentioned in the literature (Meredith & Marrongelle, 2008). However, the participants in this study seemed to recognize that students might need remediation or reminders of math skills related to graphing to be successful when asked to construct or interpret graphs related to the content taught by the individual teachers.

All participants indicated either a willingness to provide remediation for students who might lack the necessary math skills related to graphing or had some instructional strategy in place to help build and improve upon a student’s math skills related to graphical literacy. Teachers acting as a guide and providing assistance to students and help them improve their graphing skills is recognized in the literature as being necessary for students to improve those skills related to graphing (Phage et al., 2017).

Participants in this study placed much importance on students having opportunities to use skills learned in a typical math class and by applying those skills to situations and scenarios not necessarily experienced in a typical math curriculum. All the participants mentioned that students be allowed to apply skills learned in math to situations outside of a traditional math setting was important. Many participants mentioned how the construction and interpretation of graphs was a way for students to
apply skills learned in math to a content area outside of math and experience for themselves that the skills they learned in math have a use outside of the traditional math classroom. This theme of teachers using graphing as a way to help students make connections with math and apply skills learned in math in a nonmathematical setting was not an aspect of the literature review of this study, nor was it considered by the researcher.

Content and curriculum appear to heavily influence the participants’ approach to graphical literacy in their classroom. All participants mentioned how pacing, content, or the curriculum, be it the district curriculum or curriculum defined by the AP Board, defined their approach to graphical literacy in their classroom. Also, many participants mentioned test preparation, be it the ACT, district summative assessments, or an AP content test as another factor that influenced decisions related to their instruction of graphing skills. These themes are all aspects of the conceptual framework which guided this study and also directly influence a teacher’s topic-specific professional knowledge (TSPK) (Kind, 2015).

The topics and content that the participants addressed within their classrooms determined how they approached instruction related to graphing. The participants cited specific content and or concepts that required students to learn and apply skills related to the construction or interpretation of graphs. How the participants approached graphing instruction seems to support the literature related to a teacher’s TSPK, their prior knowledge of the topic, and relationships within the subject matter covered (Jones, M. G., Carter, 2007; Kind, 2015).
Research Sub Question #2

What were the specific student deficiencies in graphical literacy that secondary science teachers addressed within the context of their classroom?

Specifically, which skills related to graphing the participants would have students apply in their classrooms were very much content and curriculum-driven. Participants whose primary content area was the biological sciences had students apply graphing skills that were less math-centric, such as students being able to construct an understanding of graphs presented during class, match a narrative to a graphical representation, and interpret graphs based on the format of the graph while the participants whose primary content area was the physical sciences focused on students applying and developing skills which were more math-centric, such as students calculating the slope of the line, determining and interpreting the area under the curve, students relating one type of graph with another, deriving an algebraic equation from graph, and matching an algebraic equation to the correct graph.

The content or topic seems to have an influence on the participants' choice of which graphing skill to address with their students is supported by the literature (Geddis & Wood, 1997; Grossman, 1990; Hashweh, 1987; Loewenberg Ball, 1990; Veal & Makinster, 1999). However, regardless of subject or topic, the participants' responses to interview questions indicated that addressing skills related to the interpretation of graphs was very important, be it a math centric approach where students calculate slope or area under the curve or less math centric where students qualitatively examine the steepness of slope to make claims about the data collected. Students being able to determine the appropriate graph to construct based on the data collected and the use of appropriate units...
and labels that convey the appropriate meaning of a graph were skills deemed important by all participants and addressed by all participants with their students.

**Research Sub Questions #3**

*What were the specific instructional strategies or representations used by secondary science teachers to address their students’ deficiencies associated with graphical literacy in the context of their classrooms and the rationale for their use?*

The general purpose of any instructional strategy is for the teacher to develop illustrations, analogies, explanations, and demonstrations in anticipation of student difficulties or preconceptions surrounding a particular topic (Kind, 2015). This study tried to address what instructional strategies secondary science teachers are using when they address their students’ graphical literacy and graphing skills. The rationale provided for a specific instructional strategy or strategies used by the teacher to address graphing and improve graphical literacy among their students was an important aspect of this study (Rosenquist & McDermott, 1987; Taylor, 2010).

The use of graphs and graphing skills as a way to help students make connections with the content was a common theme identified throughout this study. Most participants mentioned that the rationale for the use of a particular instructional strategy was to help students make connections with the content (Taylor, 2010). Helping students make connections to the content and improving students’ graphical literacy by using a particular instructional strategy to address deficiencies is supported by the topic-specific professional knowledge (TSPK) construct, this study’s conceptual framework (Kind, 2015).
Participants who used some form of technology as a primary instructional strategy stated the importance of students having the opportunity experience of real-time data collection as a rationale for the use of technology to improve graphical literacy and help the students make connections with lab experiences to the content or concepts. (Dori & Sasson, 2008; Harsh & Schmitt-Harsh, 2016).

**Implication for Practice**

The purpose of this study was to determine how the participants, secondary science teachers, devoted instruction to address graphical literacy with their students in the context of their classroom. The themes that emerged from the results of this study seemed to indicate that these eight participants were familiar with and recognized the benefit of students being proficient with the skills identified in the literature related to graphical literacy. Further, the results of this study also seemed to indicate that a teacher's topic-specific professional knowledge (TSPK) does influence the depth to which the participants in this study addressed graphical literacy. All the participants indicated it was of paramount importance that their students be able to apply graphing skills, particularly those related to the interpretation of graphs, to the content and to graphs which they might experience outside the classroom in the present or future. Many of the participants discussed how teaching graphing skills provided opportunities for students to make a cross-curricular connection between math and science, and the importance of students being able to have an opportunity to connect what they learned in a math class and experience a real-world application outside of the math classroom.

The results of this study might be of use to educational leaders and how they address science curriculum and instruction by providing those leaders some insight into
the perceived importance secondary science teachers place on graphing skills. The results of this study indicate that science teachers believe graphing is a way to help students connect science to real-world scenarios and make connections between math and science.

The degree to which content influenced participants’ instruction related to graphing skills was unexpected. Each participant had their students apply graphing skills to situations specific to topics and concepts being taught and only provided remediation related to those specific graphing skills being utilized by the students. So, if the deficiencies associated with graphical literacy is a common issue for students at all academic levels and nationalities as the literature suggests (Dori & Sasson, 2008; Harsh & Schmitt-Harsh, 2016; McDermott et al., 1987; Phage et al., 2017), and only specific graphing skills are being addressed in specific science subject areas, then educational leaders may what to consider how deficiencies in students’ graphical literacy might be addressed if students do not complete a robust secondary science curriculum? Since a students’ abilities to interpret graphs and construct simple graphs is seen as a “form of academic literacy” by many participants in this study and the science education literature (Arons, 1983; Glazer, 2011; Harsh & Schmitt-Harsh, 2016; Taylor, 2010), how do we as educators and leaders in education ensure all students have some level of graphical literacy and what level of mastery should be demonstrated by students?

The level of emphasis many of the participants placed on building and developing their students’ skills related to graph interpretation and construction for the purpose of standardized test preparation was an aspect of this study not necessarily anticipated. Many participants mentioned preparation for the ACT in response to questions related to the importance of students being proficient in graphing skills. Many science educators
and educational leaders already know that the science portion of the ACT is not a content test but a measure of how well students can interpret graphs and data. The results of this study seemed to indicate that science teachers only address graphing skills related to their content area and then only with specific concepts. Should leaders in education consider requiring their science teachers to provide opportunities for students to have experiences with graphs that are not related to a specific science subject or concept as a way to help prepare students for the ACT and other high-stakes tests?

Of the eight participants in this study, only two regularly used some form of technology as an instructional strategy to help students develop their graphical literacy. The other participants made comments of possibly having a desire to use technology as a way to address graphical literacy. Instructional leaders looking for a way to help science teachers incorporate more technology in their classrooms might want to explore professional development opportunities to assist their science teachers with incorporating technology as a way to improve graphical literacy for their students.

Most participants in this study felt comfortable with providing instruction related to the construction and interpretation of graphs. Two participants did mention they felt that their instruction related to graphing was lacking and understood the importance of possibly building their instruction strategies related to graph interpretation and construction. The theme of teachers wanting to develop their instructional strategies related to graphing was not prevalent in this study. Nevertheless, the results of this study do indicate the importance the participants placed on students developing their graphical literacy. Educational leaders who are responsible for providing professional development
opportunities for science teachers might consider professional development topics related to graphical literacy.

**Limitations**

Participation in this study was limited to secondary science teachers only, and only science teachers who specialized in a particular content area such as biology, chemistry, or physics were invited to participate. The results of this study might have been different if secondary science teachers who teach in a variety of content areas were allowed to participate. The study participants whose primary content area was biology did not include an AP biology teacher whereas those teachers whose primary content area was in the physical sciences included two AP Physics teachers and an AP Chemistry teacher.

The sample size was also a limitation. There were only eight participants in this study from two different school districts who completed both the surveys and interviews. With such a small sample size and having participants from only two school districts, it is difficult to make any broad claims based on the results of this study. Another limitation of this study is no classroom observations were made during the study. The results of this study rest purely on the perceptions of the science teachers participating in this study.

Also, how the participants utilized and identified instructional strategies to address their students’ deficiencies with graphical literacy is one aspect of this study that is particularly weak and limited the researcher’s efforts to determine the specific instructional strategies or representations used by the participants to address their students’ deficiencies associated with graphical literacy and the rationale for their use. Many participants needed prompting when asked to respond to interview questions about
what specific instructional strategies or representations they used to address their students’ deficiencies with graphing skills associated with the construction and interpretation of graphs. This limitation may have been due to the order of the interview questions. The questions related to instructional strategies and representations comprised the last set of interview questions. Many of the participants may have felt they had already addressed instructional strategies and representations for graphing skills earlier in the interview. Also, the researcher may have been at fault as well. With the interview coming to an end, the researcher may not have pressed the participants for more detailed answers related to the questions about instructional strategies and representations.

**For Further Study**

Participants in this study, particularly those participants who taught AP level science courses, seemed to focus on graphing skills related to the content area they taught and specific to topics within that content area. With most secondary students not taking AP science courses, how might it be possible to build all students' graphical literacy? And to what degree?

A limitation of this study was no classroom observations were conducted. The study solely relies on the perceptions of the science teachers who participated. It might benefit educational leaders to know what specific instruction related to graphical literacy secondary science teachers are providing their students. Researchers getting into the classroom, making observations, and collecting artifacts related to instruction on graphical literacy may help to identify specifically what secondary science teachers are doing in the classroom to address graphical literacy with their students.
This study only selected secondary science teachers who teach in a specific content area to participate. Would the same themes be identified in a study that relied on data from interviews of secondary science teachers who teach a variety of content? Additionally, would conducting a similar study, which included middle school science teachers be beneficial and generate similar results? How might the importance of graphical literacy perceived by secondary math teachers align with secondary science teachers?

Finally, the importance the participants placed on helping students develop their graphing skills to prepare them for the ACT may be of interest to educational leaders. Does the development of an individual’s graphical literacy lead to higher test scores on the science portion of the ACT? Would the development of an individual’s graphical literacy be represented in the results of a student’s ACT science scores?

**Conclusion**

The purpose of this study was to help provide insight into how secondary science teachers address graphical literacy with their students in the context of their classrooms. The importance of each participant in this study placed on their students developing and building their graphing skills related to the interpretation and construction of the graph is evident in the results of this study. Participant #3 indicated that graphing is a form of academic literacy and is of important value. The value placed on graphing skills and students’ graphical literacy by the participants of this study justifies this study’s academic merit.

The use of graphing as a way to help students make connections with math and science by providing students an opportunity to make real-world connections through the
interpretation and construction of graphs was anticipated. However, the level of importance that all the participants in the study placed on providing students opportunities to help students make connections between math and science and real-world connections was a surprise. Further, the themes which emerged from this study seemed to indicate that graphing and graphing-related skills were intermeshed with the content delivered by the participants. Many of the participants used graphing and graphing-related skills as a way to help their students to make connections with content.

Many participants in this study perceived graphing as a mathematical tool to be used as a way to help students understand the concepts and content being studied. Participant #8’s comment, “graphing was not the end goal of the experience, but it was fundamental to that experience,” further demonstrates graphing skills, as perceived by the participants, is not the end goal but rather a by-product of doing and studying science. That graphing skills were not being specifically taught, but were used by the participants more as a method to teach content and help students connect with the content was somewhat unexpected.

The instructional strategies and representations used by the participants to address student deficiencies with graphical literacy varied, but the rationale for their use was consistent with all participants, which was opportunities for student practice. The participants indicated students needed to be given multiple opportunities to practice skills related to the interpretation and construction of graphs, but the instructional strategies employed varied from participant to participant. What seems to be clear from the results of this study, even with the limited number of participants, is that secondary science
teachers can recognize and anticipate specific deficiencies their students have with graphical literacy and attempt to address those deficiencies with their students.

The opinion of this researcher is that there is much more to explore within this topic of graphical literacy. Are there particular instructional strategies that happen to be most effective? Are skills related to graphical literacy transferrable between content areas, or do students need to have some content knowledge related to the content represented by the graph which they are attempting to interpret? Actual classroom observations and possibly measuring a student’s graphical literacy may help to answer these questions and others, as well as provide a better picture of how secondary science teachers address graphical literacy with their students.
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