The Effectiveness of Educative Curriculum Materials as a Form of Science Teacher Professional Development for a Geospatial Technologies–Integrated Energy Resources Curriculum

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ASTE Program Abstract:
An effectiveness study of using educative curriculum materials that promote teachers' environmental content knowledge and science pedagogical content knowledge with geospatial technologies is presented.

Abstract

Teaching and learning about geospatial aspects of energy resource issues requires that science teachers possess environmental science content knowledge and apply effective science pedagogical approaches to implement geospatial technologies into classroom instruction. To address these needs, we designed educative curriculum materials as an integral part of a middle school energy resources science curriculum. We examined the impact of implementing this curriculum on urban middle school science teachers' perceived geospatial science pedagogical content knowledge. Results indicated that curriculum implementation with the educative curriculum materials supported science teachers' science pedagogical content knowledge related to teaching about energy resources with geospatial technologies.

Environmental issues pertaining to energy resources are quite complex, involve understanding new scientific research findings, and entail thinking skills for interpreting data that are geospatial in nature. Understanding our world's energy resource issues involves inter-relationships between scientific, economic, social, cultural, and political factors. Such environmental issues include open-ended problems in which there is rarely one correct solution to solve an energy resource problem. These issues concern multiple stakeholders who view energy resource issues from varying perspectives. Solving an environmental issue requires a knowledge base of environmental science content, understanding the issue context, seeing the problem from varying perspectives, and exploring different possibilities (Environmental Literacy Council, 2007). Many environmental issues associated with energy resources involve geospatial thinking abilities and skills that include recognizing spatial distribution and spatial patterns in the environment, associating and correlating spatially distributed phenomena, imaging maps, and comparing maps (Bednarz, 2004; National Research Council, 2006).

Developing skills for understanding and addressing environmental issues is a key component of science teacher education and environmental literacy. Both the Association for Science Teacher Education (ASTE) and the North American Association for Environmental Education (NAAEE) advocate environmental study as an essential component of preparing science teachers (ASTE, 2009; NAAEE, 2004). Analyzing environmental issues provides learners with meaningful contexts by connecting their daily lives and local contexts to environmental science content (Pennock & Bardwell, 1994). In addition to developing an understanding about the underlying science, investigating environmental issues and their solutions actively involves learners in practicing and improving skills such as critical reflection, problem-solving and decision making - each an important skill inherent to science teacher education.

Teaching and learning about energy resource issues requires that science teachers possess environmental science content knowledge and understand effective science pedagogical approaches. Effectively teaching current environmental issues that are geospatial in nature, such as energy resource issues, requires specific technological pedagogical content knowledge (Mishra & Koehler, 2006) to implement geospatial technologies (GT) such as virtual globes (for example, Google Earth) or a geographic information system (GIS) into classroom instructional settings. Such geospatial pedagogical content knowledge refers to the knowledge required by teachers for integrating GT effectively into their content area teaching. Science teachers with geospatial science pedagogical content knowledge have an intuitive understanding of the complex interplay between science content knowledge, science pedagogical content knowledge, and geospatial science content knowledge by teaching science using appropriate pedagogical methods and GT.

The use of GT to spatially explore and investigate environmental issues during classroom investigations has proven to be effective in the development of accurate scientific understandings about complex environmental science concepts (Bednarz, 2004; Bodzin, 2010; Bodzin & Cirruci, 2009; NRC, 2006). Unfortunately, many science teachers have not had professional development experiences that foster sufficient geospatial pedagogical content knowledge to implement environmental science curriculum that use GT to promote environmental science learning and the development of geospatial thinking skills. Furthermore, few science teacher preparation programs integrate environmental education, and even fewer integrate environmental education and technology simultaneously (Heimlich, Braus, Olivolo, McKeown-Ice, & Barringer-Smith, 2004; Peffer & Bodzin, 2010).

Science teacher professional development can be highly effective when designed to accompany particular curriculum materials that will be adopted and implemented in the classroom. To address the need to provide effective professional development to educate middle school science teachers about important energy resources topics and to support their development of pedagogical content knowledge to teach science that promotes geospatial thinking skills that are important for investigating a range of environmental energy resource issues in our society, we have designed and developed educative curriculum materials (Ball & Cohen, 1996; Davis & Krajcik, 2005) to support science teaching as part of the *Environmental Literacy and Inquiry: Energy* curriculum (henceforth *Energy*). This effort is part of an ongoing systemic curriculum reform initiative in an urban school district to promote environmental literacy and inquiry and the development of geospatial thinking with GT as an essential component of the middle school science curriculum.

In this paper, we first present the theoretical framework that is used to guide the design and development of our educative curriculum materials. Next, we describe our educative curriculum materials that are designed to promote and support (1) science teacher learning of important Earth and environmental science subject matter about energy resources and (2) geospatial science pedagogical content knowledge. We then examine teachers' perceived impact of the curriculum materials to support their pedagogical content knowledge related to teaching with geospatial technologies.

Theoretical Framework

Curriculum science programs are viewed by many as an important lever for change – a tangible tool designed for impacting what teachers do, and therefore, what students learn. When the curriculum changes, teacher behaviors in the classroom change as well. However, research has shown that when teachers interact with curriculum materials, they do so in dynamic ways that are constructive or in some cases, may be unhelpful to learners (Barab & Luehmann, 2003; Brown, 2009; Davis & Krajcik, 2005; Lloyd, 1999; Remillard, 2005). They examine their adopted program's available materials and make decisions about which obtainable resources are the best to implement into their classrooms as a means to achieve the desired student learning goals. Such decisions are guided by a teacher's pedagogical content knowledge, instructional beliefs, intentions, pedagogical implementation skills and teaching goals (Freeman & Porter, 1989; Tarr, Reys, Reys, Chavez, Shih, & Osterlind, 2008). How teachers perceive and understand various instructional design features of a curriculum is determined in part by how the intended use of the learning activities aligns to a teacher's capacity to implement the instructional materials into an actual classroom setting (Ben-Peretz, 1990; Stein, Remillard, & Smith, 2007). During this process, a teacher must perceive and interpret existing curriculum resources, evaluate the constraints of the classroom and school setting, and reconcile their perceptions of the intended goals of the curriculum materials with their own instructional goals and capacities (Brown, 2009). During curriculum enactment, teachers may adapt and modify the intended instructional designs of curriculum materials in order to meet the needs of the students or the instructional setting. They may modify existing components that are beyond their own capacities or the capabilities of their students and may well omit components that do not interest them or that they may be unable to implement due to time constraints in the school setting (Kulo, 2011; Tarr et al., 2008). Many adaptations may be productive towards achieving student learning goals, while others may not lead to productive instructional ends.

Curriculum materials can be designed to incorporate professional development learning opportunities for science teachers to assist them with accomplishing instructional goals for their students. They may influence teacher decision-making by conveying instructional practices, providing appropriate science content materials, or providing pedagogical implementation ideas (Beyer & Davis, 2009; Davis & Krajcik, 2005; Davis & Varma, 2008; Scheinder & Krajcik, 2002). Curriculum designers can develop learning materials that better accommodate instruction by moving away from the traditional mode of instructional design models of curriculum as a "one-size-fits all students" model and instead provide for flexible adaptations to instructional implementation. Such curriculum designs can provide for different modes of instruction that are important given the diverse nature of students and their abilities in science classrooms. However, regardless of how appropriately designed the instructional activities are, curriculum developers cannot anticipate every student interpretation or response to an instructional task (Stein & Kim, 2009).

When curriculum materials are expected to take on the role of change agent and transform teacher practice – as in a systemic reform initiative – the challenges of effective implementation are heightened. Unfortunately, research studies have shown that there are many obstacles that teachers face when they attempt to use curriculum materials that are based on an instructional approach to teaching and learning that differs from their own experiences as teachers or learners (Ball, 1988; Stein, Grover, & Henningsen, 1996). This is especially true when teachers enact instructional materials that utilize GT to support inquiry-based learning environments. Studies have shown that teachers may experience technical issues pertaining to the interface design of software, have time constraints to learn how to use GT software applications to effectively teach with students, undergo difficulty with adapting developed learning materials to easily integrate into their own school curriculum, and may lack pedagogical content knowledge conducive to teaching with geospatial technologies in classroom settings

(Baker & Bednarz, 2003; Bednarz, 2003; Kerski 2003; Meyer, Butterick, Olin, & Zack, 1999; Patterson, Reeve, & Page, 2003; Sanders, Kajs, & Crawford, 2002; Shin, 2006; Trautmann & MaKinster, 2010).

One way of addressing these challenges is to design curriculum materials to promote the pedagogical design capacity of teachers - that is their ability to perceive and mobilize curriculum materials and resources for effective instructional enactment (Brown, 2009). The concept of pedagogical design capacity suggests that curriculum materials can be designed in ways to facilitate productive use by teachers to accomplish learning goals. This implies the importance of including additional supports within the curriculum in the form of educative curriculum materials - features of curriculum materials designed to support teacher pedagogical content knowledge in addition to student learning (Ball & Cohen, 1996; Scheidner & Krajcik, 2002). Educative curriculum materials have the potential to support teacher learning in a variety of ways. For example, they may help teachers learn how to anticipate and interpret what learners may think about or do in response to instructional activities (Ball & Cohen, 1996; Collopy, 2003; Heaton, 2000; Remillard, 2000). They may also support teachers' learning of subject matter (Ball & Cohen, 1996; Heaton, 2000; Schneider & Krajcik, 2002; Wang & Paine, 2003). Educative curriculum materials can also include pedagogical implementation supports provided in the materials in order to engage teachers in the ideas underlying curriculum developers' decisions (Davis and Krajcik 2005; Remillard 2000). In these ways, educative curriculum materials can promote a teacher's pedagogical design capacity, or his or her ability to use instructional resources and the supports embedded in curriculum materials to adapt curriculum to achieve productive instructional ends (Brown, 2009; Brown & Edelson, 2003).

Energy Educative Curriculum Materials

The eight-week *Energy* curriculum was designed for use with all ability levels of eighth grade students. The unit takes advantage of GT including Google Earth and GIS to promote student understandings of the world's energy resources and their impacts on the environment, energy use and misuse practices, and ways to sustain the future of our environment with sustainable energy sources. The learning activities are designed to address common student misconceptions and knowledge deficits about energy resources (see for example Barrow & Morrisey, 1989; Boyes & Stanisstreet, 1990; Holden & Barrow, 1984; Rule, 2005). As students progress through the curriculum, they further develop concepts and geospatial analysis skills with every investigation.

In our educative curriculum materials, we promote geospatial science pedagogical content knowledge by recommending baseline instructional guidance for teachers and provide implementation and adaptation guidance (Ball & Cohen, 1996; Davis and Krajcik, 2005). We designed the instructional materials to anticipate and interpret what learners might think or do in response to a learning activity and provide support materials that expand both teachers' science content knowledge and their geospatial pedagogical content knowledge. Our educative curriculum materials also provide teachers with rationales for instructional decisions. Teachers are known to draw on their own resources and capacities to read, make meaning, evaluate and adapt curriculum materials to the needs of their students (Remillard, 2005). If teachers understand the rationale behind a particular instructional recommendation, they may be more likely to enact the curriculum in keeping with the developers' intent (Davis & Varma, 2008). We develop our instructional materials in such a way that make key components of our instructional design apparent to teachers. For example, the curriculum contains an *Instructional Framework* section that provides teachers with an overview of the curriculum framework, design principles, and the instructional model for teaching with geospatial technologies. This section also overviews the enduring understandings, essential questions, standards alignments, instruction, and learning activities. These features also demonstrate the underlying principles, understandings, and intended application of the curriculum materials with classroom learners to achieve productive instructional ends.

Our curriculum materials are designed to promote and support teachers' learning of important Earth and environmental science subject matter about energy resources, geospatial pedagogical content knowledge, and teacher learning of spatial thinking skills that are geographic (see Gersmehl & Gersmehl, 2006). This is accomplished by providing teachers with multiple points of access to important energy content and pedagogical supports throughout the curriculum. For instance, the instructional sequence Web pages include a variety of implementation suggestions for teaching with diverse learners including low-level readers, English language learners and students with disabilities. As an example, the instructional sequence page for the *Energy Resources for the Isle of Navitas* learning activity includes the following implementation suggestions:

> For classes with students with special needs, you may wish to provide additional modeling, prompts and guidance for each energy source. You may wish to guide students through each question for the first energy source on the investigation sheet (hydroelectric power) before continuing to the next energy source (tidal energy).
>
> Show students examples of a good location on a river to locate a dam to produce hydroelectric energy and another location on the same river that would not be a good location to build a dam for a hydroelectric power plant. Emphasize to students that areas

that do not have changes in elevation or are not located near a confluence in a river are not optimal locations to place a dam.

In some provinces, renewable resources exist in areas of natural significance. You may wish to highlight an example (such as high wind speed areas and geothermal areas in Gaul) to discuss with students the trade-offs for acquiring a renewable resource in an area of natural significance. (Kulo et al., 2010, online).

Since there is no guarantee that a teacher will carefully read the instructional sequence page of a learning activity, all implementation suggestions are also duplicated in the *Teacher Guide* for each learning activity. Likewise, multiple access paths to the curriculum's energy content knowledge support materials are provided in multiple locations. For example, at the bottom of each instructional sequence Web page, a section labeled *"Teacher Resources/Content Support"* contains links to a series of content Web pages containing text, graphics, animations, and videos designed to enhance a teacher's content knowledge about a particular energy resource topic. A compilation of these energy resources content materials is also housed in the *Support Materials* section of the curriculum Web site.

Our curriculum materials are designed to provide additional supports for teachers who work with diverse learners. They include learning tools that enable access to learner ideas and attitudes that students bring to the classroom (for example the use of concept maps and pre-assessments). As noted earlier, it is unrealistic to assume that one set of curriculum materials can be designed to effectively accommodate the diverse nature of all learners in middle school science classrooms. Therefore, all instructional handouts are available in Microsoft Word text documents to enable teachers to adapt or modify important instructional elements including key questions, the use of visual cues, instructional scaffolding, and embedded assessment items to accommodate the various learning needs in a particular classroom setting.

Our educative curricular materials are also designed to help teachers promote geospatial thinking skills with their students. When using GT to promote geospatial thinking skills, there is a need for explicit instruction in geospatial analysis to help diverse learners understand visual representations in remotely sensed images (Bodzin, 2011; Bodzin & Cirucci, 2009). For example, in the learning activity, *Where is the Best Place to Locate a Geothermal Power Plant?,* students use Google Earth to explore features of "hot Earth" areas in Iceland and in the United States and then determine the best place to locate a geothermal power plant in the northwestern area of the USA. The instructional support materials for this learning activity are designed to help teachers display imagery in Google Earth using specific overlay features such as the terrain layer, metropolitan areas of the Northwest United States, and embedded regional overlays of hot Earth areas that we have developed (such as the Yellowstone Hotspot and Cascade Range). These educative curriculum materials are designed to assist teachers with modeling the process of identifying and interpreting important geospatial relationships among Earth features to their students.

The *Teacher Guides*, in addition to student instructional handouts for the *Energy* learning activities, are highly scaffolded and include many design elements to facilitate geospatial instruction with GT. Instructional supports in the *Energy* curriculum include screenshots of GIS data layers with added graphical arrows adjacent to the instructions in order to simplify the procedures involved with the learning task or to assist in learning new GIS software applications. Such design features are key elements to assist teachers who work with below grade-level readers and students with disabilities to help them to understand how to manipulate a GIS for displaying spatial data of interest. For each energy geospatial learning activity, teachers are provided with instructional prompts for each GIS data layer they need to focus on to analyze geospatial relationships.

Instructional guidance to support teachers with geospatial analysis is also provided. For example, in the *Isle of Navitas* activity, to analyze whether hydroelectric energy is a viable energy resource for their province, the *Teacher Guide* models a thought process for determining suitable locations for the placement of a hydroelectric dam:

> The factors needed to determine the ideal location of a hydroelectric dam include the topography, a canyon that can be dammed, and an area to make a reservoir upstream of the dam. Zoom in to where the streams start in the mountainous areas (light green or white). Hydroelectric power requires a power plant at the dam site and access to the grid for power distribution. (Kulo et al., 2010, online).

Teachers are then prompted to display the lakes, major rivers, electrical grid, and the national significance layers in their GIS. The national significance layer contains areas that are environmentally sensitive or culturally significant.

In addition to the instructional scaffolds in the *Isle of Navitas Teacher Guide*, we developed a series of teacher supporting materials that include visual guides for each province that contain important background information of each energy resource. The visual guides include a screenshot of the location of each energy resource and discuss the feasibility of each energy resource use for the provinces. If an energy resource is available in a province, we indicate the most ideal location to place a power plant with regards to the proximity of the electrical grid, transportation infrastructure, and the city locations. The visual guides also include examples of tradeoffs that students may need to consider if they choose various energy resources for their province. For example, a location may receive enough average annual sunshine to make it suitable for solar power generation but the area is under cultivation. Teachers, therefore, need to consider the tradeoffs involved in converting productive farmland into a solar power plant or using that area for growing food or switchgrass for biomass/biofuels production. A visual guide example is provided in Appendix A.

We contend that the use of the *Energy* educative curriculum materials in and of themselves provides a form of professional development since they include designs to promote teacher learning and support effective teacher decision-making for implementing curriculum materials. These materials may be used independently or with other forms of teacher learning such as face-to-face or Web-based professional development experiences. Remillard (2000) describes using curricular materials to "speak to" teachers about rationales behind instructional decisions. Since the classroom teacher is the agent who ultimately decides and structures what is to be taught, our educative curriculum materials should help teachers to understand how science instruction with GT fits contextually within the adopted middle school science curriculum.

Evidence of Effectiveness

We conducted an efficacy study to examine (1) the impact of the curriculum materials to support teachers' perceived pedagogical content knowledge related to teaching with GT and (2) the perceived usefulness of the curriculum support materials. Our interest is focused on how teachers *perceive* their ability to do certain things within a specific curriculum implementation context; that is, to enact a GT-integrated curriculum in urban middle school classrooms.

Setting and Participants

Fifteen urban middle school teachers in the northeast region of the United States implemented *Energy* curriculum with their students during the 2010-2011 academic school year. The participants included all fourteen eighth grade Earth and space science teachers from four different urban middle schools in the same school district and one teacher from a different nearby urban school district. Seven teachers were male and eight were female. The teachers had a wide range of teaching experiences from a first year science teacher to a teacher with 37 years of experience. Content area certifications backgrounds were quite varied and included general K-8 certifications, middle school science certifications, and specific secondary-level science content domain certifications.

Three teachers had pilot-tested the initial version of the *Energy* curriculum with their students during the previous school year. One of these teachers was a member of our curriculum development team. Eleven teachers had prior experience using Google Earth embedded in a *Land Use Change* curriculum during the previous year. This was the first time that twelve of the fifteen teachers enacted the *Energy* curriculum with their classes and used GIS as a learning technology in their classroom instruction. This was the first time that four teachers had used geospatial technologies in their science curriculum instruction, one of which was a first-year science teacher.

During September and October 2010, all fifteen teachers attended nineteen hours of professional development to become acquainted with the *Energy* curriculum's geospatial learning activities and laboratory investigations. Eleven hours focused primarily on teaching and learning with GT. The remaining eight hours focused on laboratory activities, an energy content overview, and a session that addressed students' energy misconceptions and knowledge deficits.

During the curriculum enactment, the teachers requested no additional support from the professional development providers. It should be noted that two district technology-integration support personnel also attended the professional development sessions to become familiar with the curriculum so they could assist with any technology issues if they were to occur during the classroom implementation. They also ensured that all required geospatial software applications and Web browsers were available to the teachers and loaded on classroom laptop computers.

Data Sources

During the curriculum enactment, we asked the teachers to complete bi-weekly surveys that included a set of Likert items that asked them to rate their interactions with the curriculum and support materials. The teachers also completed a second survey at the end of the curriculum enactment that included items designed to help determine how useful the curriculum support materials were to them and if they perceived any professional growth through the use of the curriculum materials. Teachers also responded to the following open-ended prompt: *Which types of curriculum support materials did you find most helpful during the implementation of the Energy unit?*

To examine teachers' growth in their perceived geospatial science pedagogical content knowledge, we administered two subscales of the Geospatial Science-Technological Pedagogical Content Knowledge [GS-TPACK] instrument (Peffer, Bodzin, & Kulo, 2010) to all participating teachers at the beginning and end of the school year. One teacher was unable to complete the post-measure at the end of the year due to a life-threatening illness. The *Geospatial Science Content Knowledge* (GSCK) subscale is designed to measure teachers' perceived understanding to how GT can be used in science education. The *Geospatial Science Pedagogical Content Knowledge* (GSPACK) subscale is designed to measure teachers' perceived knowledge of how geospatial technology interacts with their pedagogical content knowledge in ways that produce effective teaching and student learning opportunities. The reliability (Cronbach alpha) of the GSCK subscale is .873 and the reliability (Cronbach alpha) of the GSPACK subscale is .893.

Porter (2002) discussed the question of validity of teacher self-report survey data. He indicated that teacher surveys are valid only when teachers are willing to complete them and noted that there are a number of studies that have used teacher survey data for reporting instructional practice and professional growth.

Results

Table 1 displays the results of the completed biweekly survey items that teachers completed during the curriculum enactment to rate their interactions with the curriculum and support materials. Seventy bi-weekly responses were obtained from the fifteen teachers during the school year. The data summaries show that during the curriculum enactment, the teachers perceived the educative curriculum materials to support them with content knowledge, pedagogical implementation ideas, and using geospatial technologies with their students.

--Insert Table 1 About Here -----------------------------------

Table 2 displays the responses to the survey items pertaining to the usefulness of the curriculum support materials that teachers completed after they enacted the *Energy* curriculum with their students. Data results show that most teachers perceived the educative curriculum materials to be quite useful for a variety of science pedagogical strategies for teaching with geospatial technologies and providing them with sufficient content knowledge. Table 3 displays the teacher responses to the survey items pertaining to their perceived pedagogical content knowledge growth through their use of the *Energy* curriculum materials. The survey item responses indicated that most teachers perceived that the educative curriculum materials helped them to grow professionally in their knowledge about geospatial technologies, geospatial technology skills, energy content knowledge, and technological pedagogical understandings with geospatial technologies.

--Insert Tables 2 and 3 About Here ----------------------------------

Teachers reported that they found many different types of curriculum support materials to be the most helpful during the implementation of this ELI unit. Specific responses that were listed included *Teacher Guides* (n=5), design of student handouts (n=4), energy content background materials (n=3), supports for implementing geospatial technologies with students (n=3), instructional sequence pages (n=3), laboratory *Teacher Guides* (n=3), the entire Web site (n=2), and the face-to-face professional development sessions (n=1).

Tables 4 and 5 display the mean results from the pre- and post-administration of the GS-TPACK instrument subscales. Overall, the findings revealed that modest growth occurred from the beginning to the end of the school year in teachers' perceived geospatial science content knowledge (mean GSCK subscale difference = 3.00) and geospatial science pedagogical content knowledge (mean GSPACK subscale difference = 2.35). Two GSCK subscale item mean differences were significant at the .05 level. The modest gain scores were not surprising since the majority of teachers had prior experience using a GT-integrated curriculum that included educative curriculum materials during the previous school year. Gain scores on the GSCK and GSPACK subscales from pre- to post administration for three of the four teachers for whom this was their first time implementing geospatial technologies into their science curriculum instruction were substantial, with the largest gains for the first year science teacher (see Table 6).

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Finally, it should be noted that considerable student learning of important energy concepts and student growth in geospatial reasoning abilities related to energy resources use occurred with the GT-integrated curriculum enactment. Student results are discussed elsewhere (See Bodzin, Anastasio, & Sahagian, 2011).

Discussion

The results indicate that the *Energy* educative curriculum materials were perceived by the urban middle school teachers to be an effective form of support for teaching with a GT-integrated curriculum. Data from the GS-TPACK instrument subscales corroborate teachers' beliefs about the effectiveness the educative curriculum materials to support professional growth related to geospatial science pedagogical content knowledge. The findings support that the curriculum materials were designed effectively to assist science teacher learning of important Earth and environmental science subject matter about energy resources and promote the development of geospatial pedagogical content knowledge. Most teachers perceived that both their science content knowledge and geospatial technology skills were enhanced as a direct result of their use of the *Energy* curriculum. Our results also support that the teachers' geospatial science pedagogical content knowledge, that is, their understandings of how GT can be used effectively in science classroom instruction to achieve learning goals was also enhanced as a result of their direct interactions with the educative curriculum materials. Teacher survey responses also support that they perceived their interactions with the curriculum to enhance their capacity to adapt their instruction using geospatial curriculum learning materials for effective instructional enactment.

Our findings point to the fact that appropriately designed educative curriculum materials can be used by science teachers as a productive form of professional growth to support them with new ways of teaching environmental science content with GT. Curriculum materials are connected to teachers' daily work and therefore situates teacher learning within their own practice providing ongoing content and pedagogical support (Beyer, Delgado, Davis, & Krajcik, 2009; Collopy, 2003; Putnam & Borko, 2000). Effective designs of educative curriculum materials for a reform-based, science curriculum that embed multiple access pathways to science content and geospatial support materials can foster geospatial science pedagogical content knowledge on a large scale. However, in order for teachers to use educative curriculum materials, they must first access the materials. As one teacher noted in her open-ended survey response item, no matter how well developed the educative curriculum materials are, there is no guarantee they will be used: *The teacher documentation was great (although I didn't read it that much) and the day to day sequencing was great!!*

Inservice science teachers may not have sufficient professional development opportunities to acquire appropriate pedagogical content knowledge, science content knowledge, or the technological capabilities that are necessary to successfully implement GT-integrated instruction with diverse middle school students. Providing provisions to augment the geospatial science pedagogical content knowledge of inservice science teachers is of paramount importance if teachers are to effectively implement investigations of complex environmental issues such as energy resources use with classroom students. Our educative curriculum materials are a form of embedded teacher support that is designed to provide for such provisions. Such effective educative curriculum materials provide important support for science teachers to adopt and implement reform-based, GT-integrated science curriculum.

Many professional development constraints exist for science teachers to adopt and implement reform-based science curriculum in urban school systems (Fishman, Marx, Best, & Tal, 2003). Urban middle school teachers today have many demands placed on them during the academic school year that are related to federal and state accountability initiatives. Often, these initiatives will reduce the available time an urban school district may have to provide professional development opportunities for district-wide science curriculum adoption. The need to provide professional development to all middle school science teachers simultaneously is a fundamental challenge of scaling up any instructional reform initiative in a school district. This challenge is further exacerbated in urban school districts that commonly incur financial constraints. We acknowledge that ideally, professional development to support the teaching of science with GT should include intensive training, ongoing support, a supportive learning community, and flexibility in terms of support provided and implementation expectations (Trautmann & Makinster, 2010). However, extensive provisions for all teachers in an urban school district to attend more than a few days of professional development sessions and obtain sustained support from professional development providers from outside of the school district is not realistic in many urban school districts without significant external funding and thoughtful management of teachers' schedules to allow for contractual time for additional support opportunities. Therefore, we contend that educative curriculum materials play a crucial role to support the adoption and implementation of a new GT-integrated middle school science curriculum in urban school districts, especially when organized opportunities for professional development and sustained support for all grade-level teachers may be limited. In our case, the school district allowed for the equivalent of three days of professional development to introduce teachers to a new reform-based, eight-week GT-integrated curriculum of which only eleven hours were primarily dedicated to teaching and learning with GT.

Challenges exist to sustain reformed-based curriculum adoption especially in urban schools where the teacher turnover rate may be high. In this efficacy study, only three of the five eighth grade teachers who pilot-tested the *Energy* curriculum during the previous school year taught the same grade level again the following year. Key to successful adoption and sustained implementation of the GT-integrated *Energy* curriculum requires strong administrative support at all levels of a school district. In this study, the administrative support in one school district involved four middle school principals, a science supervisor, the assistant superintendent of curriculum, the district head of technology and network services, and two technology-integration specialists. By working collaboratively with these administrators, necessary provisions for the professional development sessions and classroom technology support was made available. Prior studies (McClurg & Buss, 2007; Russell & Bradley, 1997; Speck & Knipe, 2001) indicate that without such support, the likelihood that the adoption and use of the GT-integrated *Energy* curriculum by all grade level teachers in this urban school district may have been compromised. Systemic and sustained science curriculum reform in urban schools is difficult and demands time and support from multiple stakeholders (Anderson 2002; Johnson 2007; Johnson & Marx, 2009). In school districts where sustained science curriculum reform efforts are not substantial, well-designed educative curriculum materials can help support teachers' pedagogical design capacity to teach science with GT.

Implications and Conclusions

The findings from our efficacy study have important implications for science teacher education. First, effectively designed educative curriculum materials can be used to support the professional growth of science teachers when coupled with other forms of professional development experiences. Such materials can be used to support science teachers' learning of important environmental science topics in addition to supporting science teaching with GT. Curriculum supports can be developed in ways that help to promote the geospatial science pedagogical content knowledge of teachers; thus, enhancing their pedagogical design capacity to use virtual globes and GIS in the teaching of environmental science to diverse urban classroom learners. Our designs described in this paper may serve as a model to other science teacher educators and curriculum developers to help promote environmental science content knowledge while helping teachers to understand effective science pedagogical approaches when teaching with GT.

Second, there is much value for incorporating educative curriculum materials coupled with GT-integrated environmental science curriculum into teacher education programs and other professional settings. Curriculum learning experiences that use environmental issues investigation such as energy resource issues, climate change, land use change, and global water availability involve geospatial analysis and reasoning skills, and align to important goals for science teacher education (ASTE, 2009; ASTE, 2007). Incorporating GT-integrated curriculum that includes educative curriculum materials into science teacher preparation can be used to promote the learning of important environmental science content in addition to supporting the development of geospatial science pedagogical content knowledge with novice teachers.

Third, educative curriculum materials by themselves may not guarantee successful implementation of a GT-integrated environmental science curriculum in an urban school district. Key to successful adoption of such curriculum is administrative support within the school system that includes invested support for professional development. We worked closely with the school district's administration to provide 11 hours of professional development that focused on teaching and learning with GT and worked closely with the district technology support personnel to ensure technology issues would be minimal. Without some form of intensive professional development, systemic implementation of a reform-based GT-integrated curriculum across all grade-level science teachers in an urban school district is unlikely to succeed.

The reality of time constraints for professional development within many urban school districts limits the extent to which schools can adopt and sustain the needed professional development for new science reform-based curriculum that takes advantage of GT to promote learning. Without other forms of support, such as the use of educative curriculum materials to promote geospatial science pedagogical content knowledge, successful implementation of GT-integrated reform-based science curriculum may be compromised. Therefore, developing educative curriculum materials as a form of embedded support for classroom enactment of GT-integrated science curriculum is essential for such reforms to succeed.

There are limitations of our efficacy study. First, our findings are based on a small sample size of fifteen urban middle school science teachers, fourteen of which were from the same school district, with three having implemented an initial version of the curriculum during the previous school year. A much larger sample size with teachers from different school districts would enhance our ability to generalize our results. Second, our efficacy study relies on teachers' perceptions of their abilities within a specific curriculum implementation context. Our interest was primarily focused on teachers' perceived abilities using a specific set of educative curriculum materials designed to support the implementation of an 8-week GT-integrated energy resources curriculum. To truly measure teachers' science content knowledge, science pedagogical content knowledge, and geospatial science content knowledge, one would have to conduct many classroom observations to examine actual classroom science teaching practices that use appropriate pedagogical methods with GT, and develop additional pre- and post measures to examine gains in teacher content knowledge. Future research efforts might focus on actual classroom implementation of GT-integrated curriculum that is coupled to educative curriculum materials to examine specific pedagogical enactment approaches in a variety of different middle school classrooms.

This paper describes educative curriculum materials that were designed to promote and support science teacher learning of important Earth and environmental science subject matter about energy resources and geospatial science pedagogical content knowledge. We conducted an efficacy study in the context of a reform-based GT-integrated curriculum adoption to examine the perceived effectiveness of our educative curriculum materials. We found that the educative curriculum materials supported science teachers' science pedagogical content knowledge related to teaching with geospatial technologies as they enacted the curriculum. The use of educative curriculum materials coupled with GT-integrated environmental science curriculum may also be useful for teacher education programs and other professional settings to help science teachers enhance their geospatial science pedagogical content knowledge. Such materials are designed to support effective teacher decision-making for implementing GT-integrated curriculum materials. The use of these supports may likely enhance the pedagogical design capacity of science teachers, resulting in productive curriculum adaptations to achieve science learning goals in their classrooms.

Acknowledgment.
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Table 1

Bi-weekly survey response summary to educative curriculum materials.

N = 70 responses from 15 teachers. *Scale: 1 (Strongly Disagree) to 5 (Strongly Agree)*

Item **Please rate your interactions with the curriculum.**	**Strongly Disagree** **% (n)**	**Disagree** **% (n)**	**No Opinion** **% (n)**	**Agree** **% (n)**	**Strongly Agree** **% (n)**	**Mean**
The curriculum and support materials provided me with appropriate content knowledge.	0.0% (0)	4.3% (3)	5.4% (4)	62.9% (44)	27.1% (19)	4.13
The curriculum and support materials provided appropriate teaching ideas to help me use the instructional materials.	0.0% (0)	7.1% (5)	15.7% (11)	48.6% (34)	28.6% (20)	3.99

Please rate your interactions with the curriculum.	**Strongly Disagree** **% (n)**	**Disagree** **% (n)**	**No Opinion** **% (n)**	**Agree** **% (n)**	**Strongly Agree** **% (n)**	**N/A**	**Mean**
The curriculum and support materials helped me use geospatial-learning tools with my students.	0.0% (0)	1.4% (1)	5.7% (4)	60.0% (42)	25.7% (18)	7.1% (5)	4.18

Table 2

End of Energy unit implementation survey responses pertaining to the usefulness of curriculum supports

N = 15 teachers. *Scale: 1 (Strongly Disagree) to 5 (Strongly Agree)*

Item **CURRICULUM MATERIALS Please indicate your agreement with the following statements:**	**Strongly Disagree** **% (n)**	**Disagree** **% (n)**	**No Opinion** **% (n)**	**Agree** **% (n)**	**Strongly Agree** **% (n)**	**Mean**
The teacher support materials (teacher guides, content materials, FAQs) alerted me to and provided suggestions to address potential student misconceptions or naïve conceptions about specific concepts.	0.0% (0)	13.3% (2)	26.7% (4)	40.0% (6)	20.0% (3)	3.67
The teacher support materials provided me with sufficient content background to implement the *Energy* unit.	0.0% (0)	13.3% (2)	13.3% (2)	46.7% (7)	26.7% (4)	3.87
The curriculum materials provided me with information to model scientific inquiry processes and skills during the *Energy* unit.	0.0% (0)	6.7% (1)	6.7% (1)	66.7% (10)	20.0% (3)	4.00
The teacher support materials (teacher guides, content materials, FAQs) enabled me to help my students understand connections between concepts in this unit and others throughout the school year.	0.0% (0)	0.0% (0)	20.0% (3)	60.0% (9)	20.0% (3)	4.00
The teacher support materials helped me to use geospatial learning tools (Google Earth or GIS) with my students.	0.0% (0)	0.0% (0)	0.0% (0)	66.7% (10)	33.3% (5)	4.33
The teacher support materials (teacher guides, content materials, FAQs) provided pedagogical	6.7% (1)	13.3% (2)	6.7% (1)	53.8% (8)	20.0% (3)	3.67

supports for me to think about how I might adapt my instructional practices to meet the needs of my students.						
The curriculum materials introduced me to new ways of teaching environmental science with geospatial learning technologies.	0.0% (0)	0.0% (0)	6.7% (1)	73.3% (11)	20.0% (3)	4.13

Table 3

End of Energy unit implementation survey responses pertaining to pedagogical content knowledge

N = 15 teachers. Scale: 1 (Strongly Disagree) to 5 (Strongly Agree)

Item	Strongly Disagree % (n)	Disagree % (n)	No Opinion % (n)	Agree % (n)	Strongly Agree % (n)	Mean
My knowledge about geospatial technologies increased as I used the curriculum support materials provided in the *Energy* unit.	0.0% (0)	6.7% (1)	0.0% (0)	80.0% (12)	13.3% (2)	4.00
My geospatial technology skills increased as I used the curriculum support materials provided in the *Energy* unit.	0.0% (0)	0.0% (0)	6.7% (1)	73.3% (11)	20.0% (3)	4.13
My content knowledge about the topics presented in the *Energy* unit increased as I used the curriculum support materials provided in the *Energy* unit.	0.0% (0)	13.3% (2)	0.0% (0)	80.0% (12)	6.7% (3)	3.80
My understanding to why certain technologies were used in the curriculum to promote science learning increased as I used the curriculum support materials provided in the *Energy* unit.	0.0% (0)	6.7% (1)	40.0% (6)	46.7% (7)	6.7% (1)	3.53
My understanding of how and when to adapt my instruction while using geospatial learning tools (Google Earth or GIS) increased as I used the curriculum support materials provided in the *Energy* unit.	0.0% (0)	13.3% (2)	6.7% (1)	66.7% (10)	13.3% (2)	3.80

Table 4

Responses from the pre- and post-administration of the Geospatial Science Content Knowledge (GSCK) subscale

N = 14 teachers. Scale: 1 (Strongly Disagree) to 6 (Strongly Agree)

Item	**Pre Curriculum Mean (SD)**	**Post Curriculum Mean (SD)**
I am comfortable answering student questions during science investigations that use geospatial technology.	3.64 (1.28)	4.29 (0.73)
I can think of many scientific concepts that students can learn more effectively with geospatial technologies than without these applications.	4.14 (1.23)	4.29 (1.07)
I can think of many science concepts that can be taught effectively using Google Earth.	4.71 (0.91)	4.57 (0.94)
I can think of many science concepts that can be taught effectively using GIS.	3.79 (1.12)	4.43 (0.85)
I can use geospatial technologies to investigate real-world scientific issues.	3.86 (1.29)	4.57 (0.94)
I can plan science lessons that make effective use of Google Earth.	4.43 (1.09)	4.71 (0.99)
I can plan science lessons that make effective use of GIS.	3.43 (1.16)	4.14 (0.95)
GSCK Subscale Total	28.00 (6.99)	31.00 (5.53)

Table 5

Responses from the pre- and post-administration of the Geospatial Science Pedagogical Content Knowledge (GSPACK) subscale

N = 14 teachers.   Scale: 1 (Strongly Disagree) to 6 (Strongly Agree)

Item	**Pre Curriculum Mean (SD)**	**Post Curriculum Mean (SD)**
I can *design* lessons that effectively combine science content, geospatial technologies, and teaching strategies.	3.93 (1.07)	4.29 (1.07)
I can *teach* lessons that effectively combine science content, geospatial technologies, and teaching strategies.	4.29 (1.14)	4.57 (0.94)
I can choose geospatial technologies to use in my classroom that enhance how and what students learn.	4.00 (1.04)	4.29 (1.07)
I can choose geospatial technologies that enhance both the content and teaching strategies of a science lesson.	4.07 (1.00)	4.43 (0.85)
I can use geospatial technology to teach science effectively using a variety of teaching strategies.	4.00 (1.04)	4.43 (1.16)
I can effectively assess student learning in projects that make use of geospatial technologies.	3.79 (0.97)	4.29 (1.07)
I can adapt my use of teaching strategies when using geospatial technology for student learning.	4.29 (1.07)	4.43 (0.85)
GSPACK Subscale Total	28.36 (6.75)	30.71 (6.16)

Table 6

GSCK and GSPACK subscale gain scores of teachers for whom this was their first time implementing geospatial technologies into their science curriculum.

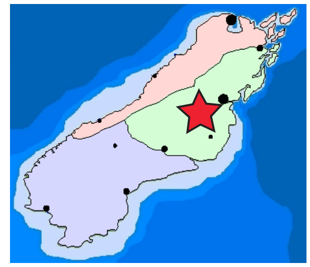
	GSCK Subscale Gain Score	**GSPACK Subscale Gain Score**
Teacher 1*	14	15
Teacher 2	8	8
Teacher 3	3	7
Teacher 4	4	1
Average Gain Scores	7.25	7.75

* First year science teacher

Appendix A. Visual Guide to Assess the Isle of Navitas Activity: *Province of Iberia*

Visual Guide to Assess the Isle of Navitas Activity

Province of Iberia



General Statement: Navitas is designed to be a flexible capstone project on ENERGY. Please note that when provinces are analyzed in isolation, students may wish to consider the accessibility of available resources from neighboring provinces to maximize energy efficiencies while mitigating negative environmental consequences. While this activity is designed for student group analysis of an individual province, the learning activity may be modified to analyze the entire island.

Note: For images that are zoomed in such that coastline features do not indicate the location of the picture, please use the latitude and longitude coordinates in the lower left of the image to guide you.

Hydroelectric Energy

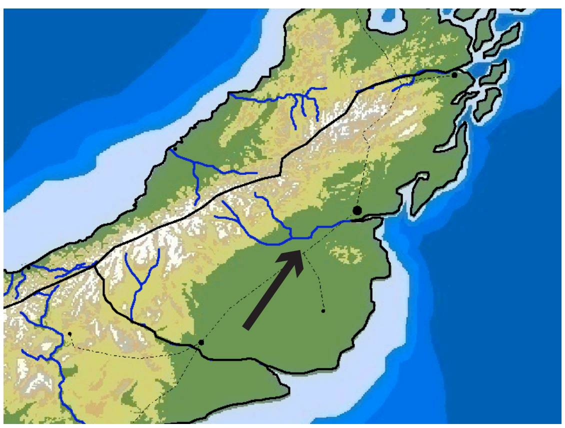


Figure 1: Map showing the location of the Jaro River.

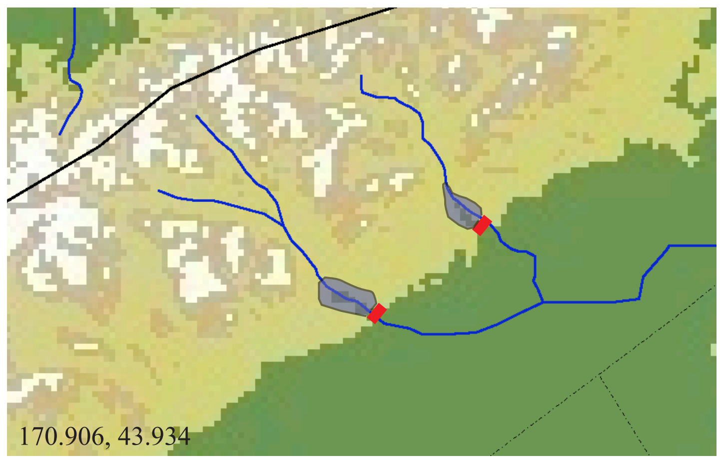
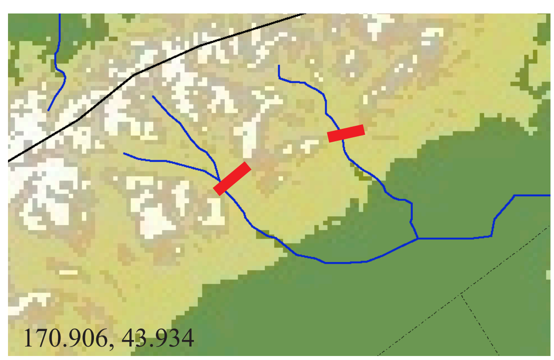


Figure 2: Map showing the locations of dams along the Jaro River that are most feasible given the wide valleys that drain the mountains in the this area. These dams would not create huge reservoirs, but rather smaller ones like those shown. These locations benefit from being close to the existing power grid.

Figure 3: The dam sites shown here in red are examples of unsuitable locations because the valleys are over 10 km (6 miles) wide and could not be effectively blocked by a man-made dam.



Tidal Energy

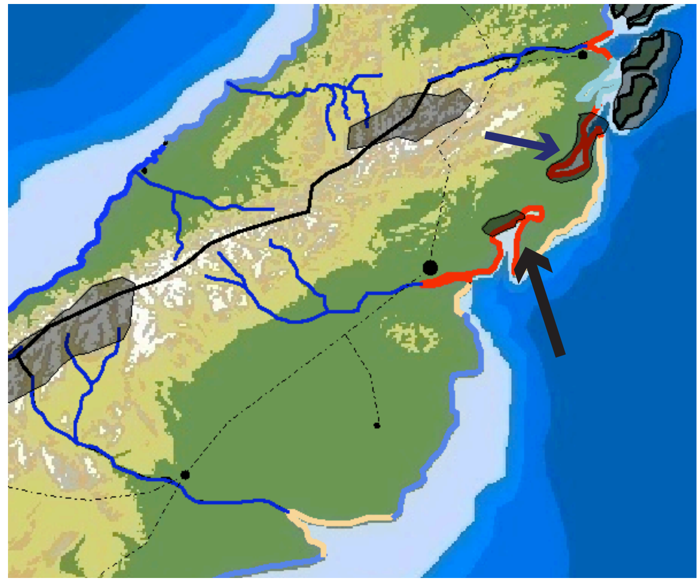


Figure 4: The most ideal location for tidal power generation is indicated by the black arrow, where the funnel shape of the coastline causes a large tidal range. The inlet to the north (indicated by the navy blue arrow) also has a large tidal range, however it is not as close to a large city or the power grid, and lies within an area that is protected for it's biological diversity.

Biofuels/Biomass

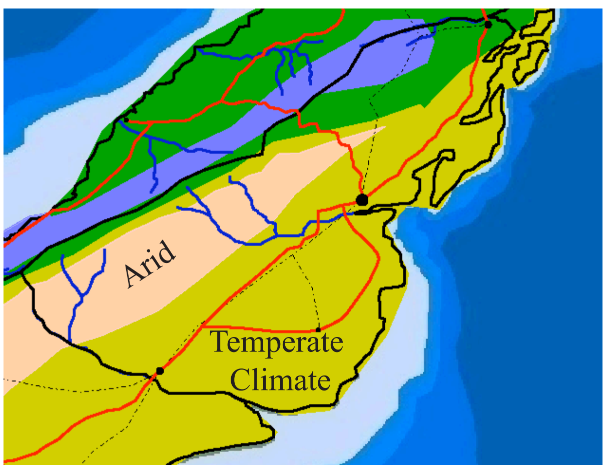


Figure 5: Map showing the distribution of temperate climate suitable for farming.

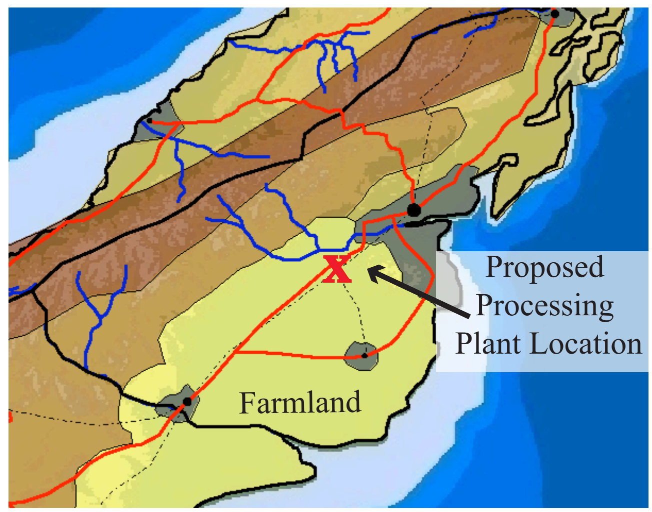


Figure 6: Map showing the distribution of farmland and transportation infrastructure necessary for biofuel/biomass production. The red "X" denotes an ideal location for a proposed processing plant since it is located along the transmission line and a highway. It is also close to a city.

Solar Energy

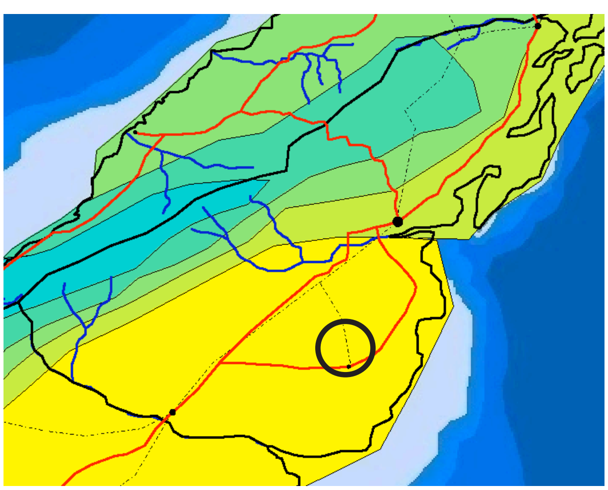
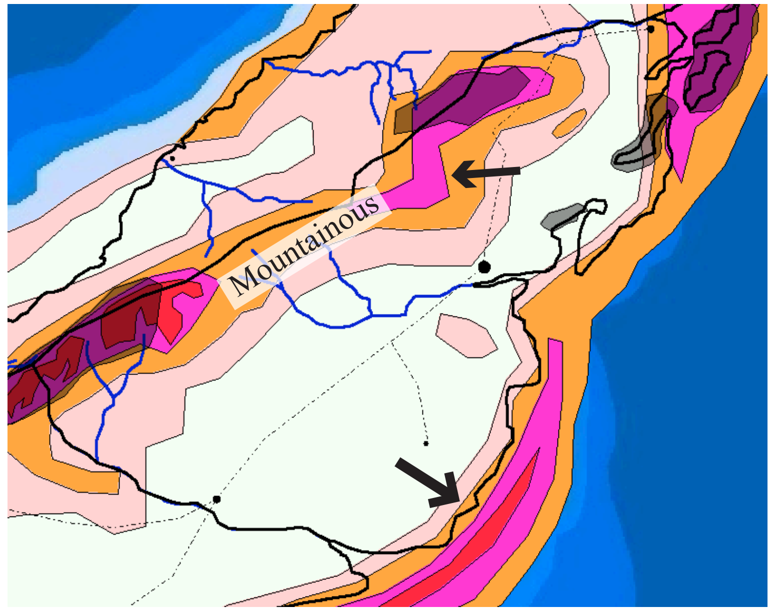


Figure 7: Map showing the percent sunshine for Iberia, the yellow area in the southeast receives enough sun to make it suitable for solar power generation and the proximity of transmission lines and cities make it a good option. However this area is also productive farmland, a good answer might discuss this tradeoff. An ideal location for a solar plant is indicated by the circle.

Wind Energy

Figure 8: Map showing the distribution of average wind speed for Iberia and the locations of national significance (transparent gray polygons). The purple area to the northeast has the advantage of being close to the power grid and the largest city on the island, however it is mountainous and half the area is protected parkland. The offshore area in the southeast does not have the conflict with protected lands, however construction offshore could be costly and it is further from the established power grid.

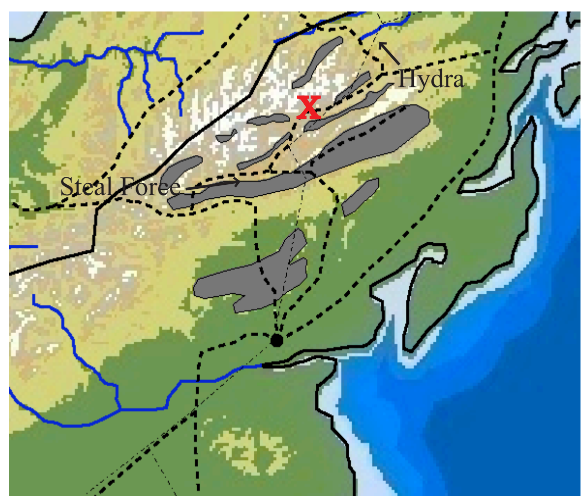


Fossil Fuels

Iberia contains all of the fossil fuel reserves for the Isle of Navitas and as a result coal, petroleum, and/or natural gas are all viable options for energy generation. However, as students have already learned, these resources have the potential for detrimental environmental impacts both during extraction, transport, and energy generation. In addition several of the largest fossil fuel deposits are located next to or within protected areas of national significance. All these things should be considered by the students when they decide whether or not to utilize these resources.

Coal

Figure 9: Map showing the distribution of coal reserves in Iberia. The red X marks the ideal location for a coal fired power plant because of the short transport distance and proximity to the existing power grid.



Natural Gas

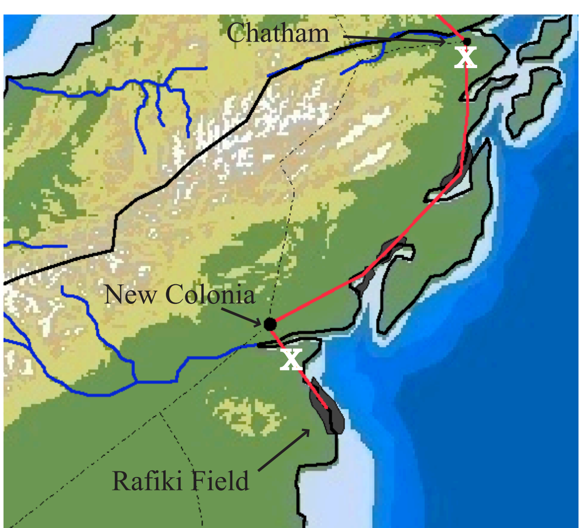
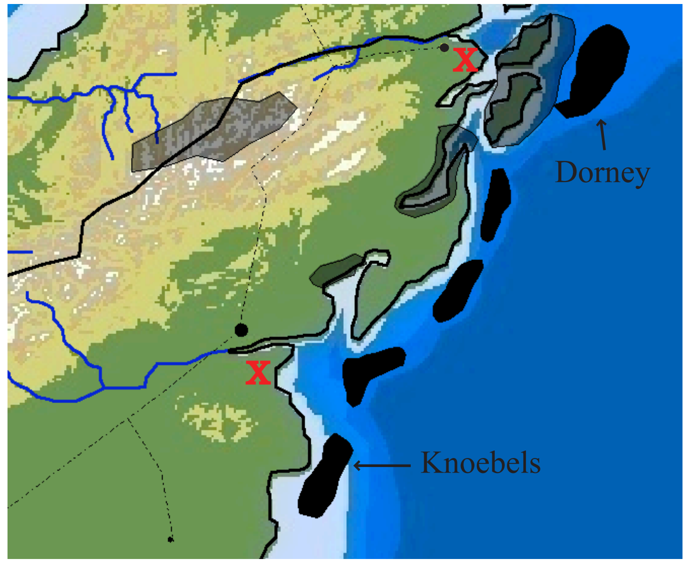


Figure 10: Map showing the location of natural gas fields and the gas pipeline for transportation. Both New Colonia and Chatham lie on the pipeline making natural gas power generation a viable option for Iberia. White X's show potential locations of power plants.

Petroleum

Figure 11: Map showing the distribution of crude oil reserves in Iberia. The Dorney Field is the largest and is close to a city on the coast. However, between the field and the city is a protected area of national significance. Therefore, a description of how the oil will be transported to a power plant should be included. Another possibility is tapping one of the smaller fields to the south and having a power plant near the large city of New Colonia. Red X's show potential locations of power plants.



Nuclear Energy

Figure 12: Map showing the location of the mineable uranium reserves and a potentially good location for nuclear power generation in southern Iberia. This site (red X) is good because the transport distance of the uranium is relatively short, the river provides plenty of water, and it is located along the power grid.