A Conceptual Framework for the Development of Curricular Supports for Phenomena-Based Teaching Using Geospatial Technology

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Plan B Project

Submitted in partial fulfillment of the requirements
for the degree of Master's of Science in Natural Science Education
in the Science and Mathematics Teaching Center and the Haub School
at the
University of Wyoming
2022

Laramie, Wyoming

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Abstract

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (National Research Council (NRC), 2012) identifies ta new vision for K-12 science learning. Phenomena-based, storyline learning is an instructional strategy used to successfully achieve these new goals in science education. The Framework (NRC, 2012) also indicates students must engage with technology to build practical knowledge and skills that will be applicable outside of the classroom. Geospatial technologies may serve as platforms for students to develop some of these skills, specifically the evaluation and analysis of data and an improved conception of space. While both geospatial technology and phenomena-based, storyline learning hold promise for students, the literature lacks connections between them. This project was designed to investigate how the literature informs a conceptual framework that aids the development of curricular supports for educators teaching with geospatial technology and phenomena-based, storyline methods. This work began with a literature review that investigated important principles from the fields of K-12 science education, geospatial technology, curriculum support, and technological acceptance. The final product is a conceptual framework that backs the development of curricular supports for phenomena-based, storyline learning for geospatial technology. Through the conceptual framework, I present connections between the various fields that inform curricular development. I conclude with a discussion on the limitations and benefits of the conceptual framework analysis process, along with recommendations for future work.

Keywords: geospatial technology, phenomena-based learning, storyline learning, three-dimensional learning, technological acceptance, curricular supports

Acknowledgements

I would like to thank my entire committee for their continued support throughout this project. Special thanks are owed to Martha Inouye and Ana Houseal for their care, expertise, and willingness to continually try to get me to use the active voice. Thanks to Daniel Laughlin for his support and the introduction to this work through The Global Vegetation Project.

Thanks to my Laramie family, Daryl, Emily, Gaby, Cassie, Libby, Kieran, Jack, Sheena, Piper. Without your continued love, encouragement, and the joy you bring to my life, I would not have gotten through this. Thanks to Alex, whose unwavering, nurturing support brought me back from the brink too many times to count.

Thanks to the others in the Laramie community who have lent their time and energy to me this year and contributed something new to my life. I owe you a great debt.

Thanks to friends near and far, Lee, Aaron, Mike, Chris, Jared, Allison, Danny, Nick, Jimmy, Evan, Jordan, Emily, Bryan, Eric, Jorge, Paul and so many others who lift me up, share their lives, and always give me a reason to move forward.

Thanks to Dominique, the fiercest educator I know, who reminds me that every second spent in education is worth it, even when it’s unfathomably difficult.

Thanks to my Bubbie and Mom Mom, who provide flattery on a level that only a grandmother can.

Most importantly, thanks to my family, Jamie, Mom, Dad, who I truly would not be walking this Earth without and whose love and compassion are my life’s foundation.

To anyone I may have forgotten, living or not, who has brought me to this point in my life, I humbly thank you.

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Chapter 1

Introduction

Background

Science education for K-12 students and educators in the United States has undergone significant upheaval during the past four decades. The pathway towards current science academic expectations can be traced back to the early 1980's, when the National Commission on Excellence in Education released *A Nation at Risk: The Imperative for Educational Reform* (1983). This report suggested that American test scores in literacy, mathematics, and science had all fallen significantly in the previous decades and that this academic deficiency was a threat to American economic success. The report called for unified standards and expectations in public schools that would result from collaboration between scholars, educators, and politicians. While this report was issued, the science education community itself was searching for its identity and how to align itself with these new challenges to reform (DeBoer, 2000).

Several responses to this call for standards-centered education followed. In 1989, the American Association for the Advancement of Science (AAAS) published Project 2061's *Science for All Americans* (AAAS, 1989). This report identified goals for science literacy and provided foundational skills and knowledge the authors suggested all students should know. To achieve these goals, the AAAS produced a companion publication, the *Benchmarks for Science Literacy,* in 1993 (AAAS, 1993). This publication provided standards that the authors hoped would serve as the basis for science curriculum design. The National Research Council (NRC) added to the discussion with the publication of the *National Science Education Standards* in 1996 (NRC, 1996). The experts suggest these standards delivered "a new way of teaching and learning about science that reflects how science itself is done, emphasizing inquiry as a way of achieving knowledge and understanding about the world" (p. ix).

The NRC, with a new group of researchers, built upon their work 18 years later with a new publication: *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012), hereby referred to as the Framework. The Framework acknowledges that the previous publications from the AAAS and the *National Science Education Standards* provided the foundation upon which this new work was built (NRC, 2012). However, the Framework suggests that the integration of new understanding in science and education was needed to better support student development of science proficiency (NRC, 2012). The Framework identifies three dimensions of learning that are to be taught in an integrated way that better mirrors what scientists do: science and engineering practices (SEPs), crosscutting concepts (CCCs), and disciplinary core ideas (DCIs). Following the publication of the Framework, the Next Generation Science Standards (NGSS) were released (NGSS Lead States, 2013). The NGSS incorporates the three dimensions of learning, relying on their interaction to achieve student learning. Educators must engage learners in three dimensions if they are to meet the goals the Framework has outlined.

Like their predecessor publications, the Framework and NGSS do not provide curricular materials for educators. For educators to meet the goals of both the Framework and the NGSS, they must employ strategies that engage students in the three dimensions of learning in integrated ways. One of the more promising strategies to achieve this is phenomena-based learning. In this type of instruction, phenomena are defined as "observable events that occur in the universe and that we can use our science knowledge to explain or predict" (Achieve, 2016, p. 1). Phenomena-based learning has students engage with all three dimensions and deepen their understanding of scientific understanding as they make sense of phenomena (Lee, 2020). Students work to generate explanations for phenomena based on data and evaluate these claims in a community-based manner (Inouye et al., 2020). Community-based problem solving is important to human cognitive growth (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018). Phenomena-based learning also prioritizes students' prior experience and allows them to take control of their own learning, two important features that promote human acquisition of new ideas (NRC, 2000).

Storyline learning is an associated strategy developed in conjunction with the NGSS and provides structural support to phenomena-based learning. Learning through storylines involves a lesson progression tied together by students attempting to explain phenomena through their own questioning (Next Generation Science Storyline Project, 2017). The combination of both exploring problems through phenomena and connecting them through storylines allows educators to provide students an opportunity to participate in all three dimensions of learning.

Technology use can also assist with attaining the goals of the Framework. An essential part of the Framework is to centralize practices that scientists and engineers perform in real life (NRC, 2012). As the NRC (2012) explains, "scientists and engineers try to use the best available tools…which today means that modern computational technology is integral to virtually all aspects of their work" (p. 45). Technology can provide students affordances, or opportunities for learning, that may not be available through other means (NASEM, 2018). Geospatial technology are tools that can support connections to the Framework and NGSS in classrooms and provide students with practice in technologies that have a growing place in society (Baker, 2014; Bodzin & Fu, 2014). These tools can support several important features of learning with technology described by the NASEM (2018), such as engaging with models, self-regulating learning, and collaborative learning. Employing phenomena-based, storyline strategies in conjunction with geospatial technology can support the integration of the three dimensions, achieving the vision of the Framework.

Statement of Problem

There are challenges in getting educators to use geospatial technology in a phenomena-based, three-dimensional manner. While the Framework (NRC, 2012) and NGSS (NGSS Lead States, 2013) have been published for almost a decade now, learning that aligns with their vision is limited in classrooms (NextGen Science, 2021; Smith & Nadelson, 2017). Furthermore, while phenomena-based learning and storylines have been shown to be an effective way to integrate the three dimensions in teaching (Deverel-Rico & Heredia, 2018; Islakhiyah et al., 2018; McGill et al., 2021; NextGenScience, 2021; Valanne et al., 2017), there is a disconnect between the development of resources and their use (Mitchell et al., 2019; NextGenScience, 2021). Educators tend to not benefit from fully formed unit plans, curriculum designs, or individual lessons; what educators need are tools that allow them to engage more deeply with phenomena and the integration of the three dimensions (Mitchell et al., 2019). Educators require resources that guide them through building storylines for their own classrooms (Mitchell et al., 2019).

Barriers also exist to geospatial technology implementation. Use of technology in education is often disproportional to the technological resources available to educators (Kurt, 2014). Geospatial technologies can also be complex and require time for educators to learn them to a degree that they may be successful in teaching with them (Adaktylou et al., 2016; Hammond et al., 2019). Hammond et al. (2019) describes classrooms as “crowded”, both conceptually, physically, and temporally, reducing the chances teachers include geospatial technologies. With increasingly complex content, larger class sizes, and further demands on their time, educators are often unwilling to invest the resources into something like a geospatial tool (Hammond et al., 2019).

Purpose

The purpose of this project is to create a conceptual framework for the production of curricular supports for three-dimensional, phenomena-based storyline teaching with a geospatial tool. Technological acceptance, or the willingness of an individual to use computational technology (Davis, 1989), is central to an understanding of supports for educators. An array of factors, including perceptions of the technology's usefulness and an individual's own confidence in using technology impact whether a tool will be used (Davis, 1989; Taylor & Todd, 1995). In addition to considering technological acceptance, one must acknowledge that the development of materials for educators differs from developing materials for students. Ball and Cohen (1996) suggest that when attempting to provide teachers with resources in how to use curriculum, teacher learning must be central to the material. These resources, referred to as "educative curriculum materials" (ECMs) by Davis and Krajcik (2005), are built around a teacher's knowledge base and develop content knowledge, pedagogical knowledge, and the intersection of the two. Through carefully designed ECMs, educators can build confidence and the agency to adapt new strategies and technologies to their own classrooms (Davis & Krajcik, 2005). This means ECMs have the potential to support phenomena-based, three-dimensional teaching with a geospatial tool. Guidelines for developing ECMs that target this do not exist. My research will therefore explore the creation of an initial conceptual framework for ECMs that support phenomena-based, three-dimensional storyline teaching with a geospatial tool.

The question guiding this research is: How does the literature inform an approach to creating a conceptual framework for curriculum materials that support phenomena-based, three-dimensional storyline teaching with a geospatial tool?

Chapter 2

Methods

Conceptual Framework Analysis

This research project was designed to create a conceptual framework for a particular social phenomenon: supporting educator use of geospatial technologies in a phenomena-based, three-dimensional storyline manner. A conceptual framework is defined as “a network…of interlinked concepts that together provide a comprehensive understanding of a [social] phenomenon or phenomena” (Jabareen, 2009, p. 51). For this research, a concept is defined by their relative components and is viewed as having indefinite boundaries existing at the intersection of their history, their components, other concepts, and the problems to which they have been applied (Deleuze & Guettari, 1991). According to Jabareen (2009), social phenomena are “complex and linked to multiple bodies of knowledge that belong to different disciplines” (p.50). In the case of this research, one must consider literature across several disciplines, including education, geospatial technology, technological acceptance, and curricular supports, to address the indicated social phenomenon.

Given these definitions, Jabareen (2009) proposes an eight-phase method for generating a conceptual framework for a social phenomenon:

1. Mapping the selected data sources.
2. Extensive reading and categorizing of the selected data.
3. Identifying and naming concepts.
4. Deconstructing and categorizing the concepts.

5. Integrating concepts.
6. Synthesis, resynthesis, and making it all make sense.
7. Validating the conceptual framework.
8. Rethinking the conceptual framework.

Due to the complex, multidisciplinary nature of this study, I employed Jabareen's conceptual framework analysis. This method uses grounded theory, which originates in the work of Glaser & Strauss (1967) and involves deriving theory during the collection and synthesis of data. Orlikowski (1993) suggests grounded theory is "inductive, contextual, and processual" (p. 311). By engaging in a process based in grounded theory, one can avoid explanations that are objective and causal (Jabareen, 2009; Orlikowski, 1993).

Phase 1: Mapping the Selected Data Sources

In Phase 1, one must engage in a literature search to identify sources that "effectively represent the relevant social, cultural, political, and environmental phenomenon or social behavior, and the multidisciplinary literature that focuses on the phenomenon under study" (Jabareen, 2009, p. 53). The data should also cover practices connected to the phenomenon and involve discussions with specialists and scholars as well. Given the phenomenon of this research, search items needed to address ECMs, geospatial technology, instructional strategies associated with the Framework and NGSS, and technological acceptance.

Using Education Source, ERIC (Educational Resources Information Center), and Google Scholar as databases, sources were selected using the same series of queries in each database. The search was limited to the first 50 sources that came up for each query, and final sources were selected based on review of the title and abstract. In addition to the sources identified through this process, recurring sources cited in these works were reviewed based on the title found in the references and its abstract. Any sources initially reviewed and deemed to be relevant but investigating higher education were later excluded from my review, since the research was focused on the K-12 context. See Table 1 for a summary of the search queries, results, and sources selected.

Table 1

Source Selection During the Literature Review

QUERIES	RESULTS (From Education Source, ERIC, and Google Scholar combined)	SOURCES SELECTED (By Title and Abstract)
"Phenomena-based learning" or "Phenomenon-based learning"	2125	17
"Storyline learning"	514	4
"Geospatial technology" and "education" or "teaching" or "learning" or "curriculum"	1307	23
"Educative curriculum materials"	2345	12
"Technological acceptance" and "education"	5507	27
Total	11798	83

Note. Queries and total results from all three databases are listed above. This table does not include sources that were selected after repeated reference in other works.

Phase 2: Extensive Reading and Categorizing of the Selected Data

In this phase, sources must be categorized into selected data and disciplines (Jabareen, 2009). In this research, selected data are considered landmark works or themes present in the reviewed literature. While the term “discipline” lacks a widely agreed upon definition (Oldnall, 1995), this research considered disciplines to be ideas that were supported by multiple data sources. The data was organized and ranked by their historical role within each discipline. For example, if one source drew on the work of another source, the older source was ranked higher than the new source.

Phase 3: Identifying and Naming Concepts

This phase requires an investigation of the data to pull out concepts, an idea drawn from the work of Glaser and Strauss (1967) and Strauss and Corbin (1990). Concepts should be emergent from the literature and not the other way around. Morse et al. (2002) argue that if qualitative research begins with concepts, the subsequent analysis of the literature may be invalid. Concepts were identified through terminology and ideas that were present across multiple points of selected data.

Phase 4: Deconstructing and Categorizing the Concepts

This phase involves an investigation and break down of each concept with the goal of identifying its major components and finding points of synergy that will be used in Phase 5. This research described each concept, highlighted specific data sources that support the concept, and assigned each concept a role. The roles were described as ontological, epistemological, or methodological. In this research, ontological roles were assigned to concepts that addressed the study of the nature of the world and investigations into what can be known (Ahmed, 2008; Crotty, 2003). Epistemological roles were assigned to concepts that inform human approaches to the nature of understanding and behavior (Crotty, 2003). Methodological roles were assigned to concepts that addressed strategies or design choices that work towards specific outcomes (Crotty, 2003).

Phase 5: Integrating Concepts

This step requires grouping concepts that have similarities into more overarching concepts. Using a grouped concept structure described by Zhu et al. (2015) asa model for identifying similarities, concepts from Phases 3 and 4 were grouped into three main layers: Foundation, Function, and Outcome. Foundation establishes evidence that the approach taken to the research is valid; function describes the means by which to answer the research question; outcome describes the desired goals of the research (Zhu et al., 2015).

Phase 6: Synthesis, Resynthesis, and Making it All Make Sense

This phase involves putting the concepts together into a cohesive framework. The conceptual framework was built using the three layers described in Phase 5. Based on the framework created by Zhu et al. (2015), the Foundation layer was placed on the bottom, followed by Function and then Outcome. Arrows were used to demonstrate connections between concepts.

Phases 7 and 8 were not included in these methods. The research purpose was to create an initial conceptual framework. While Phase 7, validation, and Phase 8, rethinking, are pertinent for future use of such a tool, they were deemed to be beyond the scope of this research.

Chapter 3

Results

Phase 1: Mapping the Selected Data Sources

To answer my research question, the literature review required investigation of foundations of modern K-12 science education, teaching strategies, geospatial technology, technological acceptance, and educational curriculum materials. A total of 83 sources were selected for analysis through search queries in three separate databases. A number of sources that were repeatedly referenced by selected sources were also identified and included in this research. In total, 102 sources were included in the literature review.

Phase 2: Extensive Reading and Categorizing of the Selected Data

The Framework and NGSS

K-12 science teaching in the United States is witnessing a period of reform. This effort began with the publication of the Framework (NRC, 2012), which informed the development of the NGSS (NGSS Lead States, 2013). The Framework, building on prior reform efforts (e.g., *Benchmarks of Science Literacy,* AAAS, 1993; *National Science Education Standards*, NRC, 1996; *How People Learn*, NRC, 2000), is grounded in the belief that science is a crucial part of everyday life and should be taught to everyone, not just those destined for science and engineering fields (NRC, 2012). There is also an emphasis on students understanding how science and engineering is conducted in real life, with students acknowledging their own role as creators of scientific knowledge (NGSS Lead States, 2013). Krajcik et al. (2014) state this shift well, saying science education is “moving away from learning content and inquiry in isolation to building knowledge in use—building and applying science knowledge” (p. 158).

In order to better align instruction with the work of actual scientists., the Framework identifies three dimensions of learning for students to engage in: Science and Engineering Practices (SEPs), Crosscutting Concepts (CCCs), and Disciplinary Core Ideas (DCIs). SEPs are designed to highlight the ways in which scientists investigate the world and generate knowledge (NRC, 2012). Examples include engaging in argument from evidence, asking questions, and using models. These are not skills but practices, enabling students to see science as a long history of processes where ideas are frequently being tested, communicated, argued, and revised as opposed to a set of isolated, performative skills (NRC, 2012; Reiser, Michaels et al., 2017).

CCCs are ideas that span disciplines, allowing students to draw connections between knowledge, shaping a more holistic view of scientific processes and information. CCCs are lenses through which scientists (and students) can approach phenomena (Krajcik & Reiser, 2021; Quinn, 2021; Rivet at al., 2016). Patterns, cause and effect relationships, and structure and function are all examples of CCCs. Rivet et al. (2016) propose three additional metaphors to further clarify what a CCC is: bridges between phenomena, tools to confront new questions, and rules that govern scientific systems. Whichever way one chooses to view them, CCCs bring to light new ways of approaching a problem, leading to novel lines of inquiry and deeper explanations.

DCIs are identified as those ideas central to each science content area, including life science, earth and space science, and physical science. They focus on a limited number of ideas for students to explore as opposed to a wide range of disparate topics (NGSS Lead States, 2013). They are arranged as a progression of learning and that reflects the importance on building upon and deepening knowledge throughout the K-12 experience. The Framework posits that students should increase their level of engagement and complexity of thought over time, propelling them to think about these ideas throughout and beyond their schooling (Krajcik et al., 2017; NRC, 2012; Quinn, 2017).

For many educators, these new reform components demand significant change to the instructional strategies educators have engaged in for years. Teaching through lecture, a common belief in science teaching (Al-Balushi et al., 2020), has been shown to be an ineffective way to promote understanding for a variety of learners (NASEM, 2018) and does not align with the notion of students as creators and knowledge builders. Educators must move away from reciting facts, educator-centered dissemination of information, lab activities with predetermined outcomes, and worksheets (NRC, 2015) if they are to address the goals of the Framework and NGSS. The aforementioned activities promote learning facts, and while facts are important, applicable knowledge requires an understanding of concepts and context (NRC, 2000). Assessment must change as well. Instead of measuring singular ideas, educators should measure how students are building upon their understanding, constructing scientific knowledge, and drawing connections between concepts (NASEM, 2017). Educators must now find ways to reflect these changes in their daily teaching.

In addition to the shift toward more student-centered instruction that places students as agents of their learning, what students are being asked to do and learn requires a shift. The three-dimensional structure of the Framework and NGSS represents a shift from many former educational practices. Three-dimensional learning, or the integration of the three dimensions from curriculum to instruction to assessment (NRC, 2012), is a change that supports the goals of the Framework and the NGSS. Previously, science content was taught separately from how it was used, which did not maximize student ability to apply their knowledge. (Krajcik & Reiser, 2021). When all three dimensions are integrated in a science classroom, learning is enhanced because students can better transfer their learning to new contexts, build a deeper understanding of how science functions, and explain observed phenomena (Krajcik, 2015; Krajcik & Reiser, 2021; Quinn, 2021). Three-dimensional instruction is not simply a novel type of lesson that a science educator introduces once or twice a week. As Krajcik (2015) asserts, “engaging students in three-dimensional learning isn’t an item on a checklist; it is an orientation one takes to science teaching, and it should be used every day” (p. 50). In curriculum materials, integration of the three dimensions must be present throughout if teachers are to meet the demands of the Framework and the NGSS.

Despite the benefits of three-dimensional learning, integration of all dimensions has been uneven. CCCs have been rarely present in curricular materials or classrooms (Quinn, 2021). Since the Framework’s publication in 2012, there has been a clear adoption of the other two dimensions in classrooms, as educators have fixated on the content (DCIs) and how students can engage with it (SEPs), leaving CCCs by the wayside (Fick, 2018; Quinn, 2021). Engagement in two of the dimensions is not enough; for example, if students participate only with DCIs (content) and CCCs (discipline-spanning ideas), they fail to understand or acknowledge their role in generating knowledge by participating in SEPs (Houseal, 2016). If curriculum supports are intended to support more holistic three-dimensional learning, they must provide opportunities for educators to integrate all three dimensions into their teaching using methods that prioritize the student as drivers of their own learning.

Phenomena-Based Learning and Storylines

One goal of three-dimensional learning is to assist students in better understanding the world by developing the mental tools necessary to explain phenomena they may encounter in their daily lives (Krajcik & Reiser, 2021). Therefore, as curriculum supports are created that encourage educators to address the goals of the new reforms, instructional processes that center phenomena are logical to include. When explaining phenomena becomes the basis of science education, the “focus of learning shifts from learning *about a topic* to *figuring out* why or how something happens” (Achieve, 2016, p.1, emphasis added). This aligns well with the instructional shifts proposed by the Framework and the NGSS. When students engage with phenomena, they also devise their own explanations for what occurs based on evidence and revise their explanations through dialogue and feedback (Inouye et al., 2020). Ultimately, phenomena-based learning can drive students to take agency in their work, enhancing understanding, promoting competence in a variety of areas, and contributing to authentic learning experiences (Achieve, 2016; Deverel-Rico & Heredia, 2018).

There are several different views and approaches to phenomena-based learning from around the world. One of the more robust bodies of work on phenomena comes from Finnish education. Beginning in 2014, a series of educational reforms were introduced in Finland that highlight competencies that span subject areas (Symeonidis & Schwarz, 2016). Students must engage in interdisciplinary learning practices that rely heavily on phenomena (Symeonidis & Schwarz, 2016). In conjunction with these changes, Silander (2015) proposed five dimensions by which to evaluate phenomena: holistic and interdisciplinary, authentic to the learner’s experience, situated in real-world context, problem-based, and student agency in the learning process. Learning is consistently connected to phenomena and students are always returning to apply and revise their knowledge (Silander, 2019), which better mimics the work of actual scientists and engineers.

The Finnish view of phenomena has parallels to the view researchers have taken in connecting phenomena to the Framework and NGSS. Phenomena sustain student interest when based on specific, relevant examples that have meaning to students' lives (Inouye et al., 2020; Lee, 2020; Penuel & Reiser, 2017). These phenomena can serve as an "anchor", promoting questions that can "provide a context in which students can apply, test, and extend their developing ideas" (Penuel & Reiser, 2017, p. 5). To ensure alignment with curricular goals, educators must select phenomena that can target various NGSS performance expectations, allowing students to use a variety of practices, concepts, and core ideas in their path to building an explanation (Inouye et al., 2020; Penuel & Reiser, 2017). This suggests curricular supports must provide educators ample opportunities to explore and generate phenomena relevant to their own classrooms.

Phenomena-based learning changes the learning process drastically for students. In addition, the planning process for the individual educator also becomes quite different than previous experiences. Unlike previous thoughts regarding science teaching, phenomena-based learning does not necessitate a fixed progression or sequence; the phenomena, student inquiry and comprehension, and specific events in a classroom dictate where the educator should direct class (Mitchell et al., 2019). Deverel-Rico and Heredia (2018) suggest considering what student questions may arise ahead of time, as this may guide the shaping of lessons. Through this anticipation, educators can develop lesson and investigation ideas ahead of time. This enables educators to center student thinking while effectively guiding them through designed learning experiences (Mitchell et al., 2019). By allowing students to be true collaborators in the process of finding new knowledge and asserting their own purpose, students can more truthfully engage with science (Reiser, Novak, et al., 2017). Balancing all the aspects of phenomena-based learning can be difficult, slow-moving, and challenging for educators to fully embrace (Deverel-Rico & Heredia, 2018). Therefore, creating supports that ensure curricular resources support these aspects is important.

The efficacy of phenomena-based learning as an approach to instruction has been demonstrated in classrooms across grade bands. Eighth graders improved their explanatory capability for the behavior of light after engaging in a phenomena-based activity (Islakhiyah et al., 2018). Second graders improved both reading ability and engagement with literature after a phenomena-based unit bringing together mathematics, reading, and science (Valanne et al., 2017). In another work, Akkas and Eker (2021) demonstrated an increase in metacognitive awareness in seventh-grade students in a phenomena-based activity compared to a control group. This is an important finding, as phenomena-based learning involves students planning investigations, evaluating claims, and monitoring their learning. When taken altogether, this evidence indicates the efficacy of phenomena-based learning as a strategy to address the new educational reforms and warrants its inclusion in a conceptual framework informing curricular materials.

NGSS Storylines

A complementary strategy to phenomena-based learning is the use of storylines. Reiser et al. (2016) define storylines as “an approach to create, analyze, or adapt sequences of lessons to be coherent and meaningful” (slide 3). They are a “coherent sequence of lessons in which each step is driven by students’ questions that arise from their interactions with phenomena” (Next Generation Science Storylines, 2017, Storylines section). This definition highlights the centrality of phenomena to storylines along with the importance of students as agents in control of their learning. Both definitions suggest lessons must be put together in a cohesive manner that has meaning to students.

By engaging with storylines, educators will guide students into putting all the pieces together and building their own explanations for an initial anchoring phenomenon (Reiser 2017). Teaching and planning lesson progressions with storylines is not without its challenges. Educators have a difficult time cultivating student agency, and students may question the authenticity of the educator allowing students to “choose” the direction, even though materials are on hand for particular investigations (Reiser et al., 2021). Educators also have the added pressures from administration of addressing certain performance expectations in a timely manner, and student-driven work often takes extra time (Deverel-Rico & Heredia, 2018; Reiser et al., 2021). Some of these challenges can be addressed through choices in curriculum materials for educators, a discussion which is present later in this paper.

An aspect present throughout the development of storylines is that of coherence. Reiser et al. (2015) define coherence as “building ideas, piece by piece, over time by making sense of phenomena and solving problems” (slide 2). While the NRC suggests one of the purposes of the Framework is greater coherence in American science education, coherence is often only looked at from a disciplinary perspective, not a student perspective (Reiser, Novak, et al., 2017). While instructional materials may suggest progressions that are logical to the educator, this rationale and structuring of lessons may not be evident to students (Reiser et al., 2021). If student coherence is lacking, then the goal of improving coherence, set forth by the Framework, will not be met (Reiser et al., 2017; Reiser et al., 2021).

A shift that enhances student coherence is aligned with the principles of phenomena-based learning. Phenomena-based learning should involve students taking charge in making sense of a given phenomenon (Lee, 2020). In coherent learning, students are not only given agency and accountability but are true collaborators in the learning process, having a say in where they want to take their learning next (Kawasaki, & Sandoval, 2019; Reiser et al, 2017; Reiser et al., 2021). Phenomena are central to a student-driven process. As students make sense of phenomena, they generate questions, test ideas, and revise their explanations (Reiser et al., 2017). It appears that if educators are comfortable shifting authority to students and sharing the responsibility of learning, coherent learning is possible using phenomena.

This strategy is also aligned with strategies that support learning identified in *How People Learn II: Learners, Contexts, and Cultures* (NASEM, 2018). This work explored how humans learn on a sociological and neurological basis. The authors identified five strategies that support learning: retrieval practice; spaced practice; interleaved and varied practice; summarizing and drawing; and explanations, self-explanation, and teaching. The first three strategies are related to structure and providing opportunities for students to re-engage knowledge in a variety of ways (NASEM, 2018). Storyline learning pushes students to build off of previous investigations and to continually revise their ideas in light of new evidence (Reiser et al., 2015), fitting nicely with these strategies. The latter two strategies involve the creation of explanations and the centering of students as agents of their learning (NASEM, 2018). Phenomena-based storyline learning invites a process where students are consistently developing explanations, exploring new explanations, and synthesizing a variety of new information (Reiser et al., 2017), aligning with these strategies as well.

Phenomena-based learning, embedded in coherent storylines, can support both the strategies outlined by the NASEM (2018) and the goals of the Framework (Reiser et al., 2021) Modern technological tools may support these learning processes. As the NRC (2012) notes, "modern computational technology is integral to virtually all aspects" of the work of scientists and engineers (p. 45). If students are to engage in practices that reflect the actual work of scientists and engineers, technological use is essential, and if educators are to use these tools, supporting their use through curricular materials is vital. Geospatial technology may serve as an important technological resource for three-dimensional, phenomena-based storyline learning. The next section provides an overview of geospatial technology and its potential in phenomena-based, storyline learning.

Geospatial Technologies

Geospatial technology or tools (these terms are used interchangeably) may be defined as "technology used to accomplish the visualization, measurement, and analysis of features or phenomena that occur on Earth, including its landforms, climate, and infrastructure" (Adaktylou et al., 2018, p.607). Geospatial technology in education can be used to improve students' ability to make sense of phenomena and enhance spatial thinking (Adaktylou et al. 2018; Bodzin et al., 2012; Bodzin et al., 2016; Kerski, 2015; Lanouette et al., 2016), a core skill highlighted in *Learning to Think Spatially* (NRC, 2006). In this work, the NRC (2006) describes spatial thinking as a universal process humans engage in to make sense of the world and one that has become increasingly important with the widespread use of spatial technologies, such as Global Positioning Systems. Authors emphasize the development of spatially literate students who can develop a conception of space, effectively use special technology, and evaluate spatial data to think critically (NRC, 2006). Despite the presence of these ideas for over a decade, spatial thinking is an often undertaught and overlooked skill in K-12 education (Metoyer & Bednarz, 2017). This suggests a need for further curricular supports to understand and implement geospatial technologies in classrooms.

While *Learning to Think Spatially* (NRC, 2006) predates the Framework and NGSS, spatial thinking aligns well with both SEPs and CCCs. The stated principles of spatial thinking align with several SEPs, including Developing and Using Models, Engaging in Argument from Evidence, and Analyzing and Interpreting Data. The NRC (2006) also suggests that spatial thinking is not based within one subject but spans disciplines. As such, spatial thinking fits well within the realm of CCCs, a concept that serves as a lens through which to view phenomena that is not grounded in specific content (Quinn, 2021; Rivet et al., 2016). Some CCCs that could be touched upon by spatial thinking are Patterns, Systems and System Models, and Structure and Function. Spatial thinking is not a way of learning that must be taught separate from the Framework and the NGSS but reinforces the practices and concepts outlined by these new reforms. Curricular materials that support phenomena-based learning with geospatial technology should focus on the overlap between spatial thinking and the three dimensions of the Framework.

In addition to providing means to develop students’ spatial thinking skills, geospatial technologies provide other important opportunities for personal development, three-dimensional learning, and making sense of phenomena. When students engage with geospatial tools, they are given opportunities to improve skills in collaboration, feedback, and creativity (Adaktylou et al., 2018; Kerski, 2015). Geospatial technologies are uniquely positioned to improve student understanding within life science and Earth and space science, two vital DCIs. Geospatial technology can provide connections to students’ own experienced environments, promoting engagement with topics of climate, climate change, ecosystems, and biodiversity (Bodzin et al., 2012; Kerski, 2015). Geospatial tools can also serve as a vital means through which students draw relevant connections between phenomena and their own lives (Hammond et al., 2019; Lanouette et al., 2016). Based on these potential applications, phenomena inspired by geospatial tools can be used to support three-dimensional, phenomena-based storyline learning. Support for phenomena derived from these tools must therefore be a component of a conceptual framework informing curricular materials.

Technological Acceptance

While geospatial technology shows promise in three-dimensional, phenomena-based learning, barriers exist to its implementation. These barriers include challenges in teacher behavior, teacher learning, tool complexity, and access. Educators can be resistant to incorporating any new technology into their classrooms, especially if those technologies require a change to an educator's teaching methods (Kurt, 2014). Unequal access to both devices that support geospatial software and internet connectivity prohibit the use of geospatial technology (Kerski, 2015). Some geospatial tools are created without an evaluation of the ease of student use, resulting in well-intentioned but impractical platforms (Peters & Songer, 2011). In addition, many of these geospatial tools are complex, requiring time for educators to learn them and gain confidence in their own use before being able to deliver meaningful instruction to students (Adaktylou et al. 2016; Hammond et al., 2019). Therefore, curricular supports that aim to facilitate teacher use of geospatial tools must target factors that increase the likelihood someone will use a given technology.

Several important models from the literature have been proposed to identify the factors that contribute to whether educators will use a technological tool or not. The Technological Acceptance Model (Davis, 1986) is a foundational model for technological adoption for users in any setting. According to the Technological Acceptance Model, the most significant factor that influences attitudes towards technological acceptance and use is “perceived usefulness” (Davis, 1989; Davis et al., 1989; Davis, 1993), originally defined by Davis (1986) as “the degree to which an individual believes that using a particular system would enhance his or her job performance" (p. 25). Within education, perceived usefulness correlates with improvements to student understanding, student achievement, student motivation, knowledge sharing, class engagement, and educator efficiency (Muhaimin et al., 2019; Sadaf et al., 2016; Teo et al., 2018). By increasing an educator’s level of perceived usefulness towards a tool, the attitude towards technological implementation improves, increasing the likelihood that the tool will be used (Echeng & Usoro, 2016; Muhaimin et al., 2019; Sadaf et al., 2016; Scherer et al., 2015; Teo, 2011; Teo et al., 2018). In a conceptual framework that explores supporting teacher use of geospatial technology, understanding factors and models that influence technological acceptance is critical.

While perceived usefulness within the Technological Acceptance Model may be a strong factor influencing educator technological adoption, the model does not consider behavioral factors known to impact teacher decision-making. Several studies on technological acceptance (Chien et al., 2014; Muhaimin et al., 2019; Sadaf et al., 2016; Teo et al., 2018) analyzed the Technological Acceptance Model in conjunction with the Decomposed Theory of Planned Behavior (Taylor & Todd, 1995), which accounts for behavioral variables, such as self-efficacy. Self-efficacy can be described as the perception of an individual’s ability to achieve a particular outcome (Bandura, 1977). Improvements to self-efficacy have been shown to positively impact technological acceptance both directly and indirectly by increasing perceived usefulness (Chien et al., 2014; Muhaimin et al., 2019; Sadaf et al., 2016; Scherer et al., 2015; Teo et al., 2018).

Educators that are confident in using a technology and view a tool as useful are more likely to implement a tool in their classroom. Therefore, incorporating strategies to support perceived usefulness and behavioral factors influencing technological acceptance are also critical components to include in a conceptual framework on educator use of a geospatial tool.

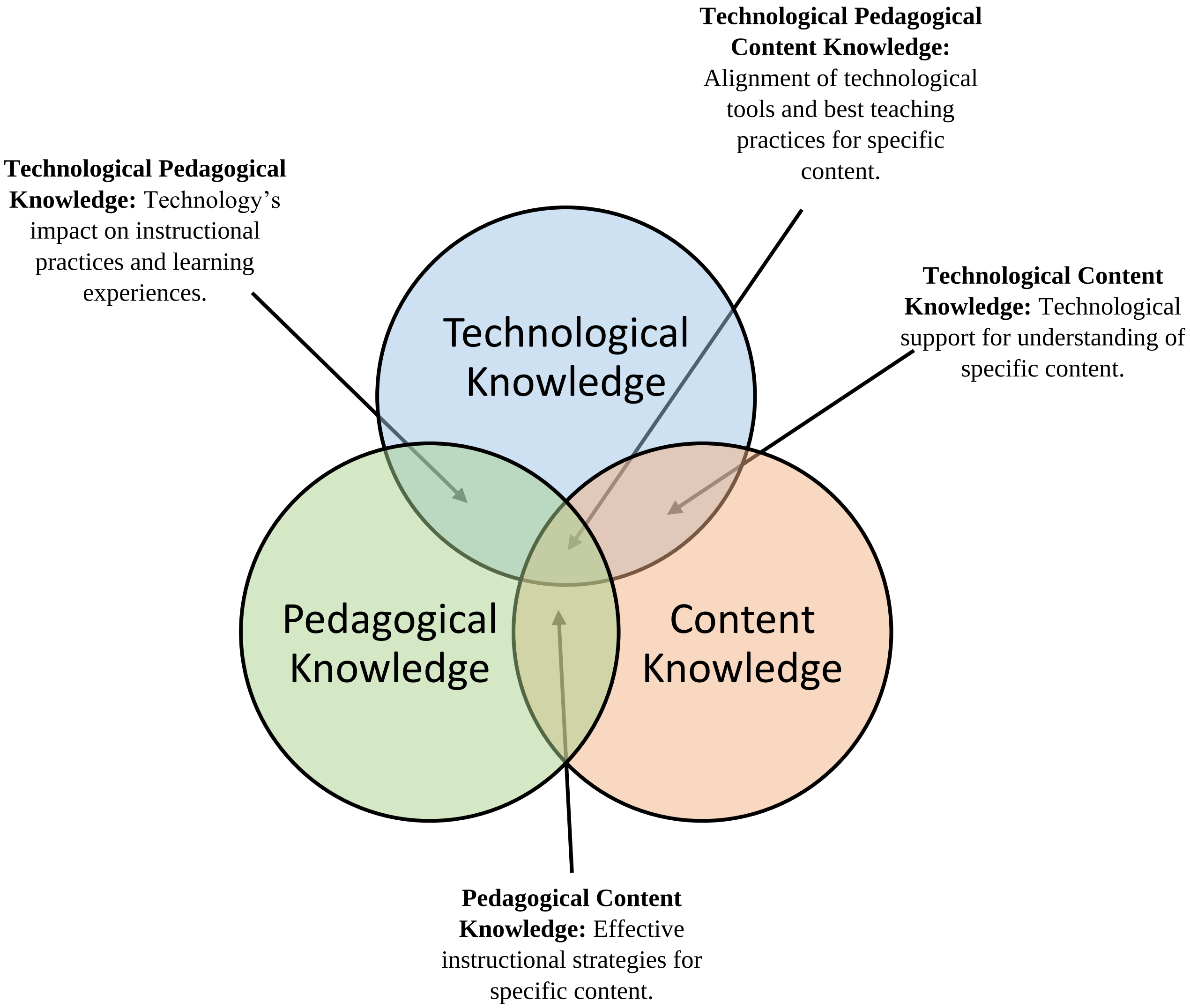
While the Technological Acceptance Model and the Decomposed Theory of Planned Behavior can explain some influences on educator acceptance of technology, Mishra and Koehler (2006) argue that a view of technological integration in education is incomplete without considering Technological Pedagogical Content Knowledge. This framework builds off the work of Shulman (1986), who proposed the idea of Pedagogical Content Knowledge, or educator knowledge of the effective methods to teach specific content, existing at the intersection between familiarity with content and teaching pedagogy. Mishra and Koehler (2006) suggest that in addition to content knowledge and pedagogical knowledge, a third type of knowledge, technological knowledge, be included as well. The use of technology in education must support both proper instructional practice as well as student understanding of content (Kurt, 2019). A model of this framework is presented in Figure 1, highlighting the various intersections of the three knowledge types with definitions for clarity.

Approaches using Technological Pedagogical Content Knowledge show promise for technological acceptance and implementation, both generally and for geospatial technology. A review conducted by Chai et al. (2013) suggests that applying the Technological Pedagogical Content Knowledge model improves educator ability to use technology to benefit student learning. Supports that foster development within each of the intersections of knowledge within the Technological Pedagogical Content Knowledge model can lead to further educator integration of technology (Chai et al., 2013). For geospatial technology, using Technological

Pedagogical Content Knowledge as a model to introduce technological tools to educators has several benefits. Curtis (2019) found evidence that Technological Pedagogical Content Knowledge-based support for educators improved both educator acceptance and implementation. The author proposes three critical aspects of support: “teaching *about* [geospatial technology], teaching *with* [geospatial technology], and the application of teacher knowledge” (2019, p.139). Trautmann and MaKinster (2010) found evidence that applying a Technological Pedagogical Content Knowledge model in introducing a geographic information tool improved educator self-efficacy and willingness to introduce the tool into classrooms. Other professional development opportunities based on Technological Pedagogical Content Knowledge can promote knowledge gains in the intersections of content, pedagogical, and technological knowledge (Hammond et al., 2018; Hong & Stonier, 2015; Oda et al., 2020). In addition, Technological Pedagogical Content Knowledge-aligned materials for geospatial technology also have the potential to increase educator use of mapping tools in a student-driven manner (Hammond et al., 2018). Based on the strong connections between Technological Pedagogical Content Knowledge and geospatial technology, this model warrants consideration in a conceptual framework intended to support curriculum for phenomena-based teaching with a geospatial tool.

Figure 1

The Technological Pedagogical Content Knowledge Model



Technological Pedagogical Content Knowledge: Alignment of technological tools and best teaching practices for specific content.

Technological Pedagogical Knowledge: Technology's impact on instructional practices and learning experiences.

Technological Content Knowledge: Technological support for understanding of specific content.

Pedagogical Content Knowledge: Effective instructional strategies for specific content.

Note: Information in this model is adapted from Mishra & Koehler, 2006. Definitions were adapted from Kurt, 2019.

Educative Curriculum Materials

A means through which to facilitate use of geospatial technology by educators while also promoting principles of Technological Pedagogical Content Knowledge and the vision set forth by the Framework may be through educative curriculum materials (ECMs). Davis and Krajcik (2005) first defined ECMs as “curriculum materials that are intended to promote teacher learning” (p. 3). The idea of ECMs was proposed earlier by Ball and Cohen (1996), who identified the limited consideration for educators in curriculum material design. Ball and Cohen (1996) advocate for materials that develop educator content knowledge, provide anticipatory responses that may be expected from students, and demonstrate transparency from curriculum designers. These guidelines may help promote educator learning, which involves the development of proficiency in content knowledge, pedagogical knowledge, and the interaction of those two: pedagogical content knowledge (Davis & Krajcik, 2005; Shulman, 1986).

In terms of the vision of the Framework, ECMs stand to have a prominent role getting educators to incorporate principles of three-dimensional learning, phenomena-based learning, and storyline learning into teaching. As ECMs can support educators as they adopt new practices, these tools have the potential to impact many educators who strive to make their learning NGSS-aligned and three dimensional (Krajcik & Delen, 2017). Roseman et al. (2017), building off the work of Davis and Krajcik (2005), provide a specific framework for designing ECMs that accommodate phenomena-based, three-dimensional storyline learning. Their framework advocates for outlining coherent storylines with relevant DCIs and CCCs, giving both educators and students an understanding of a unit’s progression. Their framework includes providing a rationale for the inclusion of specific phenomena at different moments, building pedagogical content knowledge. In addition, Roseman et al. (2017) suggest modeling activities for educators grounded in SEPs that demonstrate inclusion of the three dimensions. Integration of these ideas into ECMs for a biology unit showed increases in educator content knowledge, better understanding of student misconceptions, and improvement in SEP use in the classroom

(Roseman et al., 2017). All told, this evidence indicates ECMs have a role in any conceptual framework targeting support for educators for phenomena-based, storyline learning.

In addition to supporting phenomena-based three-dimensional learning, ECMs have been found to increase educator use of geospatial technologies. The proper use of geospatial technology in educational settings requires improvements to educator Technological Pedagogical Content Knowledge specific to those technological tools (Bodzin et al., 2012; Bodzin et al., 2016; Harte, 2017; Kulo & Bodzin, 2011). ECMs have been shown to improve educator levels of Technological Pedagogical Content Knowledge (Bodzin et al., 2012; Harte, 2017). The work of Bodzin et al. (2016) suggests ECMs provide support to pedagogical content knowledge and are critical for sustained educator use of technological tools. Carefully designed ECMs, tailored specifically to a geospatial technological tool, show promise in increasing its effective use. If ECMs can independently support both geospatial technology and phenomena-based learning, it is logical to think ECMs could support them together. Ideas from the ECM literature warrant inclusion in a conceptual framework that targets the combination of geospatial technology and phenomena-based learning.

Categorizing of Data

From the literature review selection process (Phase 1), the sources gathered through the literature were first grouped into selected data, which are the landmark works or themes common to multiple sources. Selected data were then organized into seven different disciplines. This research considered disciplines to be major ideas supported by different selected data. The results can be observed in Table 2. Within each discipline, the selected data was ranked based on its historical significance and the work that has been based off of it. For example, within the Foundational Documents discipline, *Science for All Americans* (AAAS, 1989) is ranked ahead of the *National Science Education Standards* (NRC, 1996) because the latter was influenced by the former. The same is true of the Technological Acceptance Model and the Decomposed Theory of Planned Behavior, as the latter incorporates elements from the former.

Several data sources appeared in multiple disciplines. In these instances, the same data were grouped under all applicable disciplines. For example, Technological Pedagogical Content Knowledge can improve teacher competency (Trautmann and MaKinster, 2010) and confidence in using geospatial technology (Lee and Tsai, 2010). This makes Technological Pedagogical Content Knowledge relevant for both Teacher Learning and Teacher Affect and Behavior.

Table 2

Categorization of Selected Data

Disciplines	Selected Data
Foundational Documents in K-12 Science Education	*Science for All Americans*, *Benchmarks for Science Literacy*, *National Science Education Standards*, *How People Learn I*, *Learning to Think Spatially*, The Framework, NGSS, SEPs, CCCs, DCIs, *How People Learn II*
Science Education Strategies	Three-dimensional learning, Phenomena-based learning, Storyline learning
Student Outcomes	*How People Learn I*, *Learning to Think Spatially*, The Framework, NGSS, Three-dimensional learning, *How People Learn II*, Phenomena-based learning, Storyline learning
Teacher Learning	Educative Curriculum Materials, Technological Pedagogical Content Knowledge
Teacher Affect and Behavior	Technological Acceptance Model, Perceived Usefulness, Decomposed Theory of Planned Behavior, Self-Efficacy
Technology Use and Acceptance	Technological Acceptance Model, Perceived Usefulness, Decomposed Theory of Planned Behavior, Self-Efficacy, Technological Pedagogical Content Knowledge
Geospatial Technology in Education	Geospatial Tools, *Learning to Think Spatially*, Spatial Literacy

Note. This table shows the major disciplines identified in the literature, listed on the left in no particular order. On the right are selected data within each discipline, ranked by historical significance.

Phase 3: Identifying and Naming Concepts

Concepts were identified based on common ideas within the selected data. A list of the nine identified concepts is below in no particular order:

1. Geospatial Technology in Education
2. Student Learning
3. Teacher Affect
4. Teacher Behavior
5. Teacher Learning
6. Guiding Educational Principles
7. Science Teaching Strategies
8. Curriculum Supports
9. Technological Acceptance

Each concept had a strong presence in the literature across multiple reviewed sources. For example, research on Technological Acceptance in education was conducted in wide variety of works (Chien et al., 2014; Muhaimin et al., 2019; Sadaf et al., 2016; Scherer et al., 2015; Teo et al., 2018). Similarly, Curriculum Supports were discussed in many different sources (Ball & Cohen, 1996; Bodzin et al., 2012; Bodzin et al., 2016; Davis & Krajcik, 2005; Doering & Veletsianos, 2008; Harte, 2017; Roseman et al., 2017; Trautmann & MaKinster, 2010).

Concepts were also selected that had their own history in the literature but also demonstrated links to other potential concepts, aligned with the definition of concepts by Jabareen (2009). For example, both the concepts Teacher Behavior (which includes technology use, interaction with curriculum materials, decision making in the classroom) and Teacher Affect (including self-efficacy and comfort in implementing a technology or education strategy) are supported by Curriculum Supports and models of Technological Acceptance. The same can be said of the concepts Guiding Educational Principles and Science Teaching Strategies. While the

Guiding Educational Principles describe ideal student outcomes, it is only through strategies that these outcomes can be achieved.

Phase 4: Deconstructing and Categorizing the Concepts

The concepts were synthesized through an analysis of the selected data in order to deconstruct and categorize them. Descriptions were developed that included a wide overview of the concept, informed by the selected data. Concepts were assigned roles as either epistemological, methodological, or ontological. Assignments to each role were informed by the works of Ahmed (2008) and Crotty (2003). An ontological role was assigned to concepts that described ways in which to study the world such as Guiding Educational Principles and Geospatial Technology in Education. An epistemological role was assigned to concepts that dealt with more subjective outcomes, such as Technological Acceptance, Teacher Affect, Teacher Learning, and Teaching Behavior. Methodological roles were assigned to concepts more practical and action-oriented, such as Curriculum Supports and Science Teaching Strategies. The resulting concepts are categorized in Table 3 by role.

Table 3

Categorized Concepts

Concept	Description	Role	Selected Data Sources
Geospatial Technology in Education	Technologies with educational capabilities that use some component of Global Positioning Systems, Remote Sensing, Geographic Information Systems, or mapping.	Ontological	Geospatial Technology, Spatial Literacy
Guiding Educational Principles	A body of literature proposing a philosophical shift in how K-12 science is taught.	Ontological	The Framework, NGSS, AAAS and NRC precursor documents, Spatial Literacy
Student Learning	The process of a student acquiring, retaining, and integrating new information into their existent knowledge base.	Epistemological	*How People Learn I*, *How People Learn II*
Teacher Affect	The beliefs and dispositions that educators have about their own teaching, self-efficacy, confidence, and ability to execute a certain action.	Epistemological	Technological Acceptance Model, Decomposed Theory of Planned Behavior, Perceived Usefulness, Self-Efficacy
Teacher Behavior	The decisions and actions that educators make in the classroom. This includes choices related to technology use, curriculum implementation, and teaching styles.	Epistemological	Technological Acceptance Model, Decomposed Theory of Planned Behavior, Technological Pedagogical Content Knowledge, ECMs, Perceived Usefulness, Self-Efficacy

Table 3, cont.

Categorized Concepts

Teacher Learning	Teacher development of knowledge through engagement with curricular materials and the intersection(s) of pedagogical, content, and technological knowledge.	Epistemological	ECMs, Technological Pedagogical Content Knowledge
Technological Acceptance	The process through which an individual decides whether to use a new technological tool.	Epistemological	Technological Acceptance Model, Technological Pedagogical Content Knowledge, Perceived Usefulness, Self-Efficacy
Curriculum Supports	Materials that assist educators in the implementation of certain strategies, lessons, or technologies in the classroom. These materials may also facilitate teacher learning.	Methodological	ECMs, Technological Pedagogical Content Knowledge
Science Teaching Strategies	A variety of instructional practices that suggest the best ways to achieve student outcomes outlined in the guiding educational principles.	Methodological	Phenomena-based learning, Three-dimensional learning, Storyline learning

Note. This table describes the concepts and includes a description, role, and selected data sources. Concepts are categorized by role.

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Phase 5: Integrating Concepts

Concepts were integrated into three larger concepts, based on the conceptual framework of Zhu et al. (2015), in which concepts are categorized into three layers: Foundation, Function, and Outcome. The results of this process can be found in Table 4. The Outcome layer should identify the goals of the research. The goal of this work is to provide a conceptual framework for curricular supports that will enable educators to effectively use a geospatial tool in a phenomena-based, three-dimensional manner. If the framework is to be successful, it must support curricular materials that lead to technological acceptance and changes to teacher affect, behavior, and learning. These teacher outcomes ultimately impact student learning. Based on that information, concepts put into the Outcome layer were Technological Acceptance, Teacher Affect, Teacher Behavior, Teacher Learning, and Student Learning.

The Foundation layer supports the validity of the research. Both Guiding Educational Principles and Geospatial Technology in Education were placed in this role. The data in Guiding Educational Principles provides evidence for the benefits of the proposed changes to K-12 science education. The data supporting Geospatial Technology in Education provides evidence as to why these tools can develop various important skills in students and support the goals of the Framework. Both concepts provide the grounding information that dictate desired outcomes for students.

Concepts in the Function layer must connect the Foundation to the Outcome (Zhu et al., 2015). While the Framework and NGSS describe the skills and processes through which students should engage in science, they do not provide concrete strategies to achieve those outcomes. Similarly, Geospatial Technology holds great potential for education, but these tools do not provide ways for educators to use them. Science Education Strategies support student learning, such as engagement with the three dimensions, while Curriculum Supports, like ECMs, can support teacher outcomes and technological acceptance. Both of these concepts serve as the bridge from Foundation to Outcome and were placed in the Function layer.

Table 4

Integrated Concepts

Layer	Included Concepts
Outcome	Student Learning, Teacher Affect, Teacher Behavior, Teacher Learning, Technological Acceptance
Function	Curriculum Supports, Science Education Strategies
Foundation	Guiding Educational Principles, Geospatial Technology in Education

Note. The three layers of the conceptual framework, adapted from Zhu et al. (2015). Each layer shows which concepts were included.

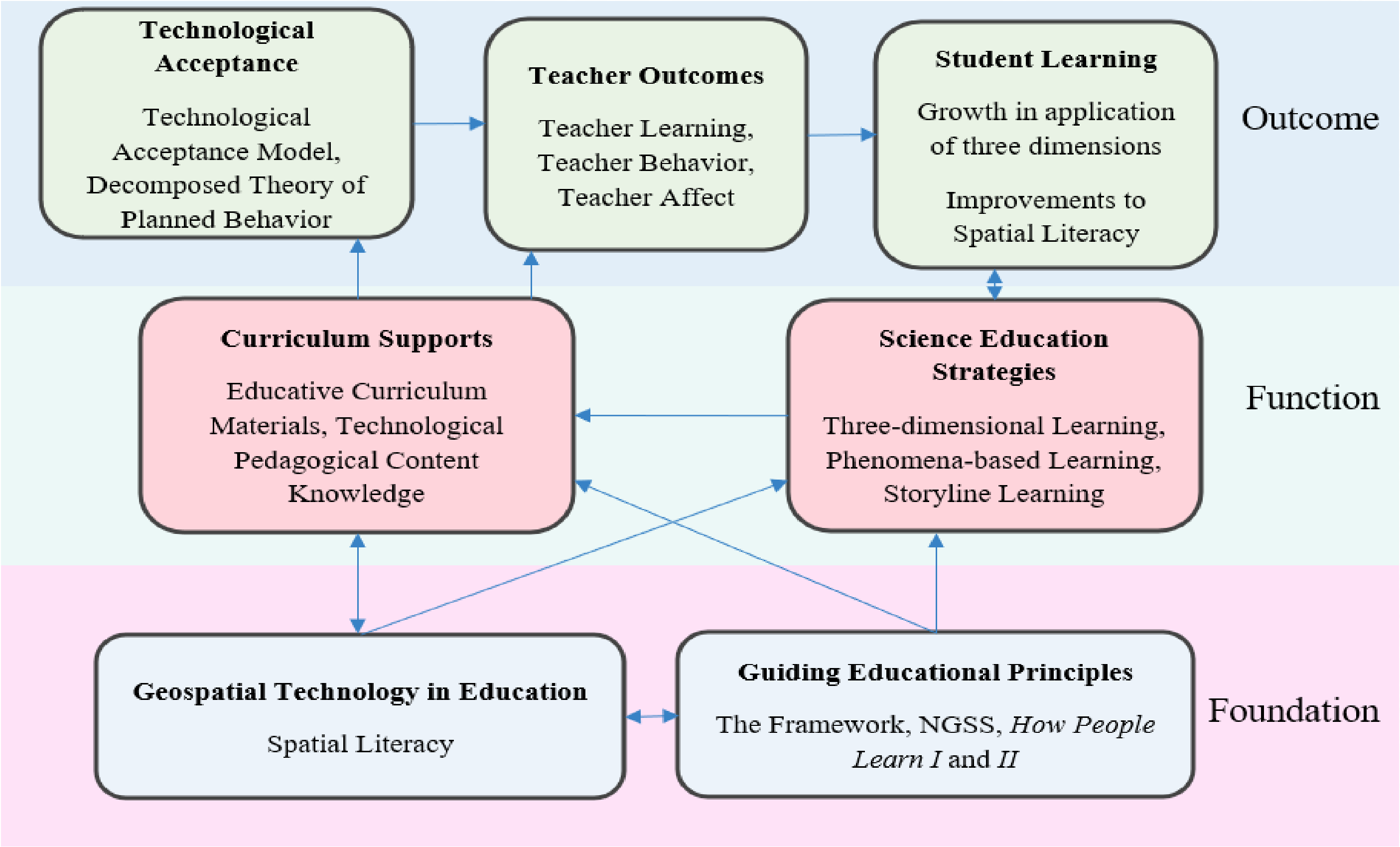
Phase 6: Synthesis, Resynthesis, and Making it All Make Sense

The final synthesis of the concepts is shown in Figure 2 as a conceptual framework that informs the development of curricular supports for phenomena-based, three-dimensional storyline learning with a geospatial tool. The model uses the layers described in Phase 5 to integrate the concepts. The layout of the conceptual framework suggests that the concepts in the Foundation are critical to understanding prior to the development of curricular materials. The concepts in the Function layer provide the tangible means to achieve the desired goals of the conceptual framework. These goals are described by the concepts in the Outcome layer, which ultimately end with Student Learning.

Arrows on the conceptual framework indicate connections between concepts. Uni-directional arrows suggest a direct influence of one concept on another. For example, in the Outcome Layer, Technological Acceptance affects Teacher Outcomes which affect Student Learning. Bi-directional arrows suggest that each concept has influence on the other. For example, Guiding Educational Principles can influence the potential for Geospatial Technology in Education, while new affordances of technology and development of spatial literacy can also inform Guiding Educational Principles. From bottom to top, there is a general flow that ends with Student Learning. While the purpose of this research is to create a conceptual framework for the development of curricular supports, these curricular supports should ultimately target Student Learning.

Figure 2

Conceptual Framework: Developing Curricular Supports for Phenomena-Based, Three-dimensional Teaching with Geospatial Technology



Note. A proposed conceptual framework for the development of curricular supports for phenomena-based, three-dimensional storyline teaching with a geospatial tool. Arrows represent connections between concepts described in the literature.

Chapter 4

Discussion

Introduction

This research, through the creation of a conceptual framework, addressed the initial question of "How does the literature inform an approach to creating a conceptual framework for curriculum materials that support phenomena-based, three-dimensional teaching with a geospatial tool?" This question necessitated drawing connections between various disciplines in the literature. The conceptual framework is presented to highlight these connections and organize them in a manner that can be used to inform the development of these materials in the future. Specific details of the connections in the conceptual framework are discussed below in an effort to provide more concrete suggestions for curricular supports that target phenomena-based learning with geospatial technology.

The literature supports the potential for ECMs to promote teacher use of three-dimensional, phenomena-based strategies. Mitchell et al. (2019) found that educators respond to educative materials that engage them in a phenomena-based, three-dimensional lesson, guiding them through a coherent sequence. This is backed by work that suggests teacher learning improves when actions are learner centered (NRC, 2000). By serving as a learner in this style of teaching, educators may better understand how to design similar learning experiences themselves.

Overlap exists in the literature on ECMs and phenomena-based, three-dimensional storyline learning. The work of Roseman et al. (2017) demonstrates how the ECM design heuristics by Davis and Krajcik (2005) can be applied to three-dimensional, phenomena-based learning. Miller and Krajcik (2019) present an ECM design that incorporates the Framework and NGSS Performance Expectations to provide coherent, phenomena-based materials for educators. Arias et al. (2017) found that ECMs that focus specifically on SEPs around scientific argumentation improve student outcomes and educator support for student thinking. The ECMs mentioned all share similar components that are critical for improvements to educator practice: transparency in the thought process behind development, anticipatory responses for student misconceptions, and opportunities to build both content knowledge and pedagogical content knowledge (Ball & Cohen, 1996; Davis & Krajcik, 2005). ECMs are a suitable vessel for encouraging educators to engage in phenomena-based, three-dimensional storyline learning.

Geospatial technology also has ample connections in the literature to curriculum supports. Work on ECMs designed to improve implementation of geospatial technology suggests principles of Technological Pedagogical Content Knowledge (Mishra & Koehler, 2006) must be incorporated into the materials (Bodzin et al., 2012; Bodzin et al., 2015; Bodzin et al., 2016; Doering & Veletsianos, 2008; Harte, 2017; Hong & Stonier, 2015; Osborne et al., 2020). Geospatial pedagogical content knowledge, lying at the intersection of technological knowledge, content knowledge, and pedagogical knowledge, “transcends content disciplinary boundaries” and can “interact with other discipline-based pedagogical content…. that may produce effective teaching and student learning opportunities” (Bodzin et al., 2012, p.363). The work of Bodzin et al. (2016) identifies major design elements for ECMs specifically for geospatial technologies, including selecting data that signals geospatial relationships, presenting relevant phenomena, and providing opportunities for both learner and educator growth.

The development of Technological Pedagogical Content Knowledge in educators regarding geospatial technology encourages technological acceptance and desired teacher outcomes in several ways. Educators are more likely to use a technological tool if they perceive it as useful and have the opportunity to improve their self-efficacy with the tool (Chien et al., 2014; Davis, 1986; Davis, 1989; Muhaimin et al., 2019; Sadaf et al., 2016; Scherer et al., 2015; Teo et al., 2018). Work by Lee and Tsai (2010) found a positive correlation between Technological Pedagogical Content Knowledge and self-efficacy. Trautmann and MaKinster (2010) identified that improvements in Technological Pedagogical Content Knowledge in relation to a geospatial tool increased educators' competency and ideas for how to best implement the technology in the future. Harte (2017) demonstrated similar findings, showing gains in Technological Pedagogical Content Knowledge in relation to geospatial technology improved educator confidence and willingness to use technology in their classrooms. By targeting Technological Pedagogical Content Knowledge and providing ample space for educators to build familiarity, comfort, and confidence around geospatial technology, ECMs can increase the likelihood educators will use a given geospatial technological tool.

Suggested Application

A geospatial tool to which this conceptual framework can be applied is the Global Vegetation Project. The Global Vegetation Project was created to "inspire and empower people of all ages to learn about the diversity of vegetation on our planet and to provide educators with a resource for teaching online" (Fleri et al., 2021, p. 41). The creators of the project provide both educators and students with an open-access, online, map-based database with photographic representation of vegetative communities across the planet. The platform contains climate data, biome information, identification of specific plant species, and other information.

Using the conceptual framework, curriculum developers could generate materials for this geospatial tool that target phenomena-based, three-dimensional learning. A good place to start would be identifying phenomena. From the data provided on the Global Vegetation Project, there is potential to develop many three-dimensional phenomena. For instance, a DCI in Life Science suggests students emerge with an appreciation of nature and the predictive power of how ecosystems will change over time, especially in response to large disturbances (Anderson & Doherty, 2017). The photos in the Global Vegetation Project can give students snapshots into a variety of ecosystems and provide an opportunity for students to explore how these may respond to climate change. This could involve students engaging with both historic and recent climate data, supporting the SEP Analyzing and Interpreting Data. Scientists, engineers, and therefore students must be able to analyze data, find relationships between components being studied, and pull meaning from the data (Rivet & Ingber, 2017). By reflecting on how an ecosystem will respond to climate change, students may engage with the CCC Stability and Change. When students explain a phenomenon, they may look for patterns of change that occur across various spatiotemporal scales (Moulding et al., 2021). A phenomenon can be selected that incorporates each of these three dimensions using the Global Vegetation Project and given to educators as an example. From this example, educators can be encouraged to generate phenomena on their own.

After phenomena selection, curricular developers could continue to build materials using other pieces of the conceptual framework. Curricular materials may include a short activity for educators to do that involves a phenomenon. This process facilitates teacher learning and models phenomena-based learning, a crucial method for teacher understanding of this teaching strategy (Mitchell et al., 2019). Both building experience with the platform and generating their own ideas stand to increase perceived usefulness and self-efficacy, two key components of technological acceptance (Davis, 1989; Taylor & Todd, 1995). Materials could also include suggested activities, questions, or possible misconceptions students may generate when first explaining a phenomenon along with rationale behind the choices made. Including a rationale achieves several goals. It provides transparency to the materials, a critical component of ECMs suggested by both Ball and Cohen (1996) and Davis and Krajcik (2005). Additionally, allowing educators to see the thought process can inform how specific aspects of the technology can be used strategically for certain subject matters, strengthening Technological Pedagogical Content Knowledge. If curriculum developers want to increase the chances an educator will use the Global Vegetation Project in a phenomena-based manner, including as many components as possible from the conceptual framework presented in this work is recommended.

Limitations of Methods

The methods used in this work included limitations. The search queries used, while necessarily narrowing the scope of the study, may have excluded other important work. By combining and synthesizing concepts into larger categories, another vital step in creating a streamlined conceptual framework, some individual components of those concepts may have been overlooked or excluded. Jabareen (2009) also notes limitations to conceptual framework analysis, such as each researchers interpreting and synthesizing concepts in a completely different manner. Another researcher taking on this work may have come up with a conceptual framework much different than the one presented here. As choices are made that intentionally narrow and focus the work, they inherently limit the number of ideas that can be incorporated into the final conceptual framework.

Despite their limitations, the methods used in this work also provided some benefits. Limiting the number of sources provided an opportunity to focus the work and identify specific factors that would support phenomena-based teaching with a geospatial tool. The continual categorization and reorganization of concepts provided ample space to identify strong connections in the literature. Exploration of these connections provided the chance to refine the conceptual framework and to determine more concrete recommendations for both the conceptual framework and future work.

Recommendations for Future Work

I excluded both Phases 7 and 8 of Jabareen's conceptual framework analysis in this research. Both phases would be logical next steps to extend the reach of this work. Phase 7 involves validating the conceptual framework (Jabareen, 2009). This work can be continued by using the conceptual framework to develop curricular supports for a particular geospatial tool such as the Global Vegetation Project. The materials could be shared with educators, curriculum developers, and the creators of the geospatial technology itself. Gaining feedback from these parties will help in determining if the framework makes sense and is useful in its current form. An additional step could be to provide the curriculum materials to educators. These teachers could attempt to use the technology in a phenomena-based, three-dimensional way in their classrooms. Feedback from educators and students along with student work could determine if the framework is valid in eliciting the desired student learning outcomes.

Phase 8 involves rethinking the conceptual framework (Jabareen, 2009). After considering the feedback from Phase 7, changes and revisions to the framework could be made. If some of the desired outcomes in technological acceptance, student learning, and teacher learning, affect, and behavior were not reached, changes to the conceptual framework will be required. Different types of geospatial technology may necessitate altered conceptual frameworks as well. Research that examines the applicability of the conceptual framework across a variety of different geospatial tools will be able to further ascertain its use.

Conclusion

Great potential exists in the synergy of geospatial technology with phenomena-based, three-dimensional storyline learning. Curriculum developers looking to generate standards-aligned content for educators with geospatial technology can look to this conceptual framework for guidance. These developers must take into consideration ideas from a range of disciplines in order to maximize support for educators. This research presents only one way to include principles from relevant disciplines to inform a conceptual framework.

Phenomena-based learning is a powerful tool for achieving the goals of the Framework and equitably engaging and centering student learning in the classroom (Achieve, 2016). Teaching with geospatial technology supports achievement in science courses while developing critical spatial thinking skills for students; however, many educators lack the training and support to effectively teach with these tools (Bodzin et al., 2016). Combining geospatial technology with these learning strategies has potential for positively impacting students in a way that the two cannot achieve alone. With further validation, this conceptual framework has the potential to fill a current a hole in the literature regarding the development of curricular supports for phenomena-based, three-dimensional storyline learning with geospatial tools. It is a step towards more robust curricular supports for educators using geospatial technology in a manner that is aligned with current recommendations for K-12 science education. As geospatial tools continue to find roles in the scientific community, this conceptual framework could be used as a way to support efforts to bring them into the educational community.

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