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Problem-Based Design Thinking Tasks: Engaging Student Empathy in STEM

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ABSTRACT

This study examines the interaction between students' expressions of empathy and the use of STEM integration in the science classroom. Third space theory provides the context from which this classroom ethnographic qualitative study took place, as it provided an environment in which discourse among students' sociocultural perspectives, life experiences, and academic backgrounds could develop and interact. Nineteen seventh-grade students from a Title 1 school, a school that receives federal aid to better support students coming from low-income families, in the Southeast United States participated in this study. Participants generated their own real-world problem-based design-thinking (PBDT) tasks to address and solve. Students exhibited significant characteristics of empathy and integration of various STEM content and practices evidenced by in-class discussions, field-notes observations, student artifacts, and individual student interviews as part of the STEM Third Space Genius Hour sessions. The PBDT Framework, inspired by the Biological Sciences Curriculum Study (BSCS) learning cycle and design thinking (DT), provides the conceptual lens through which to view the connectedness among students' PBDT tasks, STEM, and empathy.

Keywords: STEM, authentic learning, problem-based learning, design thinking, middle grades, empathy

Introduction

As early as the 19th century, scientists, educators, and educational philosophers have called attention to the need to integrate socially relevant issues using problem-based learning methods in the science classroom as a way to connect and "orient a student's efforts toward the solution of the problems that were real to the student" (DeBoer, 1991, p. 73). Famous scientist Michael Faraday (Jenkins, 2008) drew no separation between the aim of science education and the betterment of society, stating that all individuals' pursuit of scientific knowledge should "easily apply their habits of thought, thus formed, to a social use; and that they ought to do this, as a duty to themselves and their generation" (p. 203). This connectedness (DeBoer, 1991; Dewey, 1938) among society, personal experience, and problem-solving has pervaded itself into the 20th century science classrooms (Czerniak & Johnson, 2014), eventually invoking members of the National Science Teaching Association (NSTA) and the National Science Foundation (NSF) to support and stress the inclusion of the affective aspect of human thinking and processing in science education and enterprise (DeBoer, 1991). This engagement with the human elements of personal concern and involvement continues to be a part of the aims of science education in the 21st century, offering the opportunity for students to examine and explore how science can be meaningful and relevant to enrich their lives and the lives of others (NGSS Lead States, 2013; NRC Framework, 2012). The role of using students' empathic connections to relevant social concerns as an aspect of science education is not new, however, it also is not necessarily a characteristic of current science teaching and learning, nor are there explicit ways in mainstream curricula as to how empathy can be leveraged in the science classroom (Burns & Lesseig, 2017).

One goal of science education is to increase student learning and stimulate student interest in science for students to become informed global members of a democratic society and members of science-related career fields and professions (Garner, Gabitova, Gupta, & Wood, 2017; NGSS Lead States, 2013). Global citizenship emphasizes individuals' respect for the global landscape by demonstrating an acknowledgement of their social responsibility to explore collectively driven solutions and an understanding of systems, experiences, cultures, and people from a larger global perspective (Garner et al., 2017). Because of the multifaceted nature of science, technology, engineering, and mathematics (STEM) toward developing science professionals that are globally aware thinkers and doers, STEM is greatly emphasized in many K-12 learning environments. According to the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), a solid science education for K-12 students (ages five to eighteen) includes a comprehensive foundation in inquiry, problem-solving, and student-initiated discovery. The NGSS science and engineering practices act as a guide for teachers to intentionally present the relationship between science and engineering fields in K-12 classrooms (Burns & Lesseig, 2017; NGSS Lead States, 2013; NRC, 2012).

STEM-focused teaching and learning is critical for developing globally connected and innovative thinkers and leaders for the 21st century (Garner et al., 2017). However, STEM disciplines are generally focused on developing students' scientific, engineering and technological competencies without specifically addressing the emotional connectedness students have to the process and products of STEM learning (Garner et al., 2017; Gunkel & Tolbert, 2018). While there are multiple factors that impact students' interest in STEM, key factors include the connection between empathy and STEM problem-based learning tasks in classrooms (Gunkel & Tolbert, 2018; Wirkala & Kuhn, 2011). Giving students the opportunity to participate in learning science concepts with empathy and from a global perspective may improve their interest in and capacity of science learning (Garner et al., 2017).

Problem-based learning (PBL) and design thinking (DT) tasks can provide an opportunity for students to determine what problem they would like to solve as well as how they will incorporate critical thinking and problem-solving skills to develop a solution or product that addresses the initial problem (Barton & Tan, 2018; Bush & Cook, 2019; Bybee, 2010; von Solms & Nel, 2017; Wirkala & Kuhn, 2011). These tasks also provide avenues for students to develop and practice creative-thinking skills which involve asking the right questions, making connections, demonstrating empathy, collaborating with peers, and experimentation (Akcay, 2017; Cook & Bush, 2018; Wagner, 2012). Science classrooms afford students the opportunity to engage in concepts that integrate the STEM disciplines. Students can apply key content and practices from two or more of the STEM disciplines simultaneously to help develop a more robust, holistic, and workable solution to authentic problems than if the task was embedded only in science concepts (Bush, Karp, Cox, Cook, Albanese, & Karp, 2018; Roehrig, Moore, Wang, & Park, 2012). A problem is rooted in authentic learning which includes 1) real-world problems addressed by professionals "with the possibility of having an impact on people outside of the students involved in the investigation" (Rule, 2006, p. 1); 2) open inquiry that invokes creative critical thinking and problem-solving skills; and 3) a community of learners engaged in meaningful and productive discourse (Rule, 2006). To better equip students with the skills needed to improve various global systems and conditions, students need the space in the classroom to generate their own authentic problems, draw upon their background knowledge from multiple disciplines, and employ creative and critical-thinking skills (Cook & Bush, 2018; Kermain, & Aldemir, 2015) simultaneously drawing from an empathetic viewpoint that link students to the problem.

Purpose of the Study

The need for students to be exposed to integrated STEM learning in K-12 education is vital for their development of problem-solving skills to prepare them not only for next steps in their education but also for the global issues they will undoubtedly face as adults. While there are multiple factors that impact students' development and application of STEM content and practices, key factors include the integration of empathic perspectives and the integration of STEM content and practices in PBL tasks in classrooms. The purpose of this study therefore, was to allow seventh-grade students a third space in the science classroom to connect issues they identify as important to them or others to the utilization and integration of interdisciplinary content and STEM concepts. Students' authentic problem-based design-thinking (PBDT) tasks were the vehicles through which the connection between empathy and STEM was made, driving the problem-solution process. Literature exists that supports the emphasis of these problem-solving ideas in K-12 classrooms (e.g., Kolodner et al., 2003; Mehalik, Doppelt, & Schuun, 2008; Schmidt & Kelter, 2017), however further research is needed that engages empathy as a motivating factor. In this study, students were not given a specific task to solve or methods to use to solve them, as often appears in PBL research studies (Merritt, Lee, Rillero, & Kinach 2017; von Solms & Nel, 2017; Wirkala & Kuhn, 2011). Instead, students used their understanding and identification of their culture and world to both develop unique tasks as well as the strategies, processes, and methods to begin to address the PBDT task they identified. The two research questions explored in this study were:

1. In what ways does providing students the opportunity to design and solve their own PBDT task drive them to incorporate empathy into STEM problem-solving?

2. In what ways can PBDT tasks allow students to integrate STEM content and practices into their problem-solving processes?

Review of Literature

The review of literature is organized by the following three sections: defining empathy; empathy in PBL and DT tasks; and the integration of the STEM content and practices. Finally, we summarize by articulating the need for PBDT tasks in the middle grades.

Defining Empathy: Transformative Perspective-Taking

Empathy is not a stagnant or passive process or a mere feeling towards another (Bialystok & Kukar, 2018; Nelems, 2018). Furthermore, defining empathy as a straightforward process or virtue is problematic, minimizing its depth and intricate makeup (Bialystok & Kukar, 2018; Nelems, 2018). While empathy takes on various definitions, traditionally, empathy is defined as putting oneself in another person's (group's) shoes (Bialystok and Kukar 2018; Nelems 2018). Incorporating role-plays, posing positive representations of marginalized groups, testimonials, guest speakers, or interaction with social media, drama, and other experiential learning activities in the classroom are common strategies used to foster empathy according to this definition (Bialystok & Kukar, 2018; Feshbach & Feshbach, 2009). However, Nelems (2018) pushes back on this premise, because this definition lacks "a degree of openness that puts one's own worldview in a position of risk and instability" (p. 26). According to Nelems (2018), empathy is multi-dimensional and can be shaped and defined by one's worldview, surrounding culture, and experiences. It also has the potential to be transformative, enabling one to step back from and critically reflect upon one's own perspective to feel with or alongside another (Nelems, 2018). By critically examining one's perspective and worldview, and feeling with another person (or group), one's perception has the potential to be changed and therefore become the basis for externally acting upon this transformed perception (Bialystok & Kukar, 2018; Nelems, 2018).

Feshbach and Feshbach (2009) describe the attribute of being able to take on the perspective of another by recognizing shared experiences one may have with another. These authors discuss the use of "empathy-stimulating experiences in the classroom" (p. 87) that may incorporate students learning about or engaging with social issues such as poverty, homelessness, or marginalized populations. Engaging students in problem-solving and jigsaw activities and discussions and debates as part of the regular classroom instruction can deepen students' development and use of empathy in learning (Feshbach & Feshbach, 2009).

In a study conducted in a middle school science club after school, 13 students and three club coordinators participated in STEM-based lessons intended to evoke communication about empathy, interest, and belonging (Burns & Lesseig, 2017). According to the researchers' preliminary analysis of student surveys, lesson observations, and coordinator interviews, it appeared that students had a greater understanding of the purpose behind the engineering task by describing that they were thinking about the person or animal for whom they were building. However, the coordinators' responses to the surveys and interviews identified the need for empathy to be better defined and explained in order for them to better observe and assess students' interactions from this empathy lens. This provides insight into how empathy can best be enacted and implemented in the classroom for teaching and learning (Burns & Lesseig, 2017).

Bialystok and Kukar (2018), researchers from the University of Toronto, describe empathy in education as being "nebulous…that teachers and students are often called to embody [empathy] with little understanding of how [it is] developed or whether [it] can be modeled or taught" (p. 24). They describe a generally used definition of empathy as being able to hear and care about the experiences of another person. Bialystok and Kukar (2018) critique the historical insertion of empathy into North American K-12 and post-secondary classrooms in the latter part of the 20th century in response to the increased racial and ethnic diversity of society. The aim of this historical shift was to develop social harmony and create compassion for marginalized groups. There is a tension involved in developing and exercising (or acting upon) empathy as it entails "our awareness of our own identity and the attempt to understand the lived experience of someone else" (Bialystok & Kukar, 2018, p. 32).

These studies support the idea that empathy is complex and that it needs to be further explored especially in the classroom setting, particularly at the middle grades. Casale, Thomas, and Simmons (2018) assert that "empathy driven curricula nurture opportunities for deeper learning experiences" (p. 5). Collectively, this literature presents traits of empathy that are a combination of self-reflection or self-critique, finding commonality with another, and feeling with/feeling for a person or group; with the hope that some type of transformative thinking or action occurs because of these empathic traits. We build upon the literature cited to define empathy as critically reflecting upon one's own perspective (or experiences) to recognize connections between one's own and another's perspective and take on the other's perspective as a way of leading one to feel with or alongside another. In this study, students developed their own PBDT to focus on a specific issue or problem that was relevant to them. While fostering empathy was not presented as an explicit goal, the PBDT tasks served as a stirring rod, disrupter, or catalyst of sorts to get the process of empathy in action going, connecting students to STEM problem-solving content and practices.

Empathy in PBL and Design Thinking Tasks

PBL takes many forms, however at its core, PBL requires students to engage in solving a problem by using and extending students' prior knowledge to develop a plausible solution among many possible solution pathways (Cook & Bush, 2018; Kolodner et al., 2003; Merrit, Lee, Rillero, & Kinach, 2017; Odom & Bell, 2015; Prince, 2004; Thomas, 2000; Wirkala & Kuhn, 2011). PBL is often grouped into the same category as inquiry-based learning and project-based learning, as these three instructional approaches are all embedded in constructivist learning theory, promoted and influenced by John Dewey (Odom & Bell, 2015; Scheer, Noweski & Meinel, 2012; Wirkala & Kuhn, 2011). However, because of PBL, students are expected to become more adept at using critical thinking skills to solve real-world problems, a characteristic not always present with inquiry-based and project-based learning (Sarı, Alıcı, Şen, & 2017; Wirkala & Kuhn, 2011).

Design-based learning approaches began years ago, with the term Design Thinking (DT), first coined by Simon (1969) and described for use in the design world by Rowe (1987). The Institute of Design at Stanford (Plattner, 2010) has been instrumental in pushing the use of DT for non-designers to the forefront. More recently, it has been explored in educational settings (Cook & Bush, 2018) posited as a path to make instructional shifts in education which can "increase student motivation and engagement" (Mehalik et al., 2008, p. 71), providing a response to students' queries as to why they have to learn a specific concept or topic. DT focuses on giving students agency and empowering them as creative problem solvers (Cook & Bush, 2018; Spegman, 2018). DT fulfills the goals of PBL in that it "has students grapple with issues that require a creative redefinition and reimagining of solutions akin to professional skills of designers, who consider conflicting priorities and complex negotiations to arrive at a solution to an ill-defined problem" (Cook & Bush, 2018, p. 94). Key elements of DT tasks include emphases on empathy, the development of 21st century skills and student input throughout the design process (Burns, & Lesseig, 2017; Bush et al., 2018; Scheer et al., 2012; Wagner, 2012). Empathy, the stimulus that connects students to the person or cause for which their solution aims to benefit, is a distinct characteristic of the DT process, differentiating itself from the engineering design process (Cook & Bush, 2018). Through DT, problem-solving is approached in a way where students truly believe in their ability to engage in change that impacts our world (Carroll, 2014). DT allows students to utilize their "ability to imagine without boundaries and constraints" (Carroll et al., 2010, p. 52). Mehalik and colleagues (2008) and Scheer, Noweski, and Meinel (2012) present studies in which design-based and other DT tasks produced higher learning gains, engagement, motivation, and self-expression in high school science classes, supporting the idea that DT holds much promise for developing skills for students to meaningfully connect and creatively contribute towards solutions of 21st century problems.

The Integration of the STEM Content and Practices

PBL and DT have become effective and widely researched tools for integrating STEM disciplines in the classroom both nationally and internationally (Moore et al., 2014; Said, 2016; Sarı et al., 2017; Shaffer, 2013; von Solms, & Nel, 2017). Local, state, national, and international policy makers and government entities perceive STEM as a vehicle through which students become more prepared to participate and lead in the global and ever-changing workforce by engaging in solving real-world problems (Christensen, Knezek, & Tyler-Wood, 2014; Cook & Bush, 2018; Holmes, Gore, Smith, & Lloyd, 2017; Mohr-Schroeder, Bush, & Jackson, 2018; Moore et al., 2014; Roehrig et al., 2012; Sarı et al., 2017; von Solms & Nel, 2017). Sarı, Alıcı, and Şen (2017) note an increase of STEM instruction, curriculum development and interest in STEM disciplines in Europe, China, Korea, Taiwan, and Turkey in response to the global demand for innovative, creative, problem-solvers to shape the cultural and economic landscape of the 21st century. South Africa (von Solms & Nel 2017) and the

United Kingdom (Archer et al., 2013) are developing educational strategies to help decrease employment gaps in STEM careers due to fewer students choosing and excelling in STEM in school. Improving the socio-economic and living standards of its country is the impetus behind Malaysia's vision of improving the science and technology skills of their students by year 2020 (Surif, Ibrahim, & Mokhtar, 2012). Aside from the vast economic concerns STEM education may address, Bybee (2010) listed systemic issues students will face as adults, such as energy efficiency, environmental hazard mitigation, and climate change as important reasons for STEM education. Understanding these global issues prepares students to become adults who contribute meaningful insight and solution-ideas (Akcay, 2017). The multifaceted nature of these types of issues, which require 21st century skills (e.g., critical thinking, problem solving, collaboration, initiative, creativity, adaptability, data analysis and transference of learned knowledge to a new situation), is the "driving force behind national calls for changes in STEM education" (Roehrig et al., 2012, p. 31). While there exists successful school-based STEM curriculum and programs for primary through secondary students, these often are taught in silos, isolated and therefore not fully embracing the transdisciplinary goal of authentic STEM integration (Bybee, 2010; Moore et al., 2014; Roehrig et al., 2012). Conversely, integrated STEM programs can provide students with important experiences in solving problems that not only integrate but *necessitate* the use of multiple STEM disciplines to solve authentic problems in our world (Atkinson & Mayo, 2010; Bush & Cook, 2019; Czerniak & Johnson, 2014; Sarı et al., 2017).

Both the literature (e.g., Asunda & Mativo, 2016; Bybee, 2013; Honey, Pearson, & Schweingruber, 2014; Hwang & Taylor, 2016; Kelley & Knowles, 2016; Moore et al., 2014) as well as the NGSS (NGSS Lead States, 2013) support prioritizing integrated STEM education in the science classroom. Further, research on integrated STEM education points to its effectiveness. For example, a meta-analysis on STEM integration conducted by Becker and Park (2011) found that integration had a positive effect on student achievement. Likewise, Hurley (2001) found that the integration of mathematics and science had a positive effect on student achievement through a meta-analysis of 31 studies. Further, there can be a negative effect on student interest, engagement, implementation, and understanding of STEM contexts when the interconnectedness of the STEM disciplines is poor (Moore et al., 2014; Roehrig et al., 2012). Captivating and maintaining student interest in STEM disciplines, particularly between the ages of 10-14 (Archer, Dawson, DeWitt, Seakins, & Wong, 2015) is critical to address not only students' present education, but their prospective contribution in STEM fields in the future. As stated by Schmidt and Kelter (2017), "the combination of skills, interest, and preparation are keys to success in STEM careers" (p. 131). It is possible there is a connection between the decline of students choosing STEM careers and the attitudes they have towards learning science and other STEM disciplines in the classroom (Hellgren & Lindberg, 2017; Hillman, Zeeman, Tilburg & List, 2016).

Even with the research to support the integration of STEM in the classroom, there are concerns that need to be addressed. Gunkel and Tolbert (2018) present viable concerns towards this educational shift in that "there has been little attention to developing social empathy and care as essential aspects of engineering education and practice" (p. 939). They critique the over-emphasis of the technocratic viewpoint of problem-solving that does not recognize sociopolitical aspects of either the problems being addressed or the solutions to these problems (Gunkel & Tolbert, 2018). This technocratic perspective uses technology to fix multifaceted and in-depth problems that may in turn create new problems or do not get to the sociocultural and interpersonal source of the problems. This also leads to a utilitarian belief that technological process and solutions are inherently good and progressive, without considering who is deciding on what is good or beneficial, often privileging the majority culture or group (Gunkel & Tolbert, 2018). There is a need to "merge creative instructional strategies with objectives specifically designed to promote empathy among learners" (Casale, Thomas, & Simmons 2018, p. 3). Similarly, Gunkel and Tolbert (2018) argue for "a dimension of care that reframes engineering design" (p. 954) in K-12 engineering education so that students have the freedom to explore the "full socio-historical-politico context of the problems they are trying to solve and to consider the full range of possible constraints and implications of their designs" (p. 954). Despite the existence of engineering and STEM-based learning in the classroom, there is also a demand to reposition ethical approaches in education that accurately and ethically address global, sociopolitical and environmental issues encompassed in the world towards an approach that incorporates empathy, responsibility, care, and connectedness (Casale et al., 2018; Fickel, Angel, Macfarlane, & Macfarlane, 2017).

In summation, the various ways in which empathy has been defined provides challenges to observe and study its enactment in the classroom. When the collective voice from empathy-focused literature is analyzed, however, three themes or components of empathy become clear: critically reflecting upon one's own perspective (or experiences), the recognition of connectedness between one's own and another's perspective, and the taking on of the other's perspective as a way of leading one to feel with or alongside another. DT and some implementations of PBL can play significant roles in eliciting empathy from students as well as challenging them to use STEM content and practices in an effort to solve real-world multi-faceted problems in creative and authentic ways. STEM integration in the science classroom can lend itself to become yet another way of solving a problem if the connectedness to these components to empathy is lacking from the process. This study seeks to make the connections between empathy and STEM clearer and intentional by incorporating student-developed PBDT tasks.

Conceptual Framework

The PBDT Framework

The PBDT Framework in Figure 1 that incorporates the interconnecting stages of *explore*, *explain*, *engineer/experiment*, and *extend* surrounding the *empathy* stage is foundational to this study. The first author developed the PBDT Framework, however its premise lies in two learning processes: the BSCS 5E Instructional Model for science instruction (Bybee et al., 2006) and the DT Framework (Institute of Design at Stanford, 2016). The BSCS 5E Instructional Model for science instruction is rooted in the 19th century. As mentioned, the 19th century proved to be a monumental era of science education history in Europe and the United States. Johann Friedrich Herbart, a German philosopher and educational theorist in the early 1800s, developed a systematic approach to teaching and learning bringing together conceptual understanding and student interest (DeBoer, 1991) that made its way to the U.S. in the 1890s, fifty years after Herbart's death. His teaching model was built upon two key ideas: 1) *theory of interest*, developing an environment that stimulated student's interests and experiences in the natural or social world, and 2) *theory of concept formation*, connecting students' experiences to science concepts, principles, and knowledge through student discovery, discussion, and direct instruction (DeBoer, 1991). These ideas are considered instrumental precursors of the BSCS 5E Instructional Model for science instruction institute in 1990 (Bybee et al., 2006; Duran & Duran, 2004) which includes 1) *engaging* students in specific science concepts by accessing their prior knowledge and experiences, 2) developing experiences for students to *explore* science ideas, questions, and phenomena firsthand through investigation and experimentation, 3) allowing ways for students to *explain* their understanding of science concepts and for teachers to provide deeper explanation toward critical thinking, 4) challenging students to *elaborate* on what they have learned through new contexts and activities, and 5) enabling both students and teachers to *evaluate* students' understanding of the science concepts through each of the E phases (Bybee et al., 2006). The BSCS 5E Instructional Model, used in many K-12 science curricula, is an iterative process, yet each phase interacts with the preceding and following phase indicating that science learning process is not linear but can be entered at different points of the learning process and can dialogue with other phases as the refining of understanding occurs. Duran and Duran (2004) depict the 5E Instructional Model with double-sided arrows to demonstrate this point. While its intent was not to mirror or replicate the phrasing of the BSCS 5E Instructional Model, the processes composed in the PBDT Framework represent common behaviors and skills that are foundational to scientific learning and habits of mind. In its development, an effort was made to highlight key elements of scientific thinking, the engineering design process, and other processes commonly reflected in the STEM disciplines.

The second inspiration behind the PBDT Framework is the DT framework (Institute of Design at Stanford, 2016) and the steps or processes of the DT framework: *empathize, define, ideate, prototype* and *test*. Incorporating the processes of DT, the PBDT Framework is an adapted version of the DT framework, a merging of DT ideas, problem-solving practices, and scientific thinking processes that are embedded in the BSCS 5E Instructional Model and commonly reflected in STEM. The most notable element of DT that is part of the PBDT Framework is empathy. Empathy plays an initiating role in DT, and in the PBDT Framework, empathy is the connecting point or driving force of all the other processes involved. Without this integral element of identifying and feeling with the subject for whom the problem exists, the other connections can become routine processes, and the task can simply become another in-class assignment.

There are other models that integrate aspects of design-thinking and inquiry. For example, the EDP-5E (Lottero-Perdue et al., 2016) uses the BSCS 5E Instructional Model as its base, however the *explore* phase is substituted with the *engineering design process*. However, this design process does not include an empathy-driven component. In the PBDT Framework, students are driven to address specific problems of their choosing based upon their connectedness (empathy) to the problem. Their empathy drives how students engage in inquiry and how they choose to design their solutions. Therefore, the empathy-driven element is critical and central to this research.

Conceptual frameworks can be based upon existing theories, but they can also be used to "clarify and propose how concepts relate to one another in the context of the study where it belongs" (Chowdhury, 2019, p. 102). Additionally, conceptual frameworks can be a generative outworking of researchers' reflections and thinking about the research process as a whole, including its methodology, data collection, and findings (Adom, Hussein, & Agyem, 2018). While the PBDT Framework was developed prior to the start of the study, it contributes insight and a way of centralizing empathy as a connection between students to their unique authentic problems and problem-solving processes. As the study progressed, empathy became a pivotal factor in the problem-solving process. The first author did not show or describe this framework to the student participants to ensure they would not be focused on strategically moving through the process in a procedural or rudimentary way; as a result, student participants organically moved throughout each of these elements during the four weekly STEM Third Space Genius Hour (Kessler, 2018) sessions. The PBDT Framework did serve as a tool for the first author to use to provide clarity, as needed, in guiding students through the PBDT task as well as mapping out where students were throughout the study. Essentially, this PBDT Framework was embedded in reality and fueled by a third space in which authentic problems of the world interact with STEM content and practices giving way to innovative solutions and perspectives.

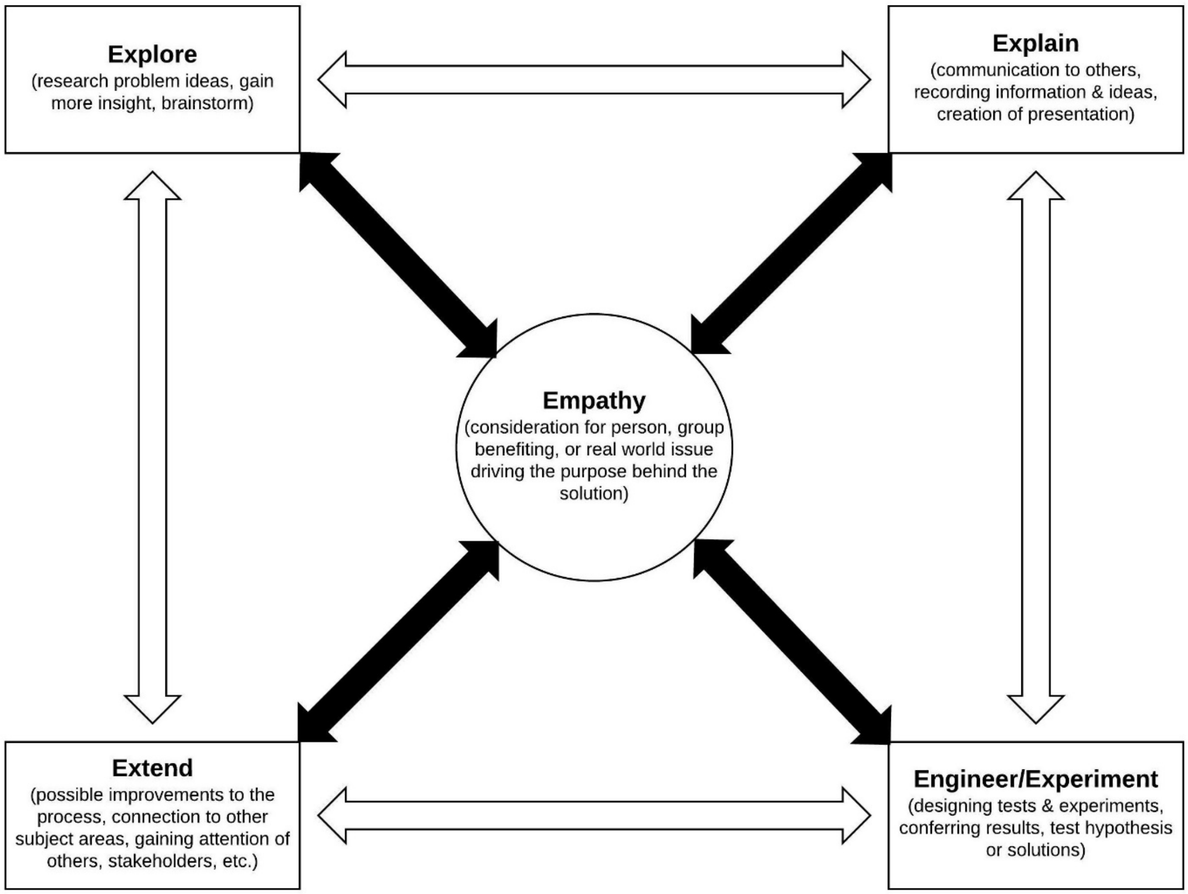

Figure 1. Five interconnecting stages of the PBDT Framework.

PBDT Framework within a Third Space

Third space refers to the creation of a learning environment in which alternative knowledge and discourses incorporate the merging of first dominant (e.g., the everyday—social and familial) and second marginalized discourses (e.g., the academic—specialized science content; Moje et al., 2004). Traditionally, third space theory has been used in educational research to denote one of three conceptualizations of how the space *in between* two or more disciplines, discourses, or physical locations is purposively reconstructed to affect students' learning and development. "Spaces are themselves agents for change. Changed spaces will change practice" (Joint Information Systems Committee 2006, p. 30). Each student's skills, abilities and experiences are interwoven within the collaborative environment and groups to facilitate the learning for all students. There is a collective space of sense-making, a type of interdependence between and among all involved in the third space (Garner et al., 2017).

The first conceptualization of third space found in educational literature is described as a figurative space which provides, "the mediational context and tools necessary for future social and cognitive development" (Gutiérrez, Baquedano-Lopez, Alvarez, & Chiu, 1999, p. 92). According to Gutiérrez, Baquedano-Lopez, Alvarez, and Chiu (1999) the third space can be produced in school settings to help students develop a relational understanding (Skemp, 1976/2006) between discrete pieces of content knowledge by connecting conventional academic discourse to everyday discourses to better understand the natural world. As students develop critical insights and inquiries regarding their world, they begin to consider new connections and relevance between global ideas and the academic concepts which encompass them in their classroom learning environment.

A second conceptualization is defined by the intent to create a "navigational" space which allows students to be successful when traversing from one specialized academic discourse (e.g., physics) to another. This space allows for the decompartmentalization of subject areas or specific academic content areas. In this type of environment, students are free to utilize and join elements of seemingly disconnected concepts to discover how these concepts collaborate to deepen understanding of a broader and more comprehensive idea or issue. These interactions or bridges between these discourses help to lay the groundwork for new types of knowledge, processes, and creative thinking evidenced by student participants' unique ways they form and solve their PBDT tasks.

Lastly, a third conceptualization can denote a space of social justice meant to incite and enact change as multiple discourses (e.g., political, social, academic) are brought together to inform students on broad cultural and epistemological issues of concern. Social issues and authentic problems are multi-faceted and often have multiple means by which to address them. As students engage in this conceptualization of third space, they will be challenged to view and assess these all-encompassing issues from multiple perspectives, values, and experiences (Casale et al., 2018). This context is key to allowing students to consider and act upon issues that are meaningful to them and to others, a necessary component of empathy. By engaging in these types of discourses, students begin to consider how these often-conflicting elements of social concerns converse and interact with each other. When students participate in this productive struggle, they can, in fact, improve the cognitive processes required to better understand the nuances of these issues of their PBDT tasks for example, approaching these concerns thoughtfully, practically and with consideration and empathy for whom these issues most affect (Idrus, 2015).

Within the third space, students are free to employ and draw upon their knowledge and discourses from their social networks and academic communities (Moje et al., 2004) as they explore their ideas, explain their information to others, engineer/experiment solutions, and extend their insights for different contexts. Most significantly, the third space creates the opportunity for participants to bring together social perspectives, life experiences, and academic disciplines to discuss complex issues; interact, debate, and collaborate with peers with varying perspectives; and enable participants to formulate, process, and solve the real-world problems most relevant to them.

Methodology

A classroom ethnographic qualitative approach best defines the methodology of this study (Green & Bloome, 1997; Goulding, 2005; Hamilton, 1999; Whitehead, 2005). General characteristics of ethnographic research approaches 1) study real-world settings, 2) aim at a whole phenomenon, 3) incorporate multiple methods and research techniques to generate data, and 4) aim to interpret participants' perspectives (Hamilton 1999). More specifically, classroom ethnographies can incorporate activities or lessons that are connected to cultural meanings and values understood and upheld by the community of study for classroom education (Green & Bloome, 1997). Whitehead (2005) describes that in ethnographic fieldwork,

> the specific ideas and behaviors of an individual member of the cultural system can be influenced by any of these components of that system (social structure, shared ideas, and preferred behaviors), and the broader issues that have some influence on that system (physical environment, history, and real and perceived human needs). (p. 5)

Additionally, ethnographic studies vary in length (from days to years) (Jeffrey & Troman, 2004), are greatly determined by the context or setting of the study (Jeffrey & Troman, 2004), and the researcher often determines when the data are adequate and saturated to the point of analyzing them to establish solid themes, explanations, and interpretations (Creswell & Miller, 2000). Jeffrey and Troman (2004) refers to a compressed time mode concept in ethnographies, often conducted in school and classroom settings, which may last from days to a month and which "captures the dynamics of a context, documenting the visible and less tangible social structures and relations" (p. 538).

The researcher (first author) was directly immersed in the field (Goulding, 2005; Whitehead, 2005), spending significant time with the individual members (i.e., students) of the cultural system of the real-world setting of the science to observe and identify the phenomenon of how students' expressions of empathy towards problems in their larger culture (e.g., the real world, social structures, the natural environment) influenced how they connect with and use STEM content and practices through their PBDT tasks. Along with the rootedness in fieldwork, this ethnographic study incorporated multiple types of data collection, each attributing to descriptions of student participants' interactions, conceptual processes, socio-cultural influences and values, as well as the merging of discourses within the third space. The data presented and analyzed therefore includes descriptions from and interpretations of fieldnotes, vignettes, video-recordings, student-student discussions, student-teacher conversations, student interviews and student artifacts to best represent and validate the focus of this study (Goulding, 2005; Green & Bloome, 1997).

Role of the First Author

"Research practice within schools is a complex and dynamic process in which the researcher identity is not fixed and stable but rather part of a fluid process" (McGinity, 2012, p. 763). The first author (researcher), who was also the classroom teacher in this study, was aware that her position could pose concerns regarding validity and objectivity. Throughout her thirteen years of teaching science in Title 1 middle and high schools, she has taught students from diverse backgrounds, cultures, and socioeconomic statuses. In each of these school settings, she incorporated problem-based learning methods to help students discover the relevancy of scientific concepts to their lived experiences. The first author recognized that her experience and background may have unintentionally influenced the data collection and analysis process, so she made intentional steps, noted throughout this study. Presenting these perspectives and being reflexive about her role contributed toward the establishment of trustworthiness and validity of the study (Creswell & Miller, 2000; Creswell & Poth, 2018).

Study Participants and Study Environment

This study took place in a Title 1 middle school (grades six through eight) science classroom in the Southeast United States. Nineteen students—nine female and ten males—participated in this research study, after obtaining parental informed consent and student assent as per IRB approval. Students and their parents were informed that their level of participation would not in any way negatively affect their grade or standing in the class. Five student participants were enrolled in the first author's Standard Comprehensive Science Class and 14 participants were enrolled in one of the first author's three Advanced Level Comprehensive Science Classes. The student participants' ethnic/racial backgrounds were Caucasian (n = 7), Hispanic (n = 3), African-American (n = 1), Indian/Indian-American (n = 2), Asian-Pacific Island (n = 2), and bi-racial/bi-ethnic (n = 4). Special consideration was given to use pseudonyms to refer to individual student participants to maintain confidentiality throughout the discussion of data in this study. At the beginning of the study, 15 student participants had either completed, or were currently enrolled in, some form of technology, engineering or STEM elective class as a part of the school's engineering magnet program. These electives include Lego robotics, web design, video game design, computer science, and various Project Lead The Way (Project Lead The Way, 2019) programs. All student participants had completed or were currently enrolled (during the study) in a digital-based career preparation course, referred to as J-Prep (a pseudonym), required for all seventh-grade students. J-Prep familiarizes students with the different facets of the school district's learning management system, informs students on digital literacy and digital citizenship, assesses students' career interest areas, provides information for career planning, and helps students develop a digital portfolio.

Fieldwork Collected

In-class Discussions and Observations

The student participants' discussions centered around problem-solving processes, student-student interactions, student-teacher interactions, as well as the students' products were video and audio-recorded throughout the duration of the study. Special care was taken to not record students whose parents did not provide informed consent for the study.

Student Participant Artifacts

Throughout the study, student participants recorded their brainstorming ideas, problems, solutions, drawings, diagrams, and various aspects of their problem-solving processes on paper and their class Padlet™ page (Figure 2, "Padlet is the easiest way"). These artifacts, along with participant-designed models and/or digital presentations (such as Power Point® or Google Slides™), were included as part of the data collection and analysis for this study.

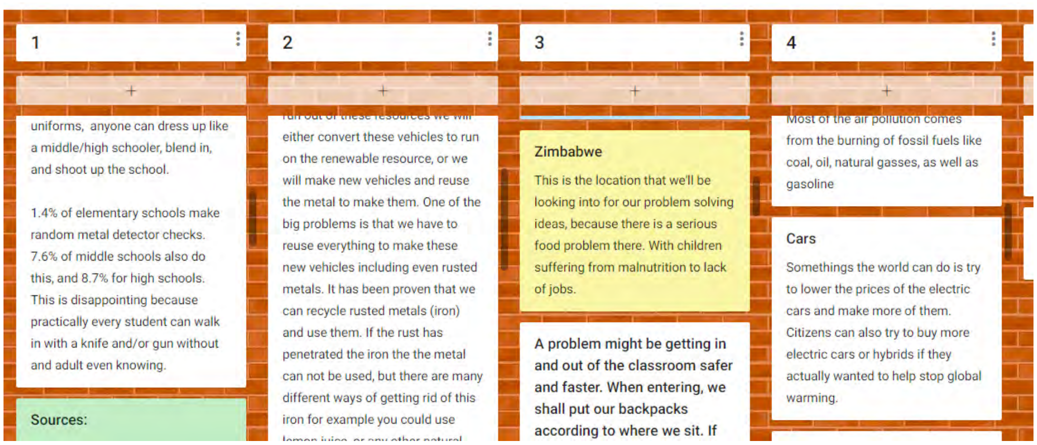

Figure 2. Student problem-solving ideas and brainstorming process posted to Padlet™ page, an online bulletin board.

Student Participant Interviews

Following the conclusion of the PBDT tasks, the first author interviewed each of the 19 participants individually. The interview questions in Table 1 included questions regarding the PBDT task, the problem-solving process, participants' interest in STEM, and their future career interests. The individual student participant interviews were video-recorded as well. The third space theory allowed student participants the freedom to consider alternative perspectives to address problems formed from the merging of their discourses. The first author noted that the openness, created by the third space, allowed for authentic responses and insight from the participants during the individual interviews. This provided meaningful feedback by allowing the first author to analyze and home in on each participant's depth of understanding of PBDT, its connection to real-world problems and student participants' perspectives and attitudes towards integrated STEM learning. Each student participant met individually with the first author before school, during homeroom, or during the school day in the first author's classroom (or teacher planning area) without any other student, teacher, or staff member present to protect student privacy. Student participants did not have to answer every interview question. Special care was taken to either rephrase or clarify interview questions as well as include additional follow-up questions to facilitate the discussion and gain insights into each student participant's development and understanding of the purpose of the PBDT tasks.

Table 1. *Student Participant Interview Questions*

1. What did you like/dislike about the weekly problem-solving activity?
2. What skills (or processes/procedures) were you using to help you solve the problem that you were tackling?
3. What makes a problem a "real-world" problem?
4. Was the problem you were solving a real-world problem or real-world concern? How do you know?
5. What are the characteristics of a person who uses science, technology, engineering and mathematics (STEM) in their everyday life?
6. What type of job or career would this person have? Why? How do you know?
7. Do you see yourself using STEM-based problem-solving in high school? In college or at a job?
8. What type of job/career do you see yourself having after high school (college)?
9. Do you see yourself attending college or a university? If so, would you study a subject that is connected to an aspect of STEM? Why or why not?

Procedures

All students participated in a weekly STEM Third Space Genius Hour during the four weeks of the study, consisting of a 45-minute class period each week, as the school schedule allowed. The STEM Third Space Genius Hour was different from what students typically encounter in science class where teacher- or district-driven curriculum and tasks guide the instruction – often linked to a curriculum map and not focused on the integration of the STEM disciplines. Instead, the STEM Third Space Genius Hour enabled students to engage in authentic PBDT tasks in a student-centered and student-driven environment under the guidance of their science teacher with an open opportunity to incorporate content and practices from multiple STEM disciplines. Each student selected and developed their original PBDT task to solve. The detailed phases of each STEM Third Space Genius Hour is presented in Table 2.

Table 2. *Phases of the PBDT Task*

STEM Third Space Genius Hour	Study Procedures Involved
Week One: Brainstorming	Students are given a sheet of notebook paper to freely jot down and brainstorm ideas, thoughts and questions they may have. This sheet will serve as their weekly record and documentation of their problem-solving development.
Week One: Initiating the PBDT Task	"Trigger questions" or statements (italicized) are used as a launching pad to initiate the PBDT task: *This is going to be an ongoing problem-solving activity. Except this time, I am not giving you the problem idea nor am I directing you as to how to solve it. I want you to come up with this... Consider a problem that others would want you to help solve for them or work to develop a solution to. What would that problem be? What would it involve?* • Students start to discuss potential ideas with their classmates (see the "Explore" stage of the PBDT Framework, Figure 1). • Students need help understanding the context of selecting and developing a problem to solve. Without having a specific context, students appeared to initially struggle with thinking of a problem or situation. • Essentially, they were processing how to tackle a problem that was authentic to them (outside of their school culture) while simultaneously considering how to approach this problem within the academic environment.
Week Two: Contextualizing PBDT Tasks	The first author encouraged students to think about how they would eventually present their problems and solutions to their classmates in three weeks. • The television show *Shark Tank* and the animated movie *Big Hero 6* were used to provide familiar examples that demonstrate the importance of visually presenting the details and intricacies of their solution to convince and increase interest and "buy-in" from others. • As students' ideas became more concrete, they posted their developments digitally on a Padlet page (see Figure 2) created for each class for students to post information from their research, websites to reference, drawings or images that were useful to them in solving PBDT task. This allowed students to move their work from their brainstorming sheet to a digital resource, facilitating the design process both in and out of the classroom.
Week Three: Facilitating the PBDT Task Process	Various types of discourses occurred simultaneously during weekly STEM Third Space Genius Hour session. • Many students had a strong solution or solution path mapped out. • Students were leading themselves more, and the first author's facilitation, primarily through questioning, lessened.

STEM Third Space Genius Hour	Study Procedures Involved
	• Students focused more on testing and confirming their solutions and beginning to create their presentations (see the "Explain" and "Engineer/Experiment" stages of the PBDT Framework, Figure 1).
Week Four: Students Finalizing PBDT Tasks	Students take complete ownership of their tasks and the progression of their four-week journey. • They view themselves as experts on their PBDT task ideas and solutions. • The first author's role is almost entirely from that of an outside observer. • Students used this STEM Third Space Genius Hour to complete the details of the presentations to be prepared for the following Monday class (see the "Explain" stage of the PBDT Framework, Figure 1). • Students were individually interviewed by the first author at the conclusion of the PBDT tasks. The interview questions are listed in Table 1.

Note. Table organization and theme adapted from "Elementary Preservice Teachers' Authentic Inquiry Experiences and Reflections: A Multicase Study," by M. Kazempour, 2018, *Journal of Science Teacher Education*, *29*(7), 649. DOI: 10.1080/1046560X.2018.1487201

Method of Analysis

The first author initially read and analyzed participants' in-class discussions, interviews, and artifacts to discover any themes or patterns that specified their use of STEM content and practices, as recognized on the NSF list of approved STEM fields (APA Presidential Task Force, 2009; NSF, 2014) and/or real-world problem solving. Upon a deeper reading and comparative analysis of the transcribed in-class discussions, students' brainstorming documents, and the first author's field notes, peer debriefing (Creswell & Miller, 2000) between the first and second author contributed to the identification of the presence of empathic connections between the participants and the person or group at the center of their PBDT task that was present throughout the four weeks of the study. Participants' discourses and written communications developed and fostered by the third space environment conveyed levels of care or concern for friends, family, students, people, animals, the environment signifying participants' connection to relationships, communities, or situations that were important or of interest to the participants in some way. These evidences or access points of empathy aligned with key components of empathy as presented in the literature leading the first author to then analyze the data once more for further empathy-driven descriptions or actions that may have been missed or overlooked. This comprehensive analytical process identified empathy and STEM connection as the two main themes of this study. For this reason, the findings are presented and discussed in relationship to one of three empathy themes—recognition of connectedness, critical self-reflectiveness, and taking on another's perspective—or to the STEM connection theme. In accordance with the Interpretivist Research Paradigm (Nickels & Cullen, 2017; Thanh & Le Thanh, 2015), reliability, validity, and objectivity of the qualitative data were maintained through the triangulation of the multiple in-depth data sources (in-class discussions, student artifacts, and interview transcripts), researcher reflexivity, and through peer debriefing of data and themes among all three authors (Creswell & Miller, 2000). These findings formed the conclusions and implications of this study.

Findings

Over the duration of four 45-minute STEM Third Space Genius Hour sessions, students were actively involved in making sense of what PBDT entailed, the steps needed to develop the task, and presented the task components to their classmates effectively. The STEM Third Space Genius Hour allowed students to bring their social concerns (dominant discourse) into the academic environment (marginalized discourse) and address these concerns in ways that allowed them to consider possible solutions to these challenging global problems. In-class discussions and observations, student artifacts, and student interviews of the STEM Third Space Genius Hour sessions were examined and highlighted as the basis for rich discussion in this study.

Each week, specific themes within the third space became evident as students were working. Each student or student group developed unique PBDT tasks to solve based upon areas of interest, backgrounds, concerns, and previous experiences contributing to the dynamic transformative sociocultural atmosphere of this third space environment. The PBDT tasks focused on open-ended problems which have multiple possible solutions and require students to think critically, learn freely, make decisions, develop and evaluate ideas, and use current knowledge and skills applied in novel ways (Johnstone, 1993; NGSS Lead States, 2013; Surif, Ibrahim, & Dalim, 2014; Surif et al., 2012). Throughout the STEM Third Space Genius Hour sessions, empathy emerged as the driving element that connected students to their authentic problems and led them to develop real solutions that incorporated various STEM content and practices. Weeks one and two reveal students intently exploring and evaluating empathic connections that continued through weeks three and four. Empathy was revealed as being the motor to engage students in the problem-solving task which provided the fuel to engage them in the more critical thinking and technical practices of STEM. For this same reason, there are no explicit findings for STEM connection during week one.

At times, there was clear evidence of empathy being the driving force in the problem-solution path. At other times, students were immersed in the details of how to make aspects or parts of the solution work in that they are utilizing critical thinking skills alongside STEM content and practices to help them continue. However, there were other times in which the role of empathy and the STEM-embedded skills were intertwined and connected, making it difficult to determine which aspect of the PBDT task was affecting or reinforcing the other. The list in Table 3 showcases student participants' PBDT tasks as well as their task descriptions, empathy-driven concerns being addressed, and the STEM content underscored throughout the STEM Third Space Genius Hour.

Table 3. *List of Empathy-Driven PBDT Tasks Participants Developed During the STEM Third Space Genius Hour*

PBDT Task	Description	Targeted Empathy-Driven Concern	STEM Content[a]	Student Participants
1. Reduce Littering for a Healthier Campus	A 3-D model of the school displaying the effects of trash on campus and identifying new locations for the placement of trash receptacles and recycling bins to keep the campus clean and improve the environment	Student health and environmental protection	Engineering, life sciences, mathematical sciences, social sciences	"Tracey"
2. Nuclear Fusion as a Source for Clean Energy	A process for using nuclear fusion to be source of clean energy	Sustainable clean energy	Chemistry, computer engineering and information sciences, engineering, geosciences, life sciences, materials research, physics and astronomy	"Nathaniel"
3. Drinkable Water Transportation and Storage	Labeled diagram of solar-driven hurricane-proof piping mechanism for an inexpensive and more efficient way of transporting clean water to homes, enabling residents to store without the possibility of rust or corrosion	Human health and resource storage and accessibility; disaster relief resources	Chemistry, engineering, geosciences, materials research, physics and astronomy, social sciences	"John"
4. Self-Sustaining Farms in Zambia	Creating sustainable farming techniques in Zambia by educating its people on incorporating new crops not previously grown	World hunger and malnutrition; sustainable farming; global unemployment; agricultural education	Engineering, life sciences, mathematical sciences, social sciences	"Luke"
5. Limiting People's Use of Social Media	An interactive app interface "Social Chat" that limits time usage of certain social media sites to increase call time and phone conversations instead	Healthy social media use; lack of human connection and communication	Computer engineering and information sciences, engineering, mathematical sciences, psychology, social sciences	"Nadine"
6. Cleaning up Littering on School Campus	"Pick up the trash you get the cash" campaign of rewarding students with school bucks who	Health and environmental protection; education	Engineering, life sciences, social sciences	"Brielle" and "Allison"

PBDT Task	Description	Targeted Empathy-Driven Concern	STEM Content [a]	Student Participants
	are actively picking up and throwing trash away properly			
7. Bullying: An Attempt to Raise Awareness	Presentation which educates students about how bullying can affect them in many ways and giving methods of how to get help if bullied	Healthy peer relationships and bullying awareness; school safety	Life sciences, mathematical sciences, psychology, social sciences	"Rosie"
8. Reducing Trash in the Ocean	Presentation and 3-D drainage grate model used to educate about the harmful effects of plastic and micro-beads in oceans and ways to decrease human impact	Environmental awareness and protection; education	Chemistry, engineering, geosciences, life sciences, mathematical sciences, psychology	"Jayson"
9. Hunger and Poverty in Zimbabwe	System of helping people of Zimbabwe build their own self-sufficient farms to decrease malnutrition and earn profit from their crops	World hunger and malnutrition; sustainable farming; global unemployment; agricultural education	Engineering, life sciences, mathematical sciences, social sciences	"Dylan"
10. Removing "Space Junk"	Designing a machine, the "Sorting Hat", that will have sensors which will sort out spaceship and satellite debris based upon sensors	Human impact; environmental awareness and protection	Computer engineering and information sciences, engineering, materials research, physics and astronomy	"Ava"
11. "Trafixing" (Reducing World Traffic)	Design for new cars and traffic lights electro-magnetically activated to help stop cars during red lights	Automobile and roadway congestion and accident prevention	Computer engineering and information sciences, engineering, physics and astronomy, social sciences, mathematical sciences	"Noah"
12. What Title 1 Schools can do for Poverty	Presentation educating others about the resources available for students in poverty at Title 1 Schools and drawing awareness to their needs	Childhood poverty; student health; education and social assistance	Engineering, life sciences, mathematical sciences, psychology, social sciences	"Krystal" and "Justin"

PBDT Task	Description	Targeted Empathy-Driven Concern	STEM Content[a]	Student Participants
13. Preventing Bullying of Autistic Students	Poster to bring awareness of autism bullying indicating ways to help autistic students (and their parents) who are bullied by peers	Healthy peer relationships; bullying awareness; students with disabilities	Computer engineering and information sciences, psychology, social sciences	"Treena"
14. Hunger in Pakistan	A process outlining how green onions can be grown in Pakistan and utilized to help reduce hunger while being a means of income for Pakistani people	World hunger and malnutrition; sustainable farming; global unemployment; agricultural education	Engineering, life sciences, mathematical sciences, social sciences	"Corey" and "JT"
15. Relieving Student Stress in School	Providing in-class strategies to help students relieve academic and social stress while in school	Student anxiety and school stress	Life sciences, psychology, social sciences	"Elaine"
16. Reducing Kids' Use of Social Media	An interactive smartphone program that will disable an app on a teenager's smartphone that is used more than two hours	Teen safety and social awareness of social media; school safety;	Computer engineering and information sciences, engineering, mathematical sciences, psychology, social sciences	"Joshua"

Note. Table organization and theme adapted from "A Longitudinal Study of Equity-oriented STEM-rich Making Among Youth from Historically Marginalized Communities," by A. C. Barton and E. Tan, 2018, *American Educational Research Journal, 55*(4), p. 774.

[a] Key for STEM Content Exhibited (as outlined in the NSF Approved STEM National Science Foundation 2014; APA Presidential Task Force 2009).

1. Chemistry: sustainable "green" chemistry, environmental chemical systems
2. Computer engineering and information sciences: software engineering, graphics and visualization, robotics, data processing, human computer interaction
3. Engineering: aeronautical and aerospace, systems, electrical, mechanical, energy, environmental, civil, nuclear, computer
4. Geosciences: marine biology, hydrology, geophysics
5. Life sciences: agriculture, biology, botany, ecology, environmental science, microbiology, physiology
6. Materials research: chemistry of materials, physics of materials
7. Mathematical sciences: biostatistics, computational mathematics, geometry, statistics
8. Physics and astronomy: astronomy, classical mechanics (Newton's Laws of Motion, gravity, force), nuclear
9. Psychology: social, other areas of psychology including behavioral, abnormal, health, counseling, cognitive, and school
10. Social sciences: communications, economics, geography, sociology, urban and regional planning

Empathy Findings: Week One

Recognition of Connectedness

In each class, students selected a range of initial topics including social issues like hunger, depression, gun control, or racism. It is necessary to mention that shortly before beginning this study, a notable school shooting occurred in a high school in Southeast United States. This event framed how several students approached their tasks; their connection to this shooting was real and they recognized others like themselves in what happened to students whose names they did not know miles away from their science classroom. Some students focused on ways to protect students in schools and considered developing ways to monitor mental health issues.

The "trigger" questions and the verbiage the first author used to initiate the PBDT task detailed in Table 2 enabled students to consider the scope of these issues and narrow these vast concepts into more focused and tangible ideas to begin to tackle. For example, Krystal and Justin's initial brainstorming list included littering, bullying, global warming, poverty and religious belief. Following the brainstorming session, they developed their unique question "How can title one schools help poverty?" From this point, their brainstorming became more specific to this question and included the initial solutions of free breakfast and lunch, school donations, free field trips, and building a donation website. Krystal expressed frustration that their school was not doing enough for students who lived in poverty. She spoke about these students as being a part of a community in which all students should have their needs met at school and no one should be left out. In her own way, she recognized her connection to students in a low socioeconomic status and this recognition drove the efforts of her team to seek solutions to this problem they identified.

Critically Self-Reflective

Some student participants gravitated toward interests and areas of concern they already had (see the "Empathy" stage of the PBDT Framework, Figure 1). These students appeared to use this STEM Third Space Genius Hour as an opportunity to explore personal problems or issues they had previously identified in their lives or in the lives of others. Nadine critically reflected upon her own habits and admitted that she spends too much time on social media, and that she is working on paying more attention to her family and friends, engaging them in more face-to-face conversations. She wanted to develop a process or tool for "getting people to be less addicted to social media."

Taking on Another's Perspective

John's brainstorming sheet did not have a list of various brainstorming problem ideas as other student participants' sheets, indicating the problem he wanted to address was already one he had been considering prior to this task. John focused on providing clean water for developing countries by supplying these countries with better temporary and permanent water storage. His problem of providing storage and transportation for drinkable water was well established during week one as well as his development of ideas toward a solution as depicted in Figure 3.

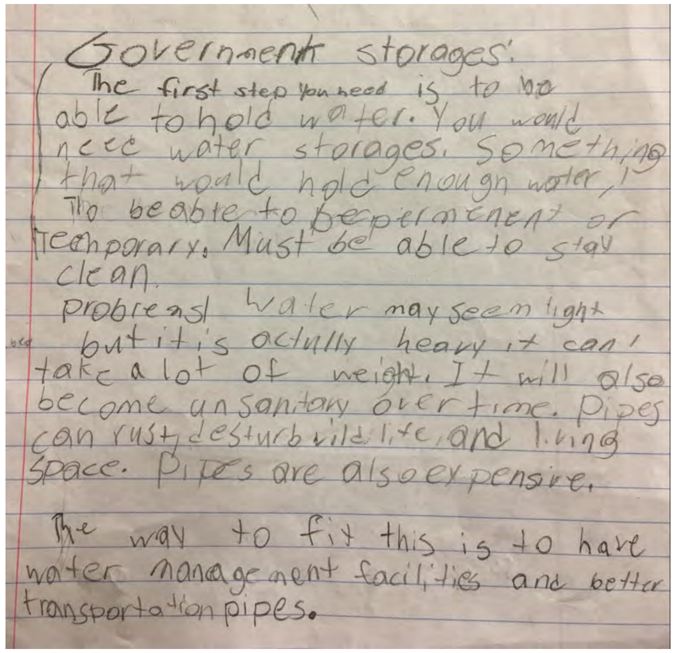
Government storages:
The first step you need is to be able to hold water. You would need water storages. Something that would hold enough water, ! To be able to be permenent or temporary. Must be able to stay clean.
problems! Water may seem light but it's aclully heavy it can't take a lot of weight. It will also become unsanitary over time. Pipes can rust, desturb wild life, and living space. Pipes are also expensive.
The way to fix this is to have water management facilities and better transportation pipes.

Figure 3. Student participant's problem-solution brainstorming sheet during week one.

Throughout all classes, some potential solutions to societal problems were dependent upon changing people's behaviors, values or mindsets. For example, a student participant may say that students just need to stop littering on campus or that disadvantaged people just need to get better jobs. In these cases, the first author would ask: "What if you could not change others' behavior to this problem? How could you develop a process or product that would help fix or address this issue?" These types of probing questions challenged students to consider the other's perspective (the student that litters or a person without a job). The questions also served to help activate empathic thinking and processing about these problems, thereby shedding light upon multiple aspects of the problem and the individuals or groups of people who were being affected by these issues. This questioning also challenged students to develop new solution options that they may not have explored or considered viable before.

Empathy Findings: Week Two

In keeping the identified authentic problem of high importance, some students began making personal connections to their problems. A key aspect of the DT process is the element of empathy, demonstrating a "deep interest in developing and understanding of the people" (Dam & Siang, 2018, para. 4) for whom this problem or concern exists. In conversations with students during week two, their excitement or fervor for helping a person, a group, or environment, depending on the specific problem addressed, provided a connection for the students between the task and their role in working towards a viable solution (see the "Empathy" stage of the PBDT Framework, Figure 1). The task became less about being another classroom assignment and more about expanding into a larger purpose, cause or motivation.

Recognition of Connectedness

Students were experiencing and wrestling with the implications their PBDT tasks and solutions would have on others, society and the world. The first author developed the Empathy-Driven Problem-Solution Pathways graphic displayed in Figure 4, while observing how students engaged in and progressed through the problem-solving process with empathy as a driving motivator. The characteristics of empathy that surfaced during week one became more pronounced during week two through students' discussions, interactions, and documentation of their PBDT tasks and their problem-solution pathways.

Critically Self-reflective

Brielle and Allison passionately voiced their concern for littering around the school campus. When the first author asked them if students are the ones littering, Allison admitted that some students litter, but others do not. Then she added, "custodians gotta' go around and clean up and then they're gonna' quit…and after they quit we got no more custodians...and then the school's a mess and then they gotta' shut down the school and then we got no more [school]."

Taking on Another's Perspective

Students were positioning themselves as being representatives and spokespeople for the problems and solutions they chose and developed. Researching facts, statistics, and current events added workable knowledge that students used to help them understand the multifaceted aspects of their problems. Luke and his teammate wanted to help fix world hunger in developing countries but were not sure which country or what help they could provide. Nathaniel and his team described the scarcity of clean energy and the need to discover new clean energy sources. Joshua expressed a strong concern regarding students who get injured during school shootings because "they were on Snapchat, Instagram, and other social media services." In discussing her problem of preventing bullying of autistic children, Treena conveyed, "…when you bully autism kids, it's like people don't take that to the heart... They can't do what we do; they don't have the capabilities to do what we do, so that's, that's sad."

For Treena, Brielle, Allison, and Tracey, the new information acquired through research became a resource they could use to more confidently support their personal experiences and perspectives of their posed problem. These elements of empathy helped them to identify with those being affected by the problem the most. Combined with new content knowledge and a better awareness of the multiple perspectives surrounding and encompassed within the problem, many students began to exhibit empathy in action. The interest students displayed in tackling these empathy-driven PBDT tasks may be a vehicle that leads them to continue to appreciate and explore both developing and solving PBDT tasks in the future.

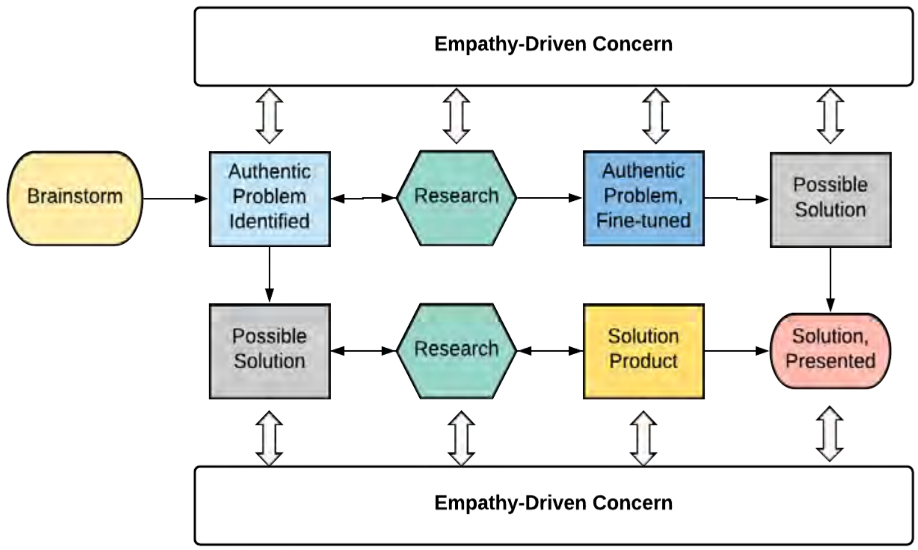

Figure 4. Empathy-driven problem-solution pathways exhibited during the PBDT task.

STEM Connection: Week Two

Students began stating their problem and the solution path when asked to explain their progress to the first author. For some student participants, this helped solidify their solution steps and for others this process made them more aware of possible holes, pitfalls or shortcomings in their solutions or processes. Research, discussion, debates (see the "Explore" stage of the PBDT Framework, Figure 1) among team members increased during this week. This exchange of perspectives, ideas, and discourse helped students prioritize the key ideas of their PBDT tasks and make decisions on how to approach designing their solutions. For example, Nathaniel was working to convince his teammates that the trillion-dollar cost of developing a nuclear fusion reactor from seawater was a necessary payout for unlimited clean energy.

At times, their solutions were hiding other "mini-problems" which needed to be solved first. Nadine was drawing a smartphone shown in Figure 5 to help her think "of a program or social media platform" that would "get people less addicted to social media" by limiting the number of times people get on social media every day. However, she was challenged with figuring out how the program would work. Tracey explained that she and her teammate were "trying to solve the issue of trash or like gum being left on campus". When the first author asked her "Why is that a problem," she struggled to provide an answer. Tracey knew that they needed to be able to articulate a reason beyond littering simply being bad for the environment.

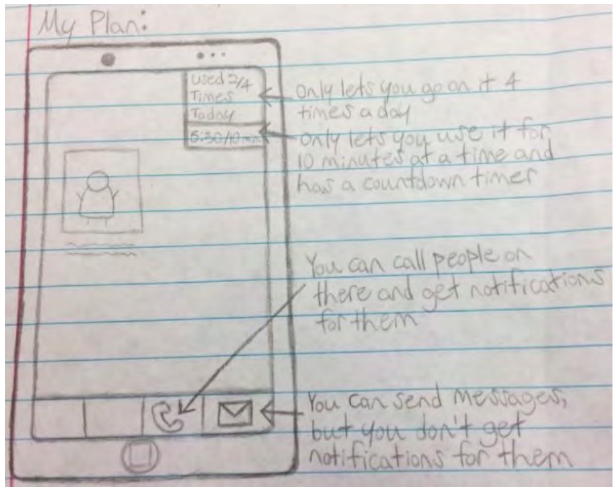

Figure 5. Student participant's smartphone app diagram during week two.

As these accounts attest, some of the student participants' PBDT paths diverged during week two. The Empathy-Driven Problem-Solution Pathways (Figure 4) depicts the two main pathways student participants worked through the PBDT task. Most of the participants demonstrated some degree of brainstorming, however, not all of them progressed from problem to solution as directly as others. This iterative movement is indicative of the DT process "in which knowledge is constantly being questioned and acquired so it can help us redefine a problem in an attempt to identify alternative strategies and solutions that might not be instantly apparent with our initial level of understanding" (Dam & Siang, 2018, para. 32). In tracking students' location on the Empathy-Driven Problem-Solution Pathways (in Figure 4), it is critical to understand the relationship between each step and between the authentic real-world problem. Regardless of the source of the challenge or detour— teammates' opinion, teacher's questioning, or discovery of pitfalls via research— students had an option of how they would address it. There were no apparent dead ends or complete roadblocks as long as students were considering the overarching authentic problem. If a student lost sight of the context of their developed problem, they may have found themselves with a solution to a problem that was illogical or unsound.

Empathy Findings: Week Three

Recognition of Connectedness

In week two, John takes on the perspective of people who do not have clean water. As he develops his PBDT task over the week, he demonstrated a sense of connecting to these people he wants to help by explaining his dilemma of discovering the best material for water storage that is strong, durable and safe for holding consumable water. Steel, he explains, is strong but it can rust and contaminate, and fiberglass is clear and strong but is unsafe if people consume it. While he may have clean water, he is still connected to the people he is helping because of being human. Essentially, all people, regardless of their means or geography deserve safe and healthy water.

Critically Self-reflective

Several teams still needed more guidance than others, even though there was only one more week to work. For example, Krystal and Justin were unsure of their next step in determining how they could help students in poverty at their school. Their view of how the school was supporting students in poverty was critical and negative. They hesitantly asked if they could go to the office to inquire about the services the school offers for students in need. Upon returning to class, they expressed enthusiasm about the information they discovered. They both had to confront and reflect upon their initial and erred judgements about their school's services. Justin concluded that this new information would allow them to make better decisions about how to participate in, add to, or improve the school's services and outreach to its student community.

Taking on Another's Perspective

Some students needed to be challenged to step outside of their cultural perspective to effectively work towards a plausible solution. In a discussion with the first author, Luke and his partner came to the realization, a kind of self-reflection, that people in Zambia may not be open to Luke and his team telling them what crops they need to grow or showing them pictures of U.S. grocery stores. The students were learning that Zambians have a perspective of their country and a way of life that Luke and his partner needed to understand.

STEM Connection: Week Three

As evidenced by week two, the STEM Third Space Genius Hour allowed for various types of discourses to occur simultaneously. During each STEM Third Space Genius Hour session, the first author spent time at each table assessing each student's or team's progress on the PBDT task. By the time students reached week three, many of them had a strong solution or solution path mapped out. Students were leading themselves more, and the first author's facilitation, primarily through questioning, lessened. Students were more focused on testing and confirming their solutions and beginning to create their presentations (see the "Explain" and "Engineer/Experiment" stages of the PBDT Framework, Figure 1).

Students were striving to make sense of how the design of their solution linked with the social issue at the center of their PBDT task. Noah and his teammate used a Hot Wheel car, a small whiteboard, magnets and other classroom items to build a makeshift ramp to simulate how their solution would help eliminate traffic. The team ran multiple tests, making necessary adjustments to their model based upon the outcomes of each trial. Nadine explained her drawing of a possible app to monitor a person's time on social media. She explained that people can call and send messages but would only receive notifications of phone calls to encourage more voice-to-voice communication instead of texting. John tells the first author about his dilemma of discovering the best material for water storage that is strong, durable and safe for holding consumable water. Steel, he explains, is strong but it can rust and contaminate, and fiberglass is clear and strong but is unsafe if consumed. He decides to draw a diagram to explain his solution for the presentation. Jayson's solutions included suggestions to people about recycling. The first author asks him to think of other solutions that would not solely rely on changing people's behavior. He discusses how sewer grates could have smaller openings to prevent certain types of trash from falling through to rivers, streams and other waterways. Instead of providing a picture of a sewer grate, he decides to build a model of one to accompany his team's presentation.

Dylan and his teammate were still determining how they would approach their PBDT task of ending world hunger. Dylan felt that starting businesses where individuals could work to buy food was a better system than setting up farms for people to own, paying a small tax to be placed back into the farming system as his teammate suggested. Ava and her teammate initially wanted to use a magnet to collect space junk of broken satellites and such. In this exchange with the first author, Ava came up with a way to combine both she and her partner's views to make an auto-piloted robot that could use sensors to differentiate between metal pieces that should and should not be in space. Referring to the Empathy-Driven Problem-Solution Pathways (Figure 4), all the students were either at the *solution product* stage or *possible solution* stage, very close to finalizing what and how they would be presenting their PBDT tasks to their classmates.

Empathy Findings: Week Four

Recognition of Connectedness

As mentioned, there were students who developed their PBDT task from their personal experiences or struggles. Rosie also used her personal experience in the development of her PBDT task focused on bullying. She relayed her knowledge of how bullying had a physical and mental effect on her and was able to use past experience to connect to students who may go through similar situations. In doing so, her insight of the problem and supportive research she found led her to develop a variety of practical solutions to prevent bullying and get help if bullied.

Critically Self-reflective

Elaine and her teammate also identified with their task personally, as they both admitted to experiencing the effects of school stress. Initially, they developed solutions that suited their personalities and attitudes toward school, such as having ten minutes at the end of class to relax or do origami. When probed about how this would practically affect the design of the school day—the learning environment and content instruction each class period—Elaine said, "I think we need to brainstorm more…to get the best solution out of this problem…We need to figure out how this could suit everyone's schedule and needs." In stating this, Elaine exhibited a critical reflection of her initial perspective to develop solutions that were plausible and accessible to more people aside from herself and her teammate.

Taking on Another's Perspective

In the course of researching about their problem, students had to consider the practical perspective of the people for whom they were wanted to help. J.T. and Corey learned that Pakistan was very sandy which made them consider how best they would grow. They also discovered various ways green onions could be cooked to enhance their sweet flavor. Krystal and Justin learned that social workers collaborate with administrators and faculty to help students in poverty. Social workers also help students in poverty interact with peers who may have more material wealth than they do. Krystal and Justin's PBDT task evolved in such a way that they were able to view their problem from the perspectives of multiple people connected to this issue.

STEM Connection: Week Four

Krystal and Justin told the first author how much they learned about the resources their school provides and were ironing out the details and facts to include in their Power Point presentation. Treena wrote a poem about autism bullying and included the hashtag #autismproblemssolvethem on the poster she made. J.T. and Corey were determining how to highlight Pakistan and the usefulness of growing green onions for this developing country in their Prezi® presentation. They were making plans to plant the green onions in the next few days (see the "Engineer/Experiment stages of the PBDT Framework, Figure 1) (J.T. and Corey showed the first author a picture of the green onions they started to grow at Corey's house). Nadine found a digital platform to build a visual of her app

SocialChat (solution product, see Figure 5). Joshua showed the first author the digital image of the app he designed and coded using Scratch, an interactive digital coding program. Tracey and her teammate built a model of the school using cardboard and popsicle sticks (see Figure 6). Even though the formal presentations had not taken place, their discussions and tasks at this point provided more than enough evidence to justify that students had progressed through each stage of the PBDT Framework (Figure 1).

Figure 6. Student participant's model of littering on school campus.

Conclusion

This study incorporated a distinctive feature in that students were given the opportunity to create their own PBDT task driven by issues of concern and importance to them to examine how empathy plays a guiding role in developing student interest in and use of STEM content and practices. The introduction of this STEM Third Space Genius Hour allowed students the freedom to consider how they could help others in unique ways. Many students demonstrated empathy-oriented perspectives and actions throughout STEM Third Space Genius Hour study.

Empathy: A Driving Force in PBDT Tasks

The first research question addresses how (in what ways) students would incorporate empathy into the STEM problem solving if given the opportunity. Based upon the findings from students' in-class discussions, artifacts, and interviews, students incorporated empathy into STEM problem-solving in various ways. These middle school students exhibited a great capability for understanding and addressing the complexities of real-world problems around them in their world. The STEM Third Space Genius Hour sessions created a discourse-rich environment for student participants to bring together their socio-cultural perspectives, life experiences and academic knowledge to formulate and select the empathy-driven real-world problems they wanted to address and solve. Some students' PBDT tasks were derived from meaningful contexts such as personal experience (Rosie's struggle with bullying), career interest (Noah's desire to be an engineer), global concerns (Jayson's concern for water pollution), or school-based issues (Krystal's goal of helping impoverished students). These seeds of transformative empathy the students expressed in various ways appeared to be the fuel that ignited students' motivation to explore solutions even to very challenging problems identified in Table 3. As students critically reflected upon their own perspectives and worldviews or recognized how they were connected to these problems (or individuals for whom the PBDT task solutions would help), they took on another's perspective in order to develop unique and appropriate solutions. During the four-week study, students took genuine ownership of their PBDT tasks. Students' empathetic connection to the problems in their PBDT tasks was evident as they explored their problems, explained information they gathered to others, engineered or designed experiments to test (or investigate) their solutions, and extended their insight to consider improvements or other content areas. Empathy was an integral component of the students' processing of their PBDT tasks. Because students were able to develop the unique PBDT tasks, there was a strong connection between the task, the process, and the solution.

Integration of STEM in the PBDT Tasks

The second research question addresses how (in what ways) students would incorporate STEM content and practices as a part of their PBDT tasks. In response to this question, students incorporated a variety of STEM content or practices into their problem, solution or process designs of their PBDT tasks throughout the four-week study. Specific STEM fields of study represented by each PBDT task as identified by the NSF (2014) are found in Table 3. As each student group's problems and processes varied due to the unique nature of the PBDT task, all the student participants defined their own problem and obtained, evaluated, and communicated information pertaining to their PBDT task, exhibiting two of the NGSS Science and Engineering Practices (NGSS Lead States, 2013). Additionally, they used various types of questioning, hypothesizing, researching, investigating or experimenting, and data collection represented as part of the PBDT Framework. These findings support the claim that students in the middle grades are capable of designing their own problems and implementing necessary components of science and engineering practices to develop meaningful solutions. Every PBDT task integrated a combination of at least two different STEM fields. They all used digital presentation resources like Padlet, Power Point, Prezi, and Google Slides as tools to collaborate with and/or present their tasks to their classmates, yet only five PBDT tasks involved specialized technology as part of their problem-solving.

All participants' PBDT tasks contained aspects of at least two of the STEM fields, only some participants verbalized an understanding of the variety of content areas encompassed within STEM fields based upon student interviews. Students need to be challenged to consider alternative discourses that infused both the academic and non-academic ways of viewing global issues. Yet, as these issues are best met from a strong understanding of STEM content, it is critical that students are supplied with the information to develop and sharpen their STEM expertise to meet these challenges successfully. Given that students developed their own question and task process, a percentage of students' PBDT tasks did not fully engage each of the four STEM disciplines. These students moved through the PBDT framework in solving their problem, but they needed further guidance (more intentional questioning) to enable them to meaningfully connect STEM content and practices as potential resources and tools to optimize their potential solutions of the PBDT process.

Implications

In DT, empathy is a critical part of the process as it helps students notice and pay close attention to the human element of the problem or task. However, this study highlights empathy as a gateway for students to consider STEM content and practices in their thinking and problem-solving. Students can be in the midst of the problem and begin to ask themselves or their team members questions that they may not have considered before. These questions may lead them to consider alternate solutions, some of which may require diving into other disciplines, particularly STEM disciplines (see the "Extend" stage of the PBDT Framework, Figure 1). Through the first author's probing and questioning, ("Why green onions…what type of land is needed to grow them?"), students were challenged to dialogue, so to speak, with the various stage of an authentic problem to provide a more comprehensive solution, often incorporating aspects of STEM. Empathy-focused thinking is a necessary element in STEM education. Additionally, this study provides insight into how empathy can be further utilized in the classroom to allow students to draw upon important topics to them and others, deepen their conceptual understanding of STEM concepts, and drive them to recognize the use of other STEM disciplines they may not have considered otherwise.

Given the global shifts for preparing students with the cognitive knowledge of STEM disciplines, it is just as important for them to be prepared to address the human or "living" element at the core of real-world problem to focus on making the world a better place (Cook & Bush, 2018). This provides the basis for implementing these types of tasks in the science classroom, as these emulate real-world decision-making situations that can greatly affect the real lives of people in multiple contexts around the globe. This implication also addresses the need for the incorporation of social and global concerns as a way to promote culturally relevant instruction (Ladson-Billings, 1995; Price & McNeill, 2013) in science classrooms to make STEM accessible to all students (Sun, 2017). Further empirical studies, in which a third space environment is developed in the middle and secondary grades, are needed to intentionally explore the effects of an emphasis on empathy-driven tasks and STEM in the science classrooms.

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