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# The Intersection of Socioscientific Issues, Computation Thinking, and Design Thinking: Toward a Framework of Inquiry Driven Disruptive Pedagogy

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# The Intersection of Socioscientific Issues, Computation Thinking, and Design Thinking: Toward a Framework of Inquiry Driven Disruptive Pedagogy

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**Abstract**

The Next Generation Science Standards call for engineering design solutions using computer technologies, but many K-12 classrooms either do not have accessible technologies or the teacher pedagogical knowledge on how to effectively implement engineering design into the curriculum. Without access to computer or mobile technologies, teachers are faced with a challenge integrating design thinking and computational thinking into inquiry-based teaching practices. Embedding design thinking and computational thinking within a socioscientific framework is a possible solution. Socioscientific issues, design thinking, and computational thinking are thoroughly researched and published constructs. There has been some research suggesting a connection between design thinking and computational thinking, however pilot data suggest a potential intersection of the three concepts which became the crux for our research. This study sought to construct a pedagogical framework amalgamating socioscienfific issues, design thinking, and computational thinking for science teacher practice in classrooms without the use of technology. Practicing science teachers enrolled in a master's level class served as the study's participants and they were charged with designing a mixed reality Serious Educational Game embedding socioscientific issues in a climate change context. Incorporating a case study design with triangulated data sources that were collected through reflective journals, design documents, and observations, an iterative process was used to analyze data to build trustworthiness. Results suggest initial hypotheses of the potential commonality between the three constructs were not completely accurate, however a refined model emerged. Articulation of how to integrate the new model using socioscientific issues, design thinking, and computational thinking are discussed.

## Introduction

Any time a novel approach commences, disruption follows. The term innovation is often used to describe new, and sometimes radically different, ways of thinking. Disruptive education aims to change schooling in positive ways, finding effective strategies to include all students in the learning process, and offering a fresh approach to skill development and knowledge transfer (Christenson, Horn, & Johnson, 2010).

Disruptive education is often quiet, like any innovation, but grows in scale when the disruption is effective (Heick, 2019). Not unlike the emergence of the calculator from the abacus or the calculator to the personal computer, much of the reference to disruptive education revolves around technology. Technology is most successful as an educational tool when it is accessed by the learner, personalized to relate to prior knowledge and experiences, and is purposefully aligned to learning goals and objectives (Annetta & Minogue, 2016). But disruption doesn't necessarily have to be about technology, rather it can be something like inquiry teaching, wait time (Rowe 1972), SSI (Zeidler, 2005) or any new way to teach and/or learn.

The National Science Foundation (NSF) in the United States has identified several challenges related to effective STEM instruction; specifically, designing culturally relevant and context-related learning experiences that facilitate STEM knowledge gains. Additionally, the NSF asks that these learning experiences promote creativity, teamwork, problem solving, and communication skills while also considering the societal implications of STEM as learner-centered and problem-based (National Science Foundation, 2020). Further, the Office of Science and Technology Policy within the executive office of the United States have recently made a call for increase computational literacy (Computational Literacy Interagency Working Group Federal Coordination in STEM Education Subcommittee and the Committee on STEM Education of the National Science and Technology Council, 2023). The report encourages STEM education to expand to include computational literacy through a lens of emerging technologies in four areas:

1. Fundamental digital skills,
2. Teacher professional development,
3. Ethics, and
4. Community outreach.

It is evident that a novel approach to teaching that is grounded in research will be required to achieve these lofty goals.

The terms design thinking (DT) and computational thinking (CT) often conjure thoughts of engineers creating schematics or computer scientists writing pages of computer code. These ideas are perpetuated by the Next Generation Science Standards (NGSS) (Lead State, 2013). These standards conflate computational thinking with computer programming, where students are expected to create and manipulate spreadsheets or create multi-parameter programs. This myopic interpretation of computational thinking reinforces the narrative that computational thinking is synonymous with computer programming instead of promoting the broader view that computational thinking is: 1. A thought process that promotes abstract thinking, 2. The ability to decompose a problem, 3. To present solutions as algorithms (step-by-step set of instructions), 4. Evaluate possible solutions, and 5. The ability to generalize solutions (Selby & Wolllard, 2013).

The integration and characterization of CT was one of the primary ISTE Educational technology problems to solve in 2020. The five CT competencies challenge educators and students to learn, lead, collaborate, design, and facilitate. CT skills can empower students to create computational artifacts that allow for personal expression through creativity and engage each of the components of CT. Design and creativity can encourage a growth mindset and work to create meaningful learning experiences and environments. These experiences and environments can inspire students to build their skills and confidence around computing in ways that reflect their attitudinal states (i.e., interests) and prior knowledge (i.e. experiences).

The Next Generation Science Standards have been a guide for science educators for over a decade (NGSS, 2013). A Framework for K-12 Science Education (2012) provided a foundation for which the NGSS could be built. From the framework arose the concept of three-dimensional (3D) learning to reconceptualize disciplinary core ideas with scientific practices and crosscutting concepts (the thread throughout every scientific discipline). At its roots, three-dimensional learning focuses on evidence that is sought by the learner about what they know and can do with their knowledge (Underwood et al., 2018). Three-dimensional learning challenges science educators to move from rote memorization of facts to a more disruptive approach that affords the learner a platform to create, analyze, and evaluate through engineering practices (e.g., design and computational thinking) and the cross-cutting concepts with core disciplinary ideas. This disruptive approach, however, requires a radical departure from traditional science teaching (Reiser et. al, 2017).

The NGSS only slightly improves their characterization of DT. While articulating the accepted components of DT (e.g. empathize, define, ideate, prototype, test), many of the engineering design standards emphasizes the need to use computer simulations to model the impact of proposed design solutions (National Research Council, 2012). The consistent reference to computer uses throughout documents like the NGSS can have a limiting effect, especially in K-12 environments, as a lack of access to technology and/or lack of training may cause teachers to preserve an inability to adequately integrate DT and/or CT in their instruction.

With a call for more design challenges in the NGSS, teachers are often not taught how to construct design activities and/or do not feel comfortable deploying design challenges in their classrooms. Kelly and Gero (2021) proposed a relationship between CT and DT. These two paradigms are often defined and studied in isolation, but their study suggests the processes of CT and DT are ontological mirror images of each other where thinkers move fluently between the two.

In response, this study advocates for *unplugged* computational thinking, the development of computational literacy without, or before, the use of computers (Peel, Sadler, & Friedrichsen, 2021). Embedding UCT, with explicit DT instruction as part of a larger unit that utilized a socioscientific issues (SSI) approach to facilitate CT, DT, and the resolution of complex issues through SSI, provides a platform to construct science lessons within an established inquiry-based framework. We propose that each component of DT, CT, and SSI are closely related and can occur simultaneously for finding solutions to complex problems by integrating cross-cutting concepts into instruction to support students' applications to science and societal phenomena.

This research has implications for how learning environments can be developed to support students' learning in the three-dimensional science framework (Fick, 2017) by aligning three seemingly separate constructs into one seamless pedagogical framework. Our research question thus became, what is alignment between SSI, CT, and DT when asking students to develop a science learning experience?

## Literature

### SSI as an Inquiry Teaching Framework

SSI emphasizes the importance of situating learning experiences in rich instructional contexts. This is consistent with Situated Cognition Theory, which states that individuals' knowledge is embedded within authentic contexts (Brown, Collins, & Duguid, 1989). Within this framework, learners are immersed and cultured in contexts as well as facilitated to assume the perspectives of nature and the community. SSI confronts learners with explicit pedagogical decisions to help them deconstruct their experiences (Bressler & Annetta, 2021; Sadler, 2009).

SSI instruction offers a sociocultural approach to the development of functional scientific literacy, which draws from the intersection of science, culture, and character (Zeidler, 2014; Zeidler, Sadler, Simmons & Howes, 2005; Zeidler, Berkowitz, & Bennett, 2014). This framework intentionally attends to normative factors, such as moral motivations, personal values, ethic of care, or other social milieu, that are often overlooked in more traditional approaches to science teaching which tend to privilege scientific reasoning devoid of such contextualized considerations. Instead of only providing a context for science content or simply pointing out ethical dilemmas, SSI instruction capitalizes on the pedagogical power of relevant real-world problems to stimulate emotional growth, as well as moral and ethical development (Sadler, Barab, & Scott 2007; Zeidler & Kahn, 2016; Zeidler et al., 2005). When SSI is well designed, students can address STEM content knowledge, nature of science, and epistemological reasoning (Fowler, Zeidler, & Sadler, 2009) through discourse, research, and critical analysis of the problem (Zeidler & Kahn, 2016). This process simulates both how scientific inquiry is conducted and provides opportunities to develop the skills necessary to become a scientifically literate contributor to society.

The proper immersion into an SSI can generate cognitive and moral dissonance as students consider their existing views side-by-side with the perspectives of others regarding those issues (Fowler, Zeidler, & Sadler, 2009). To resolve these internal conflicts, students must think reflexively and consider their biases, misconceptions, and emotions. As students engage in contentious issues, they develop a deeper understanding of the STEM content, as well as effective communication skills through collaborative problem solving, discussion, and debate (Kahn & Zeidler, 2016).

A precedent exists for the use of technology in SSI instruction. For example, the SSI Instructional Model, also referred to as the SSI Framework, has frequently included references to appropriate media or information communication technology as part of the development of science and sociocultural knowledge and skills necessary for problem resolution (Foulk et al., 2020b; Friedrichsen et al., 2016). Additionally, recent a SSI literature review has indicated that various technological resources including learning management systems (LMS), online laboratory simulations, content sharing websites, and virtual meeting and communication programs (Karisan & Zeidler, 2024).

We argue that the technology utilized thus far in SSI instruction does not reflect the most current technologies or provide opportunities for learners to develop the requisite skills for participatory citizenship. Augment and virtual reality (AR, VR) can be leveraged in multiple ways to support effective instruction. First, AR and/or VR provide unique opportunities for learners to develop knowledge related to a given issue. Learners can become immersed in locations that previously could not be accessed in traditional classrooms. Additionally, AR and VR allow learners to 'time travel' in that they can engage with historical information and future projections in more concrete ways than traditional teaching methods (Newton, Annetta, & Bressler, 2023). Secondly, and more germane to this study, designing MRSEG provide an avenue for learners to develop systematic and rational thinking via design thinking and computational thinking.

The SSI Framework draws from a myriad of research on learning and moral development (Zeidler, Sadler, Simmons, & Howes, 2005). Inquiry-based approaches are at the heart of effective SSI instruction. Most notably, SSI instruction aligns with the learning cycle approach to inquiry instruction (Marek, 2008) and more recently SSI scholars have described SSI's alignment with the 5E instructional model (Owens & Sadler, 2023). In both instances students are initially exposed to a complex problem and an associated question about the problem. Students then engage in several scaffolded experiences where they learn the content (scientific and sociocultural) and skills needed to answer the question/resolve the problem. Finally, students apply their skills and knowledge to resolve the problem. Throughout this process, students must ask questions, collect, and analyze data, communicate their thinking, and evaluate various arguments.

**Computational Thinking and Creativity's Place in it**

Computational thinking encourages scaffolded and differentiated student progress in both computational knowledge and discipline specific content knowledge. Although CT is often associated with technology-based pedagogy, the components of CT (decomposition, pattern recognition, abstraction, algorithmic thinking) promote application and implications for educators, students, researchers, and scientists (Christensen, 2023). However, it has been found that secondary science teachers' recognize CT as a specific type of thinking that can be used to build science students' problem-solving skills but view their lack of CT understanding as a primary barrier to science teaching integration and desire more professional development on best practices to implement CT into science teaching (Kite & Park, 2023). Science teacher professional development on how to best integrate CT have shown positive results on enhancing teacher CT content knowledge and collaborative engagement (Kong & Lai, 2023).

Voon et. al, (2022) proposed a framework for which constructivist argumentation is a context for problem-solving through the application of CT. Not unlike the SSI framework, Voon's Computational Thinking-Argumentation principles support innovation in the teaching and learning of science by developing problem-solving competencies and building capability in solving uncertainties throughout scientific inquiry. Learners develop creative thinking and cooperativity through negotiation and evaluation while developing algorithmic thinking in talking and writing. Finally, critical thinking is developed through the processes of abstraction and generalization.

Like any educational innovation, the challenge becomes implementation at scale. Because CT is often associated with technology, teachers need to overcome a lack of confidence in using it as an instructional paradigm while gaining understanding and the skills to include it effectively and seamlessly in practice. Teachers must be trained to ensure their level of knowledge and level of readiness about CT is high (Saidin et al., 2021). CT is arguably complex partially because it connected to computing technology, but it is a multi-faceted theoretical nature model of thinking that is important in all disciplines of STEM and integrated STEM education broadly (Li et al., 2020).

At its core, CT is about abstract thinking, problem solving, pattern recognition, and logical reasoning regardless of the presence or lack of computing technology (Angeli & Giannakos, 2020). CT is a fundamental skill for everyone in the 21st century. There is a need to understand how people interact with computation, and learn to think through the language of computation, in the field of education. Cheng, Annetta, and Vallett (2012) suggested CT falls within Pasteur's quadrant (Stokes, 1997) where scientific research has been transformed from a one-dimensional model view to a model that illustrates a research progression from pure, to applied, through use-inspired basic research. (Cheng et al., 2012) The 2012 study was heavily technology-enabled, but using this progression has informed this current research that CT, along with SSI, and DT do not have to use technology directly to engage the learner.

**DT and the Alignment with CT**

The alignment of CT with DT has been established. Kelly and Gero (2021) suggested design thinking and computational thinking as two prominent ways of understanding how people address design problems and proposed a two-dimensional ontological space of the ways that people think in addressing problems based on the orientation of the thinker towards problem and solution. (Kelly & Gero, 2021). Problem-solving is widely understood to be a central tenant in STEM abilities. According to Razzouk (2012) DT presents opportunities for students to engage in creative approaches and problem-solving, ultimately finding solutions. DT engages the learner in a process which is inherently “iterative, exploratory, and sometimes chaotic” (p. 336), ideally culminating in a satisfactory solution to the problem. Scheer, Noweski, and Meinel (2012) argued that DT in this way aligns with the theoretical and applied pedagogies of Dewey, constructivism, and experiential learning ultimately leading to growth in student’s attitudes toward science and science identities, as well as development of skills, self-efficacy, and knowledge in relation to science, computational thinking, and design thinking (Galoyan et al., 2022).

While some research suggest that design thinking may support critical thinking, the relationship between these two modes of thinking is incomplete because their shared conceptual structure because they have remained siloed in practice. By mapping the essential components of critical thinking to a variety of methods drawn from three popular design thinking frameworks, Ericson (2022) revealed that these seemingly unrelated modes of thinking share common features and that design thinking has can support and augment traditional critical thinking practices (Ericson, 2022). Both DT and CT have been increasingly recognized as the crucial basic thinking to promote scientific and/or technological innovation. Yang (2022) showed that DT was positively correlated with creativity and concluded that DT and creativity are neither completely separated, nor undifferentiated. Instead, they are different from each other but complement each other, constituting a unified whole of innovative experimental design thinking.(Yang et al., 2022)

Preparing educators to apply SSI, CT, or DT affords them an opportunity to achieve empathy with their learners, which will ensure learners successfully engage and achieve the learning objectives of the course (Shé et al., 2022). Applying these frameworks with preservice science teacher preparation in developing schema of DT, especially with respect to clarifying the problem, generating ideas, modeling, and feasibility analysis (Lin et al., 2021). The goal of introducing these concepts to preservice, or even in-service, teachers is to enable teachers to transfer their understanding and approach to their students so their students embody the SSI, CT, and DT skills (Annetta & Shapiro, 2019) while concurrently assimilating core disciplinary concepts and content (Pleasants et al., 2019).

## Methods

Baseline studies on this alignment of CT, DT, and SSI proposed a potential synthesis. Figure 1 illustrates the original concept of that synthesis, showing the individual components of each construct and the perceived alignment, which served as the guiding principle for this study.

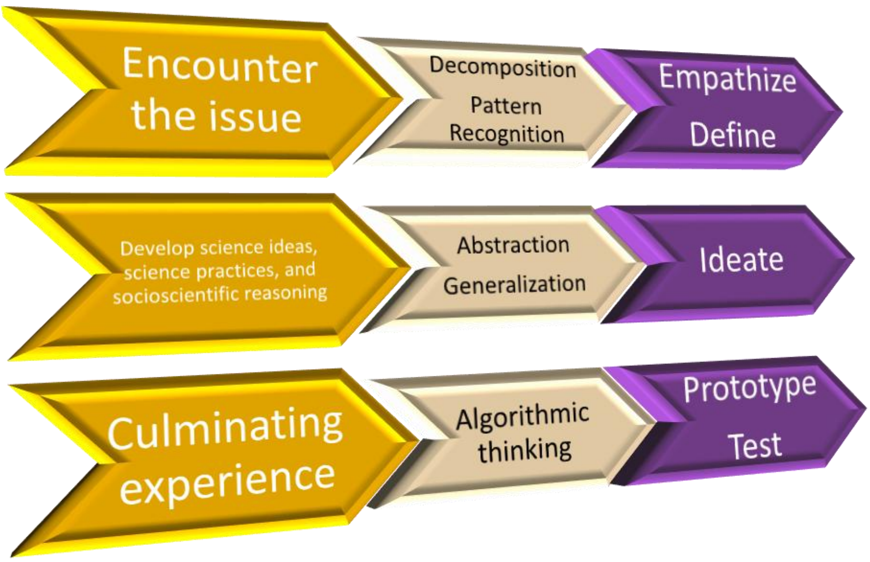


Figure 1. Original Hypothesis of DT, CT, and SSI Synthesis

### Setting and Participants

The setting was a graduate earth science pedagogical content knowledge course of practicing (in-service) science teachers (9) from a large Mid-Atlantic university in the United States. The students matriculated to this course following a technology innovations course in which they learned to design and develop a mixed reality Serious Educational Game (MRSEG) (Annetta, 2008). With an eye on students' abilities to bring their own device to schools, MRSEGs create a game-based environment where learners can interact with digital artifacts through their smart device (Annetta & Newton, 2023).

This prior knowledge and experience in creating a science based MRSEG afforded students the ability to repurpose that knowledge and those skills to create a more focused MRSEG based on SSI for the earth science course. Study participants were charged with taking the climate change knowledge they gained throughout the semester of the earth science course to design their own MRSEG. Although the final project was technology-based, the artifacts used in this study were the creation of a design document for each student's MRSEG, which captured their computational thinking and weekly reflections regarding their design thinking.

The earth science content course was designed to introduce participants to various forms of inquiry-based instruction, including using the Socioscientific Issues framework (Foulk et al., 2020a; Sadler, 2009; Zeidler et al., 2005). As discussed earlier, SSI is a sociocultural approach to teaching that using complex issues undergirded by science to teach a variety of knowledge and skills. For this study, participants focused on resolving the over wash and damage to one spot of North Carolina Highway 12 on Ocracoke Island in the Outer Banks barrier island chain. This is an area that frequently covered and/or damaged because of storms that strike the barrier island. These incidents are likely to increase as the climate continues to change. The course was structured in a way that the students were first introduced to the theory and existing research associated with SSI prior to engaging with the issue itself.

The culminating experience of the SSI became the final project for the course which challenged in-service teachers to develop a MRSEG for their own students to learn about the effects of climate change on Ocracoke Island. Participants chose a topic from the 15-week course as the learning objective for the MSEG and proceeded to use a game design document to detail their iterative MRSEG design throughout the course.

**Data Collection and Analyses**

Human subjects' approval was waived by the participating university's Institutional Review Board (IRB) and all participants provided informed consent. This study employed a case study design with triangulated qualitative data sources (Miles, Huberman, & Saldana, 2014; Yin, 2014). The triangulation (McMillian & Schumacher, 2006) used in this study called for a variety of artifacts (e.g., reflective journals, design documents, and observation) to ascertain student CT and DT within an SSI context.

To delve into the components of each of the three constructs, we developed a guide to capture student design and computational thinking. Figure 1 shows the individual components of each construct in which data were collected. Data was collected throughout the course while the game design document (Appendix A) and final project were introduced the first week of the semester to leverage the students' prior knowledge with MRSEG development. This document was the same that was used in the previous semester for the technology innovations class.

As part of the SSI experience, participants reflected weekly on how targeted readings, activities, and videos related to a particular coastal resiliency issue as it pertained to climate change impact. Each participant submitted their reflection on a private discussion board embedded within the university's learning management system. The first reflection occurred immediately after being introduced to the SSI issue through a series of short videos. Each week for the next month, a unique SSI issue was presented to the group. Participants answered prompts that asked them to connect that week's readings and activities to the specific SSI issue. Additionally, each participant completed a culminating presentation that illustrated the best solution for the issue. The presentation included evidence to support their decision, anticipated rebuttals to their plan, and how they would address the rebuttals. These presentations were recorded and shared with the class.

Each participant documented their planning, changes to design, and feedback from testers in the game design document. Starting the first week of the semester, each participant was asked to document the process of developing their MRSEG. Additionally, participants were asked to reflect weekly on what steps they had taken in the game development process. Both the design document and weekly reflections were completed for the first 12 weeks of the course.

An iterative process was used to analyze the data to build trustworthiness (Patton, 2002). The responses were organized by participant and prompt (e.g., stage on design document or week of reflection). Each participants' responses were examined holistically because the iterative nature of CT, DT, and SSI resolution could potentially allow a student to demonstrate a particular characteristic of one of the three in multiple prompts or weeks. A preliminary set of taxonomic schemes based on relevant research was developed (Presley et al., 2013; Zeidler & Newton, 2017) and then refined the codes by repeatedly reading and constantly comparing the qualitative data (see Table 1) (Glass & Strauss, 1967; Lincoln & Guba, 1985; Patton, 2002). Two researchers independently coded all the responses for two participants. The researchers then met to compare codes and to resolve any discrepancies. The remaining data was coded in this manner.

Table 1. Codes by Construct

| **Design Thinking** | **Computational Thinking** | **Stages of SSI** |
|---|---|---|
| Empathize<br>• Understand the problem you are trying to solve<br>• Consult experts to find out more<br>• Immerse in experience | Decomposition<br>• Break complex problem into manageable pieces<br>• Assess the problem | Encounter the issue<br>• Identify the components (science and sociocultural) of the issue<br>• Identify those impacted by the issue |
| Define<br>• Organize information from Empathize<br>• Analyze observations to define core problem<br>• Create problem statement | Pattern Recognition<br>• Looking for similarities between and within problems | Develop science ideas, science practices, and socioscientific reasoning<br>• Experience phenomena<br>• Engage is science practices<br>• Scaffold complex thinking<br>• Identify bias, perspectives, complexity, contributions/limitations of science |
| Ideate<br>• Consider multiple | Abstraction<br>• Take detail out of a | • Reflect on emerging ideas and |

| Design Thinking | Computational Thinking | Stages of SSI |
|---|---|---|
| perspectives to find solutions | problem and ignore irrelevant information | beliefs |
| Prototype<br>• Produce several scaled down versions of product<br>• Identify best possible solution | Generalization<br>• Adapting solutions to other problems to solve new ones | |
| Test<br>• Iteratively test the best solution<br>• Develop a deep understanding of the product and its users | Algorithms<br>• Simple rules to follow that solve problem | Culminating experience<br>• Synthesize information and skills to resolve issue |

## Results

The qualitative data is reported below in two ways. First, Table 2 provides the frequency that each code occurred in the analysis. Each sentence that represented a code was counted as unique. Additionally, Tables 3 and 4 provide student exemplars that are archetypes of the responses received from all participants.

Table 2. Code Frequency by Construct

| Design Thinking | Computational Thinking | Stages of SSI |
|---|---|---|
| Empathize<br>34 | Decomposition<br>28 | Encounter the issue<br>45 |
| Define<br>24 | Pattern Recognition<br>10 | Develop science ideas, science practices, and socioscientific reasoning<br>75 |
| Ideate<br>9 | Abstraction<br>12 | |
| Prototype<br>11 | Generalization<br>6 | |
| Test<br>20 | Algorithms<br>12 | Culminating experience<br>40 |

The results in Table 2 indicate that the codes occurred at varying frequencies over the course of the study. In all, it appears that as participants worked through the given problem (resolving the SSI or designing the MRSEG) resulting in less occurrences of each code, which is consistent with resolving a complex problem or task.

Table 3. Participant 1 Exemplar

| Design Thinking | Computational Thinking | Stages of SSI |
|---|---|---|
| Empathize<br>• The game will focus on Rodanthe<br>• It [the game] makes it feel realer, less dry<br>• Students need for space to move around to play the game<br>• The purpose of the game is to look at the impact of hurricanes on residents | Decomposition<br>• How do hurricanes form?<br>• Why do hurricanes hit North Carolina?<br>• How do hurricanes impact North Carolina?<br>• Players will need to read maps and graphs | Encounter the issue<br>• The issue at hand is what to do about NC 12, the highway that runs through the Outer Banks. This 148-mile road and its team of maintenance workers from the NCDOT are constantly fighting against nature as the Atlantic erodes the sand the road is built upon and floods what is left.<br>• Several factors are at play here that will dictate what choice will be made about NC 12; cost, environmental impacts, cultural impacts, feasibility, longevity, to name a few Right now more short term fixes like beach nourishment are cheaper, but are ephemeral. A long-term decision needs to be made so that work can begin sooner rather than later to minimize damages. Whatever decision is made will need to be palatable to locals and not so costly as to be a never-ending project.<br>• I'm not certain what other information I need… |
| Define<br>• The focus of the game will be on the impact of hurricanes in North Carolina on Rodanthe on the OBX<br>• Players will learn why hurricanes hit North Carolina<br>Ideate<br>• I wanted to split | Pattern Recognition<br>• The game will connect general hurricane formation with why hurricanes hit NC<br>• The game uses drone footage from a project done in 2022 to make the game feel more "videogamey"<br>Abstraction<br>• The game is a big file | Develop science ideas, science practices, and socioscientific reasoning<br>• I knew the Outer Banks were shaped by the constant pounding of storms and formed from sand being deposited there, but I never knew how influential sea level change was, and the submerge a beach ridge theory.<br>• I liked learning about the 4 different coastal embayments as well and how those differ. Some of the processes |

| **Design Thinking** | **Computational Thinking** | **Stages of SSI** |
|---|---|---|
| historical storms into pre-1850 and post since that is a turning point for hurricane research<br>• Ideally, I would take you inside a hurricane but I do not have the technical expertise for that | and<br>Students might not have devises<br>• Requires scientific literacy to understand, information is not "spoon-fed"<br>• It has been difficult to design game on a phone | that shape the barrier islands were new to me, like the summer and winter changes and overwash fans.<br>• This leaves protection as a long-term solution but that can't be used everywhere and will be hard to persuade people to get behind, as it diminishes the beauty of the OBX. So, we are left with retreat and accommodate. As for the ferry, moving the terminal looks to be the best long-term solution, based on the provided table. I think the hardest part of all of this is reaching an agreement with the people who live and work there, as well as those with expensive homes there. Sure, the government could declare eminent domain, but is there a way to work with the people? What's likely *best* ecologically is not feasible, so we have to rethink, adapt and compromise. |
| Prototype<br>• Create minimum viable product | Generalization | |
| Test<br>• I'm not sure if the game will run on phones, me and my partner tried to play the game and it crashed halfway through<br>• The tester liked the realism<br>• The game is not as entertaining as games he normally plays<br>• He's not from North Carolina so he liked learning about the damages and impacts from storm surges | Algorithms<br>• Action sequence in game (enter proximity of text box – text box tells you what to do – leave proximity of text box)<br>• Players wander on beach of Rodanthe they can tap on objects (animations and audio)<br>• Players take notes and decide when to "dive deeper" | Culminating experience<br>• The Outer Banks are a dynamic area, constantly shifting with seasonal, climatic and storm events. These barrier islands are moving as sand is carried and deposited by wind and water.<br>• …roughly 58,000 people call these coastal lands home.<br>• [Moving the ferry terminal] is the 6th cheapest option overall, 2nd cheapest of the long-term solutions, requires less maintenance from dredging.<br>• From 1983 through 1994, the [Army] Corps spent about $4.1 million dollars per year dredging the channel…but was only able to maintain the authorized 14-foot depth average about 23% of the time |

| Design Thinking | Computational Thinking | Stages of SSI |
|---|---|---|
| | | • Finding the proper match for sand characteristics is difficult…Dredging also causes significant damage to submerged aquatic vegetation and essential fish habitat.<br>• Ocracoke is separated from the rest of the Outer Banks and North Carolina and must be gotten to by ferry. Everyone needs a functional ferry. |

Table 4. Participant 2 Exemplar

| Design Thinking | Computational Thinking | Stages of SSI |
|---|---|---|
| Empathize | Decomposition | Encounter the issue |
| • Students will experience three different models unlike VR (high school students)<br>• The games makes content relevant to the students<br>• Feels more like a field trip and not a virtual textbook to the students | • The game focuses on human activities that impact climate change (hydrocarbons, deforestation) | • NC Highway 12 is the only stretch of road that connects all of the Outer Banks to the mainland of NC. It is used to connect the small fishing villages and increase the amount of people that have access to the Outer Banks. However, it is being impacted by climate change. The road is expensive to maintain and rebuild and the issue of what to do with NC Highway 12 is an important debate that will set the stage for how the state plans to handle climate crises that arise in the future.<br>• NC Highway 12 is a strip of asphalt that runs along the Outer Banks. The Atlantic Ocean is constantly transforming the barrier islands of NC. As a consequence, anytime a geological change happens to the Outer Banks, NC Highway 12 is impacted as well.<br>• The locals that live in the Outer Banks are impacted as they do not have access to the mainland until the road is functional. Realty/Rental properties and all associated employees (home/yard maintenance, cleaning services, etc.) do not have access to their livelihoods until the |

| **Design Thinking** | **Computational Thinking** | **Stages of SSI** |
|---|---|---|
| | | road can be fixed. The NCDOT has to pour financial and human resources into the maintenance and repair of NC Highway 12 that could probably be spent elsewhere in the state. The local wildlife is disturbed each time the NCDOT must repair the road. With each new issue that arises with NC Highway 12, there will be new impacts.<br>• This is a problem that has no permanent solution. The larger factor impacting the Outer Banks is climate change. Since climate change cannot be solved by NC alone, there will be no permanent solution for Highway 12. Also, there are so many different types of stakeholders associated with the Outer Banks and it is impossible to devise a solution that pleases everyone. |
| Define<br>• The game focuses on human activities that impact climate change (burning hydrocarbons and deforestation)<br>Ideate<br>• I want to model the game after Cosmos reboot (Halls of Extinction)<br>• Originally, students solved an anagram but I changed it to a scavenger hunt and then to cypher so answer cannot be guessed and player need to explore entire game<br>Prototype<br>• Create minimum viable product | Pattern Recognition<br>• This game connects human actions to climate change<br>Abstraction<br>• Take detail out of a problem and ignore irrelevant information<br>Generalization<br>• Originally, students solved an anagram but I | Develop science ideas, science practices, and socioscientific reasoning<br>• I learned how barrier islands formed. I did not know that barrier islands were created by very precise geologic conditions set in motion thousands of years ago. I also did not know that inlets along barrier islands can migrate. That information makes the debate about NC HWY 12 seem almost worthless in the long-term. No matter the chosen solution, the islands and inlets will continue to be moved by the ocean. No solution will be permanent.<br>• I started to wonder about the composition of sediment along the Outer Banks and how that may be contributing to the issue. Is the Ocracoke hotspot made of different sediments than other areas of the Outer Banks, thus contributing to the NC HWY 12 issue? I also started to wonder if there were any differences between |

| Design Thinking | Computational Thinking | Stages of SSI |
|---|---|---|
| | changed it to a scavenger hunt and then to cypher so answer cannot be guessed and player need to explore entire game | shoreline sediments and sediments underwater further away from shore. The video stated that beach nourishment efforts that use the incorrect type of sediment can be detrimental to shoreline organisms, like sea turtles. Would the type of sediment used in beach nourishment also impact how quickly the sediment can be eroded by moving water?<br>• Dune construction put people to work and encouraged economic growth. Now that times have changed, I think it may be time to let nature take its course. The Outer Banks were never meant to be permanent and investors (property, business, etc.) want some kind of reassurance in their investment that simply does not exist.<br>• I would explain to these people [those who live in hurricane prone areas] how climate change is causing the average temperature of the earth to increase. I would tell these people that even small, relative changes in ocean temperatures can generate more powerful hurricanes. Ultimately, I would tell these people that climate change is going to impact individuals financially as more powerful hurricanes have the potential to cause more damage. When people can relate science concepts (climate change) to their personal lives (financial impact of storm damage), then people will begin to truly understand climate change and its importance. |
| Test<br>• After playing, I decided to change doorways for golden rectangles<br>• The anagram was too easy, I want to make it a | Algorithms<br>• Player explore each corridor<br>• Solve cypher<br>• Timed game | Culminating experience<br>• The best option is service to new ferry terminal north of the village with dredging<br>• I think the offshore breakwater will create a living shoreline on the sound side of |

| Design Thinking | Computational Thinking | Stages of SSI |
|---|---|---|
| riddle, or a key so it cannot be guessed<br>• I need to resize assets to fit indoors<br>• I need to clarify which assets belong in each corridor to avoid overlap | | the island<br>• This option would impact less wetlands than other options<br>• We have to consider the 24 federally protected species and other at-risk species<br>• According to the NCDOT, this option does not impact any cultural or historic |

The exemplars begin to reveal a pattern across the types of thinking. For example, similarities can be seen in the *Define* and *Empathize* stages of DT, the *Decomposition* stage of CT, and the *Encountering the Focal Issue* stage of SSI. In all three cases, participants identified the problem and began to consider the smaller components of the problem. For example, Participant 1 effectively deconstructed the SSI dealing with coastal flooding and NC Hwy 12 into various science and sociocultural components. Likewise, we then see them clearly state the problem related to their MRSEG and how players will be impacted by the game in the *Define* and *Empathize* stages of DT. These statements are echoed as part of the *Decomposition* stage of UCT. These similar types of responses are visible throughout the data.

## Discussion

It is important to revisit the focus of this inquiry that although the culminating experience was the development of a technology based MRSEG, the study only focused on the implementation of CT and DT within the context of SSI before the use of any technology. The findings indicate the potential overlap of DT, CT, and SSI resolution. It is apparent that designing a MRSEG with explicit DT and CT support not only facilitates the development of both types of thinking but also can be applied to an SSI resolution. Specifically, those participants who addressed the characteristics of a MRSEG demonstrated the need to consider all three ways of thinking (DT, CT, SSI) to develop their MRSEG. Put another way, participants who created an MRSEG before digital development, used DT and CT to construct experiences for their own student that followed the SSI framework and promoted SSI resolution.

What was evident in the MRSEG development process was that the participants needed to have a comprehensive and detailed understanding of climate change to create a MRSEG that accurately portrayed the scientific and sociocultural dimensions of climate change impacts on the Outer Banks of North Carolina. While the development of DT and CT are important for learners to address the engineering demands of the future, explicit instruction in these types of thinking are also beneficial for students resolve to complex issues outside of engineering practices. Clearly, DT and CT promote a rational and more systematic approach to problem-solving that would also benefit individuals looking to solve non-engineering specific problems, like climate change. Returning to the SSI literature on informal reasoning (see Herman, Zeidler, & Newton, 2018; Topcu, Sadler, & Yilmaz-Tuzun, 2010), it has been shown to be imperative that learners receive explicit support in rationalistic reasoning when considering SSI if the goal is to develop a functionally literate citizenry capable of resolving complex problems in a manner that is sustainable for people and nature. The current study indicates that explicit DT and CT support to develop MRSEG after experiencing SSI and then examining the research and underlying theory can facilitate the type of rationalistic reasoning that is too often absent from SSI resolutions.

Results of this study created a reconceptualized model of the synthesis across these constructs. Because SSI is grounded in inquiry-based teaching and learning and the infusion of DT and CT in science instruction is disruptive to customary practice, we have called the synthesis of DT, CT, and SSI: Inquiry Driven Disruptive Pedagogy (IDDP). This study begins to suggest that the original model for IDDP was not exactly as hypothesized. Through baseline analysis prior to this study, we began seeing a pattern where individual components of DT, CT, and SSI aligned at three levels. Originally is was assumed that at the *Encounter the issue* stage of an SSI resolution learners were simultaneously using CT skills of *Decomposition* and *Pattern Recognition* while also using DT skills of *Empathize* and *Define*.

Results of this study, however, suggest that *Pattern recognition (CT)* is more aligned with *Develop science ideas, science practices, and socioscientific reasoning (SSI)* and the components of *Ideate* and *Prototype (DT)*. Further, *Prototype (DT)* was originally thought to align with *Algorithmic Thinking (CT)* and the *Culminating experience (SSI)* but it is clearly best aligned with *Ideate*. Figure 2 illustrates the current model of IDDP based on this study's results.

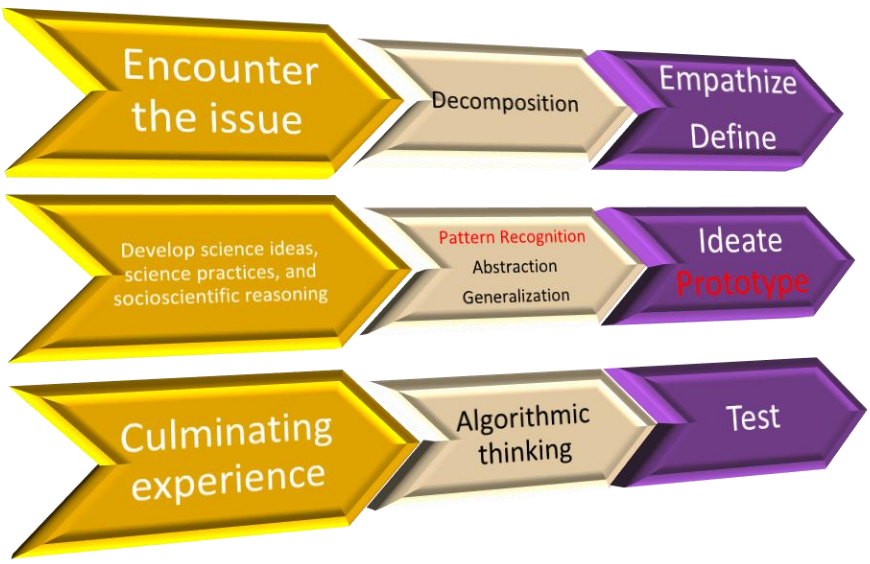


Figure 2. Current model of Inquiry Driven Disruptive Pedagogy (IDDP)

As this study begins to approach a new framework of IDDP, we must revisit its underlying tenets. First, much like the widely references TPACK (Koehler & Mishra, 2009) where a framework was developed to help teachers integrate technology effectively using Shulman's PCK model (1987) as a foundation. IDDP promises to provide a model for teachers to seamlessly integrate DT, CT, and SSI with or without technology. Although we used the

MRSEG as the culminating experience within SSI, it was the unplugged design of the MRSEG that drove creative thinking in both CT and DT.

Implementing the amalgamation of SSI, CT, DT as a new instructional framework (IDDP) will be disruptive. Disruptive innovation in education is not a new concept. In fact, Christenson, Johnson, and Horn (2008) introduced it over a decade ago but it has not completely emerged in the science education literature. Disruptive education forces a revisioning of our current model and methods of teaching and learning. IDDP can guide a teacher to create something that is a completely different classroom from the norm. This disruption allows for students to implement individualized creativity and promote critical thinking. Heick (2019) introduced a model of disruptive innovation as a learning model that includes four categories of: 1. Emergence of the disruption, 2. Impact, 3. Recalibration, and 4. Evolution.

Emergence of the disruption is often quiet-it is not immediately recognized as a disruptive practice. SSI, DT, and CT by themselves have been used for some time so wholistically introducing these may not seem disruptive at first. SSI is the first to be introduced with DT and CT coming later in the IDDP process. Impact is next in Heick's model and when using IDDP the roles of teacher and student may change, the curriculum and science content may go deeper than the stated content standards and objectives, and teacher and student emotions from taking on different perspectives, using different resources and different applications than traditionally used may change as well. The impact of disruptive education can cause some uncertainty whether it be excitement and enthusiasm of doing something new or concern because instruction has become curvilinear. Recalibration exposes the weaknesses of traditional instruction, but this stage is where progress begins to emerge. New assessment methods, data sources, and learning models materialize and teacher planning and curricular design processes morph into something different than what many were taught in preservice methods classes. Finally, evolution is where IDDP is currently situated. A growth mindset is established and how, where, and why science students learn is reconceptualized. Student imagination and creativity flourish and the critical thinking skills encouraged by NGSS, and the executive office of the current United States administration take form as a new purpose for science education.

This model acknowledges that most of the literature of classroom disruption relates to technology use or student-centered technology integration. Learning is, or should be, dynamic and does not have to end when class ends and does not necessarily have to include technology. Flipping classroom instruction or learning remotely (as the world was forced to do during the COVID pandemic) are two examples of the dynamic nature of a disruptive pedagogy. Integrating the constructs of IDDP provides a framework for learners to make real-world connections, to learn about potential STEM careers, and motivate students to learn beyond the walls of their school. IDDP allows for methodological opportunities of integrating new ways of teaching and learning that will make the science classroom even more dynamic, albeit disruptive.

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