Crisis Response Serious Spatial Thinking Games: Spatial Think Aloud Study Results

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ABSTRACT

We present work on developing and evaluating a serious GIS spatial thinking game called SerGIS. We conducted a spatial think-aloud study with ten participants new to crisis response who used SerGIS with a coastal city hurricane scenario. Four themes emerged from participant responses: processes of reasoning, tools of representation, overlay and dissolve operation, and geographic information concept learning and knowledge gaps. The first three themes match directly with the spatial thinking theory and evaluation underlying SerGIS. The fourth theme identified addresses GIS and spatial thinking crisis response educational issues. Furthermore, statistical evidence indicates there is likely a relationship between participants from spatially-oriented backgrounds (but with no GIS experience) performing better with SerGIS than participants from non-spatial backgrounds. Finally, we found that with a game scenario based on established disaster management practitioner literature, participants could focus on spatial thinking tasks and not be limited by understanding the game scenario itself.

Keywords

Spatial Thinking, Serious Games, Crisis Response, Evaluation

INTRODUCTION

Spatial thinking is a learnable skill for structuring and solving spatial problems and decision making support, such as using a map to support navigation or structuring time using spatial metaphors (e.g., "the event is far off in the future"). The National Research Council (2006) defined *spatial thinking* as an amalgam of three items—concepts of space, tools of representation, and processes of reasoning (National Research Council, 2006). *Serious games* target non-entertainment purposes using gaming concepts, such as a score based on actions taken for measuring game player learning and progress (Michael and Chen, 2005).

In this paper, we present a theoretical framework and results of piloting a crisis response serious spatial thinking game framework and implementation called SerGIS (i.e., Serious Geographic Information Systems). Our motivations for developing SerGIS are to:

- Implement scenarios and simulations for crisis response, whereby novices to learn how to think spatially about a crisis using commercial GIS tools. GIS has long been recognized as a crisis response support tool (Cutter, 2003). However, little research has been conducted on crisis response and the underlying spatial thinking enabled by GIS, with more emphasis placed on GIS tool adoption and spatial methods in crisis response (Berse, Bendimerad and Asami, 2011, Tomaszewski, Judex, Szarzynski, Radestock and Wirkus, 2015);

- Develop a new spatial thinking ability quantification method that can inform GIScience research applied to crisis management. Spatial thinking ability quantification is a nascent field with a primary emphasis on geography education research (Ishikawa, 2015). To the best of our knowledge, no research is being conducted on quantifying crisis response spatial thinking ability.

We present results of a spatial think-aloud experiment designed to quantify how crisis response novices conduct spatial thinking tasks supported with GIS tools and using SerGIS. We conclude the paper with planned framework extensions.

THEORETICAL FRAMEWORK

Application Context: The Relationship between Spatial Thinking, GIS, Crisis Response and Serious Games

Spatial thinking concepts are a natural fit with crisis response due to the inherent spatial nature of disasters. Various crisis management actors (e.g., responders, incident commanders, and planners) have the responsibility to carry out particular spatial thinking tasks in varied geographic areas and circumstances, often in continually evolving spatio-temporal situations (Nourjou, Smith and Jan, 2013). Another important aspect of crisis management is training and simulation. Serious games are a key area for crisis management training purposes (Ishikawa, 2015).

Salen & Zimmerman (2004) created an oft-cited and fundamental reference that defines game, play, and other fundamental concepts. Through a discourse on the variety of definitions, they distill each into their own: “A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.” This definition captures essential notions of challenges presented to players through structured rules and goals that the players seek. Rather than narrowing the definition to specific genres and platforms, they broaden the concept. Their “umbrella” helps to distinguish “game-like” experiences, like work, school, and even simulations, where structured experiences provide real rules that the participants follow to achieve real goals.

When thinking of simulations, especially those for scientific fields like GIS, a “sliding scale” of simulation of physical reality in which a designer might reduce fidelity to focus on certain features may actually blur the line between simulation and game. The game discussed in this paper would probably appear more game-like with 3-D immersion and real-time interaction akin to many commercial videogames. However, we have started at the “core,” in which we present a series of challenges, albeit via multiple-choice questions, in artificial scenarios to provide an environment in which increasingly difficult problems help the player improve spatial thinking.

When considering serious games, the community has struggled with the term “serious,” as the word implies that such games aren’t fun for the players. When considering the definition of game, as discussed above, “serious” really implies that the artificial conflict and rules derive from the real world—the stakes for winning are much higher in the sense that the player may develop real-world knowledge, which is the category in which our game resides.

The primary tools for crisis management training are textbooks and simulated drills, either in the frame of table-top or full-scenario exercises whereas some formats lack a realistic feel or others require large money and time investments. Recent introductions of virtual environments and serious games, however, seek to eliminate these shortcomings. Virtual geography-based games have also seen growing research attention for teaching concepts such as resource management and human-environment relations, or social-ecological systems (Ahlqvist, Loffing, Ramanathan and Kocher, 2012, Cheng, Hao, JianYou and Yun, 2010). However, this prior work has not made an explicit focus using serious game concepts to measure and teach spatial thinking ability in novices (e.g., students) through industry-standard, commercial-grade GIS tools as they are most often used by professional disaster management agencies (Hodgson, Battersby, Liu and Sulewski, 2013). Additionally, a serious game can create a closer connection between the serious gaming experience and real-life—especially for crisis response novices who will likely work with commercial GIS tools which are the focus of our work (Ohmori, Muromachi, Harata and Ohta, 2003). It is within this overall application context that we situate SerGIS’s theoretical framework.

SerGIS Theoretical Framework

Figure 1, below, graphically summarizes SerGIS's theoretical framework based on Tomaszewski et al.(2014). The framework starts with (1) the elements of spatial thinking defined in National Research Council (2006). Spatial thinking elements are then operationalized as (2) spatial thinking concepts based on Lee and Bednarz (2012) research that developed and validated a spatial thinking ability test (STAT). For example, the spatial concept of a buffer can be considered a combination of the concepts of space and a tool of representation. Lee and Bednarz (2012) outlined tangible spatial thinking concepts specifically to measure spatial thinking ability via the STAT—concepts that we incorporate into our theoretical framework to justify quantifying spatial thinking ability. Many spatial thinking concepts, like buffer, correspond directly to (3) GIS operations found in industry-standard GIS tools. Game players then match GIS operations, grounded in relevant spatial thinking concepts as defined in the literature, to develop (4) crisis response serious game scenario questions and GIS operations to answer a given question. Finally, a score (5) based on spatial thinking choices made to allow the game player understand decisions made and the spatial thinking processes behind those decisions (Berse, et al., 2011).

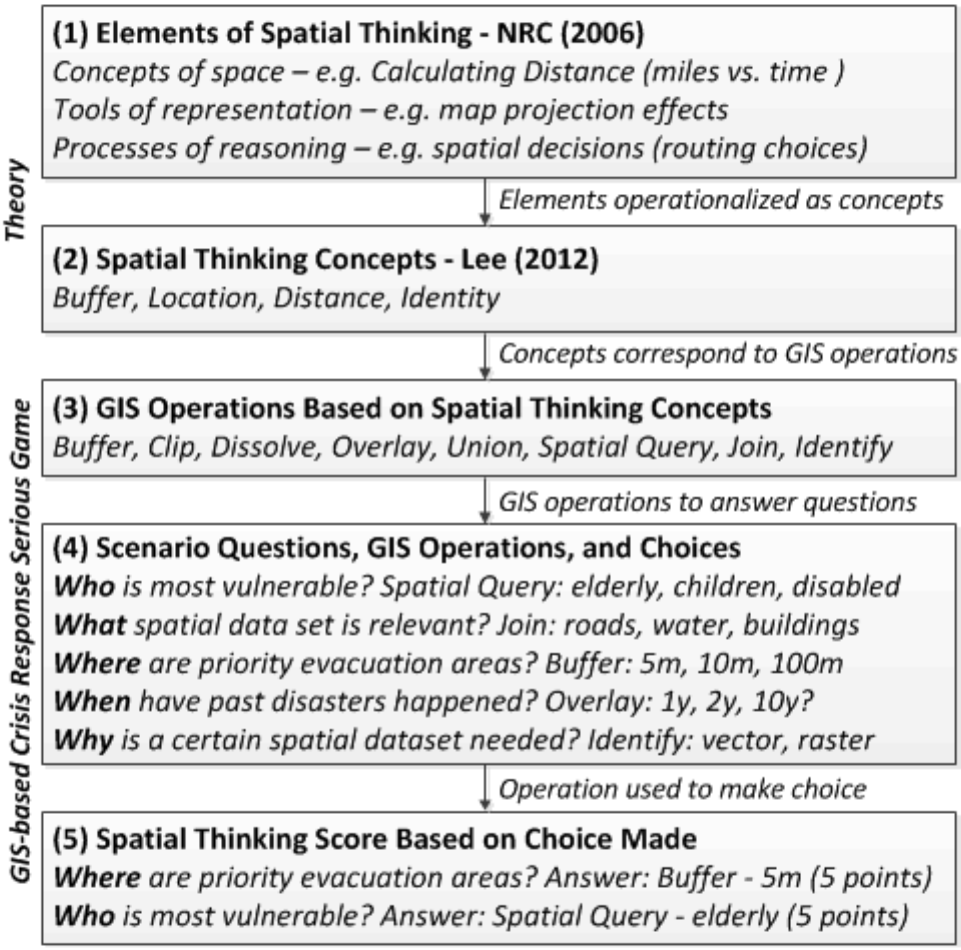

Figure 1: SerGIS theoretical framework.

SerGIS Desktop Technical Overview

Figure 2 graphically demonstrates an overview of SerGIS's technical implementation in a desktop environment.

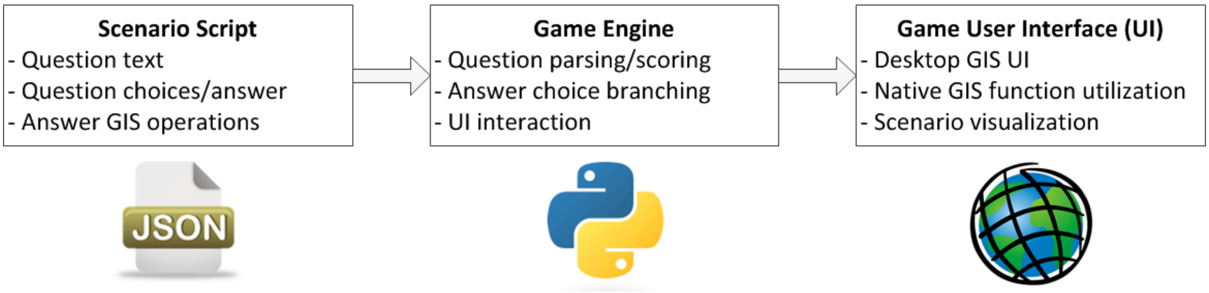

Figure 2: SerGIS technical implementation.

Starting on the left of Figure 2, specific game scenario questions, GIS operations, and choices are encoded using JavaScript Object Notation (JSON). This structure allows creation of flexible, easy-to-code scenario questions, answers and answer decision trees. Answer decision trees is the idea that specific answer can each have different outcomes thus allowing game scenarios to be designed so questions and answers do not necessarily have to follow a linear sequence order.

The middle section of Figure 2 shows the game engine. The current game engine is written in the python language for ease of use with commercial GIS tools that use python as a scripting language. The game engine is responsible for parsing the scenario JSON files, managing scores received based on answers made by game players, and general interaction with the game user interface (UI).

SPATIAL THINK ALOUD STUDY

Serious Spatial Thinking Game — Costal City Hurricane Scenario

We developed a coastal city hurricane scenario in SerGIS loosely based on actual events from 2012 Hurricane Sandy, previous research on the serious gaming concept from practitioner perspectives, and established hurricane disaster planning scenarios from the literature (US Department of Homeland Security, 2006, Mathews, Tomaszewski, Szarzynski and Vodacek, 2014). In our game scenario, a Category 5 hurricane is approaching a coastal city. Before beginning the game, the game player was also given the following scenario contextual information via a PowerPoint presentation:

You must make damage impact assessments based on this forecast:

- Slow-moving Category 5 hurricane
- Wind intensities between 111 mph to greater than 155 mph
- Hurricane will make landfall in highly populated area

Tasks:

- Use spatial thinking skills supported by GIS
- Use serious game environment to make hurricane situation decisions and assessments
- Can only go forward with scenario decisions (i.e., can't return back if you do not like your choice)
- Take as much time as you need for making decisions

Parameters:

- Can only use GIS tools available in the interface (go over what specifically is available – pan, zoom, identify, measure, modify layer display, change table of contents)
- 3 choices per question, each question worth 0, 1, or 2 (5 questions total)
- Possible 10 point max score

The game player must use spatial thinking supported by GIS to make choices from five different questions based on spatial thinking tasks provided by SerGIS and based on the STAT (discussed previously).

We used two STAT categories with the closest connections to specific ArcGIS operations: (1) *overlaying and dissolving* and (2) *comprehending geographic features represented as point, line or polygon* - that could be measured with SerGIS. The reason being that previous studies have found these particular STAT categories provide specific learning outcomes related to GIS operation and spatial thinking (Tomaszewski, Vodacek, Parody and Holt, 2015). For example, how well could SerGIS game players think spatially about storm surge using buffer tools? Table 1 outlines the five questions, answers to those questions along with their point value on a range of 0 (worst choice) to 2 (best choice), how the question relates to a STAT category, and comments about the question such as the questions connection with the established hurricane disaster planning scenario from the literature.

Table 1: Game Scenario Questions, Choices and Theoretical Grounding

Question	**Question Choices, Point Values and Choice Comments**			**STAT Category**[2]	**Scenario Comment**[1]
	A	**B**	**C**		
1. Storm surge is important. The buffer tool can be used to represent storm surge. Based on the hurricane type, what size buffer should you create?	100 Yards (0 Points) *Comment:* Too little of a distance.	500 yards (2 Points) *Comment*: Best choice based directly on scenario text.	1000 yards (1 Point) *Comment*: Too much data far, will overestimate.	*VII*	*Structures in areas less than 15 feet above sea level and within 500 yards of the shoreline have received flood damage and destruction*
2. It is important to know the ground elevation. The map currently does not contain a ground elevation representation. Choose a ground elevation representation to add to the map:	A contour map in 5' increments (2 Points) *Comment*: Best, easier to see elevation in relation to other features for overlay.	A Digital Elevation Model using a stretched color representation (1 Point) *Comment*: Slightly better, can't see elevation in relation to other features for overlay as easily, but the colors help.	Geodetic control points such as USGS bench marks containing elevation data (0 Points) *Comment*: Sampling of points will not be good for clear elevation understanding.	*VIII*	
3. The Hurricane has great potential for Environmental/Health Impacts from HAZMAT (hazardous material). Several piers are located on the coast. Oil tankers docked at the piers have the potential to rupture. Based on the situation, what size buffer should you create for dock's potential HAZAMAT issues*?*	50 Yards (0 Points) *Comment*: Too little of a distance.	200 Yards (1 Point) *Comment*: Better, but still not the best distance.	500 yards (2 points) *Comment*: Best choice based directly on scenario text.	*VII*	*500 yards of the shoreline have received flood damage and destruction. Flooded and damaged petrochemical facilities, chemical plants, sewage treatment plants, and other facilities threaten the health of citizens, create a hazardous operating environment, and require cleanup and remediation. An oil tanker is blown off course during the storm, sustains serious damage, and leaks.*

4. Decision makers want to know how vulnerable populations will be affected for search and rescue. Elderly people are a particularly important. Choose an elderly vulnerability risk layer to add to the map:	A choropleth map of elderly populations by census tract normalized by total population (2 Points) *Comment*: Best choice for meaningful representation (normalized data representation).	A choropleth map of elderly population raw counts by census tract (1 Point) *Comment*: Good for showing general counts but not as good for comparison.	A qualitative map showing using unique colors for elderly population counts (0 Points) *Comment*: Very bad choice that will not present anything meaningful.	*VIII*	Not directly related to STAT questions, but still important for spatial thinking – tools of representation, reasoning about data, With added factor of data representation and map reading comprehension.
5. Based on the risk layer you chose (in question 4), determine where there is a need for locating, extricating, and providing onsite medical treatment to victims trapped in collapsed structures using the following choices:	Union between the storm surge and hazmat buffer (2 Points) *Comment*: Best choice spatial thinking-wise, even if the buffers themselves weren't best– want extent of both hazards.	Intersect of hazmat buffer from storm surge (0 Points) *Comment*: Least desirable choice (spatial thinking-wise, even if the buffers themselves weren't best) – sections of one could be missed by being reduced out from the intersect.	Clip of storm surge buffer from hazmat buffer (1 Points) *Comment*: Second best choice (spatial thinking-wise, even if the buffers themselves weren't best) – sections of one could be missed by being reduced from the clip.	*VII*	*Search and Rescue Operations: There is a need for locating, extricating, and providing onsite medical treatment to victims trapped in collapsed structures.*

[1] – Scenario Comments in italics are direct quotes from US Department of Homeland Security (2006)

[2] – STAT Categories from Lee and Bednarz (2012):

VII - overlaying and dissolving maps - buffer not explicit in the STAT, but buffer is an overlay operation

VIII - comprehending geographic features represented as point, line, or polygon

Figures 3 show an example of what one of the questions from Table 1 (Question 2) would look like to a SerGIS game player.

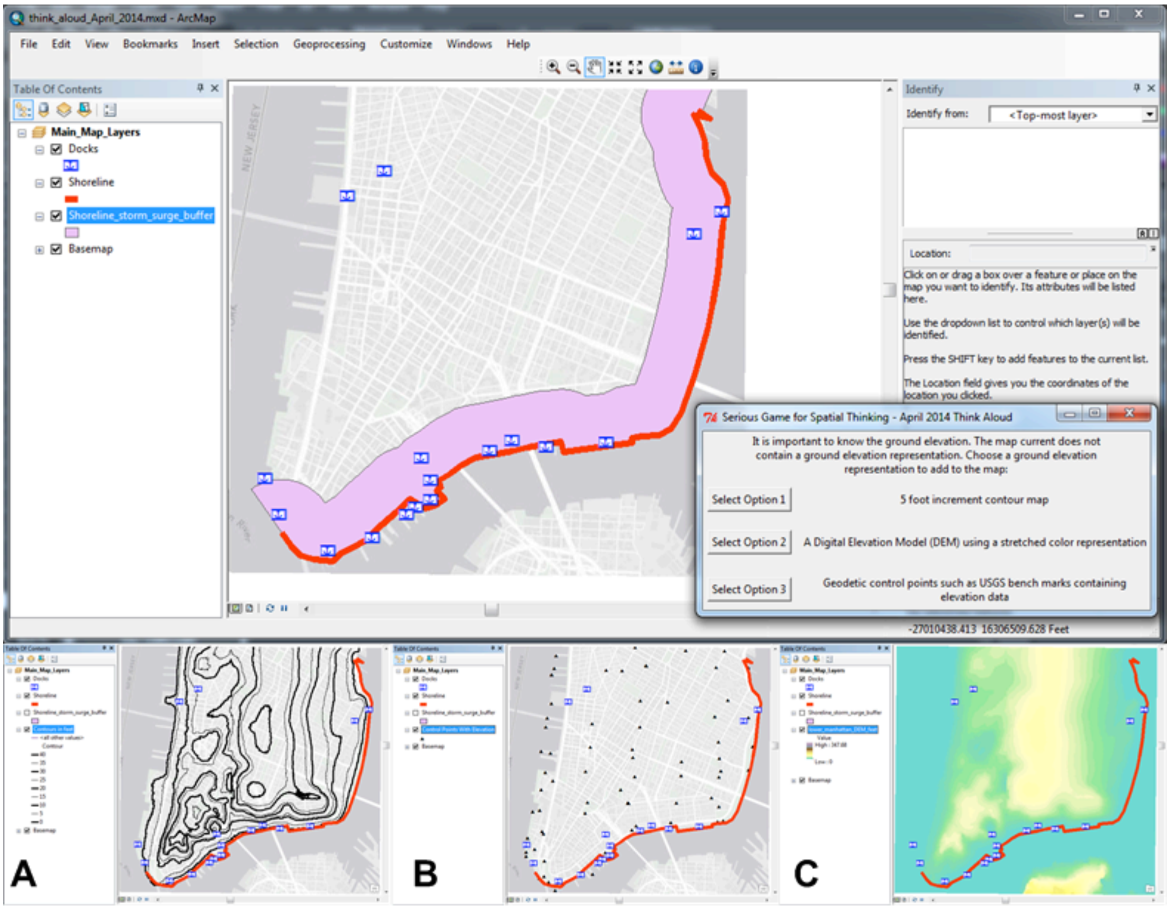

Figure 3: Question example showing answers to the three possible choices. The top part of the figure shows the question prompt, the three images below marked A – C are possible answers to the question prompt.

In this question, there are three choices for determining the best elevation representation for thinking spatially about storm surge impact—a 5′ contour map (3A), a stretched color Digital Elevation Model (DEM) representation (3B), or geodetic control points containing elevation (3C).

As per the previously discussed theoretical framework, the line (contours), raster (DEM), and point (survey controls) aspects of the choices closely relate to spatial thinking component VIII on the STAT—comprehending geographic features represented as point, line, or polygon outlined in Lee and Bednarz (2012). Furthermore, the choices are a good example of prompting novice crisis response spatial thinking. A crisis response expert would know that a contour map would likely be the best choice of elevation representation to allow for ease of comparison with other layers via overlay. A DEM would be a second-best choice, and survey control points are the worst choice—as by themselves, they cannot easily convey elevation as a continuous surface.

Participant Background

We tested ten US-based college students: six graduate, three undergraduate and one in-between undergraduate and graduate school – a size deemed sufficient based on past work of developing GIScience tools to study crisis management-specific tasks (Tomaszewski and MacEachren, 2012). A background survey was administered to potentially use student gender, language and educational backgrounds to interpret actions, comments, and scores made when using the game as these categories are commonly used for understanding spatial thinking (National Research Council, 2006). Participants had an average two prior GIS classes (but no practical crisis response experience) before participating in the think-aloud session, four of the ten were native English speakers and one was deaf and hard of hearing. Six of the participants were female, four male. Students were asked to define their general education background from pre-determined categories along with a write-in option. Study participants educational backgrounds, along with the number of responses per category shown in parenthesis, were:

- Science/Mathematics (2)

- Science/Mathematics and Computing/Technology (1)
- Computing/Technology (3)
- Science/Mathematics; Computing/Technology; Liberal Arts/Social Science (1)
- Engineering/Engineering Technology (1)
- Human Computer Interaction (1)
- Geography (1)

A background questionnaire was given to the participants allowing them to self-report using a one (nothing) to five (expert) Likert scale their responses to the following questions:

- *Question 1: My knowledge of Geographic Information Systems (GIS) is:*
- *Question 2: My spatial thinking skills are:*
- *Question 3: My knowledge of maps and mapping concepts is:*
- *Question 4: My knowledge of disaster management is:*

Participant responses to these questions are shown in Figure 4:

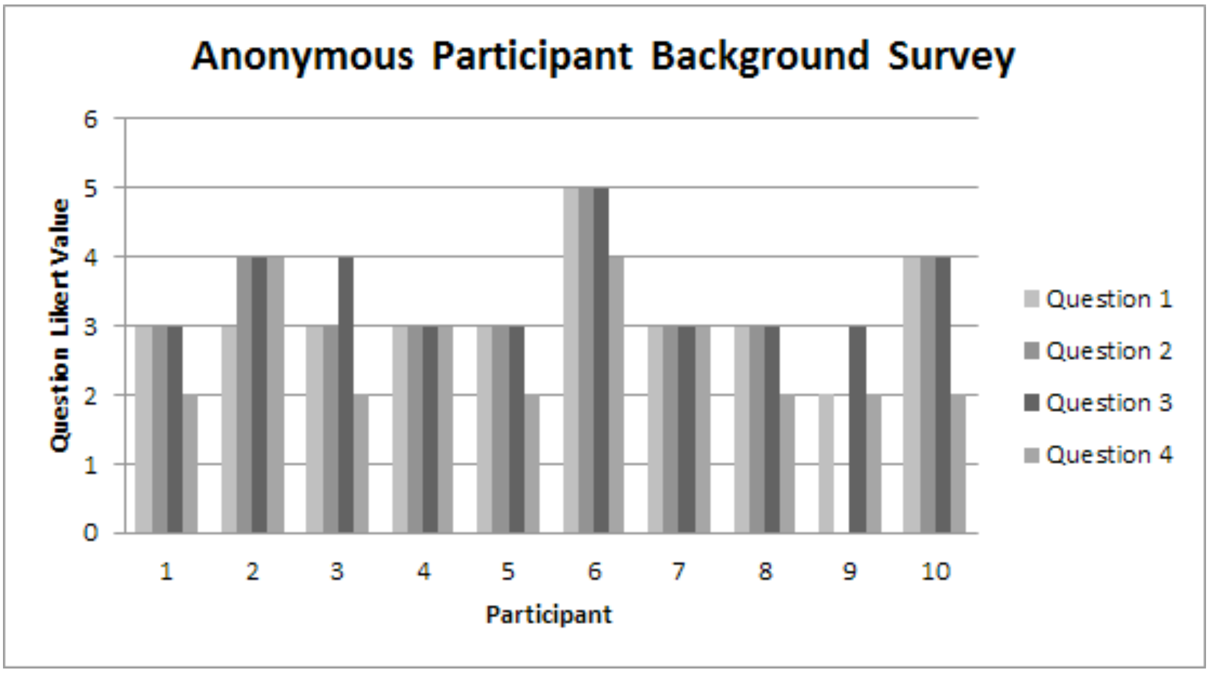

Figure 4: Anonymous Participant Background Survey Results.

Tasks

SerGIS was used to gather evidence on novice crisis response spatial thinking supported with GIS tools via spatial think-aloud sessions. Participants were first given a scenario background briefing and what GIS tools were available to them when using SerGIS. The game environment was then loaded (Figure 5)

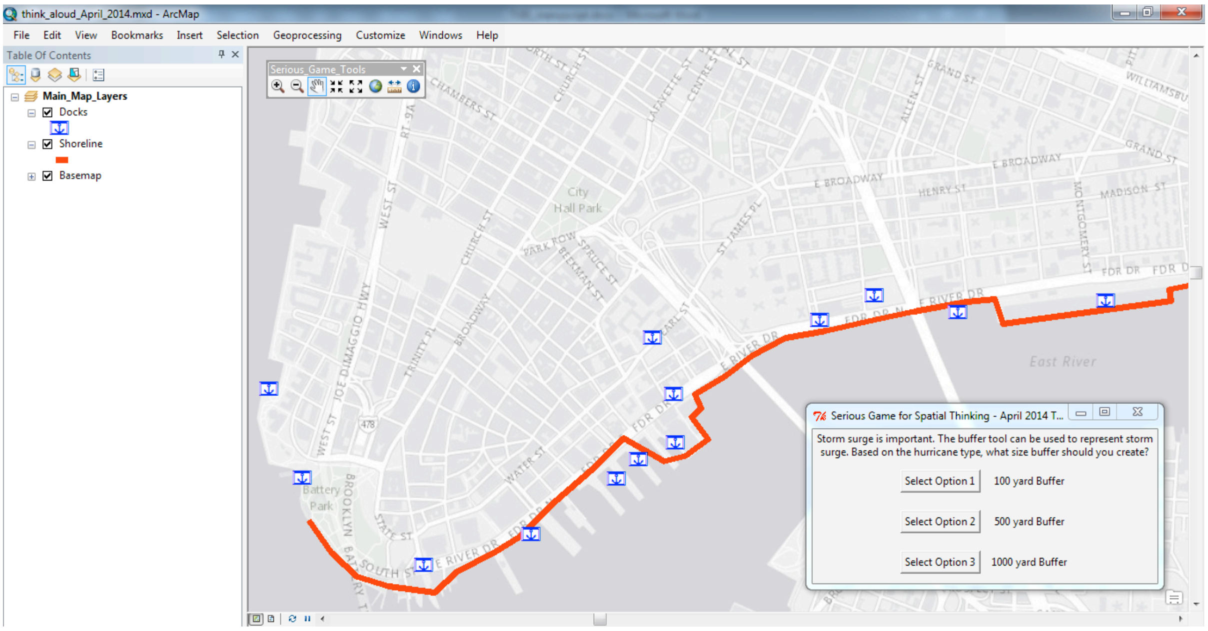

Figure 5: SerGIS on load up.

Note how a very minimal interface (i.e., control, pan, and zoom) is shown in Figure 5. This approach was used so the game player could focus on spatial thinking tasks and accommodate users of various GIS skill levels. All of the questions the player had to answer could be accomplished using the tool sets provided. The participants then began using the game and answering the questions outlined in Table 1. While playing the game, they verbally expressed what they were thinking about spatially when using the environment, akin to prior spatial thinking/think-aloud research (Taylor and Tenbrink, 2013). Audio transcriptions made of the participant spatial think aloud sessions were transcribed and keyword frequency content analysis was performed to find thematic patterns that matched STAT categories and any other themes related to novice crisis response spatial thinking (Berg and Lune, 2004).

Results

The ten participants' final game scores are shown in Figure 6.

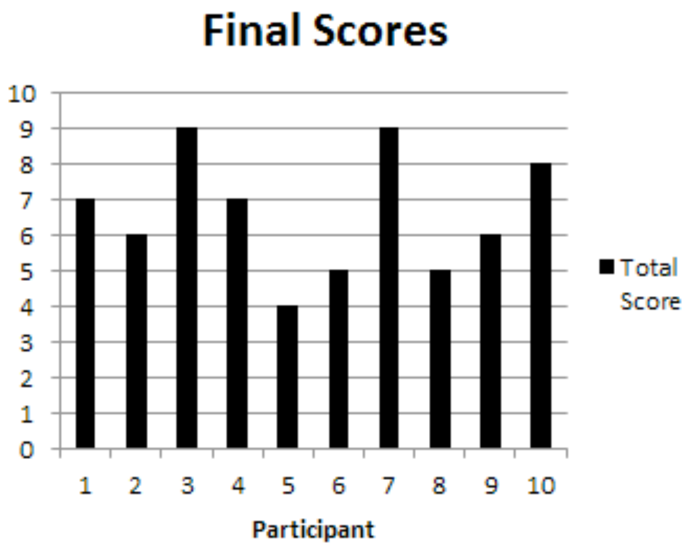

Figure 6: Study participant final game scores. A perfect score is 10.

Participant spatial think-aloud responses revealed five themes derived using keywords based on spatial concepts and relationships (Golledge, Marsh and Battersby, 2008). The spatial think-aloud responses were relevant to this type of analysis as think aloud data reveals cognitive processes, like spatial thinking (Van Someren, Barnard and Sandberg, 1994). The first and second themes related, respectively, to two of the National Research Council (2006) elements of spatial thinking — processes reasoning and tools of representation. The third theme related to the overlay and dissolve STAT category as per our learning outcomes and the scenario question design outlined in Table 1. The fourth theme was geographic information concept learning and knowledge gaps. The fifth themes were comments related to improving the gaming experience itself. The following sections discuss the first four themes. Theme five is discussed in the Future Work section.

Theme 1: Processes of Reasoning

All of the participants made comments related to their reasoning about the scenario. In particular, a common pattern was making distance estimations of storm surge impacts and the built environment — *Reasonably, I would say 500* (yards) *because New York City is small. And there are a lot of buildings in between. Hundred would be too small to cover all the areas, and 1,000 yards would be unreasonably large. So, I would go with 500* (yards). Besides discrete distances, some participants also reasoned about relationships between spatial patterns and potential vulnerable population impacts by taking a cautious "better safe than sorry" approach — *we want to make sure that we have an area there that's going to be safe for these people. So, that's why I chose like a large geographic area because we never know where there might be a lot of elderly people; you would rather have more people like in the buffer area just so that they all know. And even if it doesn't reach all of them, you would rather not take chances with hazardous material and contamination*.

Theme 2: Tools of Representation

Participants with some GIS experience but unfamiliar crisis response were fairly capable at utilizing spatial thinking for different representation types such as points, lines, or polygons — *with these choices* (about elevation)*, you're really going to want to know how the water's going to flow in and where the water will go, so this last one (the survey control points, Figure 3c) doesn't have as much information as the first two* (contour lines — Figure 3A and DEM—Figure 3B). Alternately, some participants demonstrated good judgments and reasoning about deciding which type of representation to choose, but ultimately made the wrong representation choice — *Since New York City has a lot of buildings, very, very tall ones, I don't need a five-foot increment. I need to see all the buildings and the roads that go between these buildings and all the small alleys that would possibly be flooded if there's too much water. So, I would say a USGS benchmark.*

Theme 3: Overlay and Dissolve

Participant abilities on overlay and dissolve task were mixed. Some participants were comfortable with thinking about overlay and dissolve tasks, in particular for question 5 (determining priority evacuation) that involved choosing an advanced operation such as union, interest, or clip — *Well, for the union, between the two, the two areas would just join together as one. And the intersection would be the difference of the two. And the clip would be like the opposite of intersect.*

However, it was equally the case that some participants struggled with choosing between clip, intersect, and union for determining priority evacuation areas — even after two prior GIS classes (*I'm not that familiar with intersect*) and challenges with applying more advanced crisis response spatial thinking— *I think that where the storm surge buffer and the HAZMAT* (hazardous material) *buffer overlap is where you will want medical treatment…but I am blanking as to which* (GIS) *tool is the one best to use.*(for determining the medical treatment areas)." A comment like this one could also be classified with the theme 4 — areas of learning and knowledge gaps.

Theme 4: Areas of Learning and Knowledge Gaps

This theme relates to learning and knowledge gaps in GIS operation and mapping and geographic information principles and not crisis response. Some participants were not familiar with the term "choropleth map"—*The choropleth map. Can I ask what choropleth is?* Another mapping principles knowledge gap identified was understanding different types of ground elevation representations — *Well, I'm not going to lie. I'm not really as* *familiar with the ground elevation stuff as I might want to be. So, I don't necessarily know the differences between all of these, but in this case I'm trying to figure out if a five-foot increment contour map might be a good plan or if that would just kind of overload everything* As previously stated, even though many of the participants had prior GIS background, they could not remember how to use common spatial analysis and geoprocessing tool worked — *I'm trying to remember how we used intersect before.*

Discussion

The final game scores and previously discussed themes lead to three observations. The first is that participants with limited GIS experience, but with spatially-oriented educational backgrounds, had very high game scores when compared to participants from non-spatial educational backgrounds. We further examined the relationship between educational background and final game score using chi-square test for independence with a null hypothesis that student major and game score are independent. Participants were classified into two categories – spatial and non-spatial. Spatial backgrounds, based on the previously described categories were: (a) Science/Mathematics, (b) Science/Mathematics and Computing/Technology, (c) Engineering/Engineering Technology, and (d) Geography as these backgrounds have strong connections to spatial concepts. Non-spatial backgrounds were (a) Computing/Technology, (b) Liberal Arts/Social Science, and (c) Human Computer Interaction as these backgrounds do not necessarily have strong connections to spatial concepts. Given that the overall lowest test score was four, and the highest test score was nine, we examined scores within this range. We dichotomized the final score range into two different delineations; those of six and greater and those of seven and greater. Results of this analysis are presented in Tables 2 and 3.

Table 2: Chi-Square Independence Test - Background and Game Score of > 5

	Background		**Total**
Score	*Non-Spatial*	*Spatial*	
4 through 5	3	0	3
6 through 9	2	5	7
Total	**5**	**5**	**10**

Table 2 notes:

X^2 statistic = 4.2857

α < or = 0.038

Table 3: Chi-Square Independence Test - Background and Game Score of > 6

	Background		**Total**
Score	*Non-Spatial*	*Spatial*	
4 through 6	4	1	5
7 through 9	1	4	5
Total	**5**	**5**	**10**

Table 3 notes:

X^2 statistic = 3.6000

α < or = 0.058

The α values of 0.038 and 0.058, respectively, indicate that there is a likely association between major and higher game scores. The chi-square independence test results and games score evidence matches prior observations of the high spatial thinking ability in disciplines such as science, mathematics and engineering (National Research Council, 2006).

Second, although many of the other study participants had one or more prior GIS classroom experiences, this prior experience did not necessarily translate into significantly high games scores. As stated previously, some participants struggled with choosing which GIS tool to use for accomplishing a spatial thinking task. Although it was beyond the scope of this paper to further investigate this specific issue, as to why existing GIS courses failed to give the required abilities, it could be due to the fact that GIS instruction is often software product and tool-centric and not necessarily focused on emphasizing the spatial thinking supported by tools and technologies (Gahegan, 2005).

Third, although the study was specifically designed to work with participants with no crisis response experience, many participants were able to demonstrate good judgment and spatial reasoning about factors in the scenario such as spatial relationships between storm surge and the urban environment. This fact could suggest that the level of scenario complexity, as per our use of an established hurricane disaster planning scenarios from the literature (US Department of Homeland Security, 2006) and practitioner feedback from previously work was effective for designing a crisis response scenario that allowed the game players to focus on the spatial thinking tasks and not be limited by understanding the scenario itself.

FUTURE WORK

As previously discussed, participant responses to the spatial thinking aloud session revealed two areas for improving the game playing experience itself. The first is to provide comparisons and "what if" previews before selecting a final answer choice. We did not specifically provide this functionality as we were interested to understand what game players were thinking about *before* making a choice to understand their spatial thinking processes via a think aloud protocol. However, many game players expressed interest in seeing what the choice would look like before making their final decision—*It's hard to say without actually being able to kind of play out the scenarios first and then choosing the best one, actually seeing it; I kind of wanted to see what some of the other options could be and what they would look like*. Given these participant response types, we plan to provide option choice previews. In addition to helping game players see what the outcome of a choice would be, previews can potentially address some of the previously discussed issues by helping novice spatial thinkers see and learn what different map representation and GIS operation look like. Second, for future games, we also plan to explore use of GIS tool recommendation functions. For examples, although participants were told before starting the game they could use all the GIS functions and features as shown in Figure 5, several game players were observed focusing almost primarily in on the game question interface itself and had to be reminded by the study moderator that GIS tools were available to them. For example:

Moderator: Do you think you used the tools to their fullest capacity?

*Respondent: I probably could have used them a little bit more to know like—especially with the first question (*about buffering*), was it 100 feet or 100 — I could have used a ruler to kind of judge where that was going to fall* (a measure tool was available in in the interface).

Recommendation tools could help support game player spatial thinking by guiding them to the proper tool to use and address issues previously discussed where participants with GIS backgrounds did not remember which tools from their prior classroom training to use for which tasks when playing the game. Additionally, standard GIS classroom activities could also use disaster management scenarios more explicitly as GIS training case studies to help new GIS students think spatially about disasters while building technical GIS software operation skills (Tomaszewski, et al., 2015).

We are also conducting preliminary work on porting the SerGIS platform from a commercial, desktop GIS environment to an open source, web-based platform (Hartz and Tomaszewewski, n.d.). Our intent here is to make the ideas of SerGIS more accessible on a technical level and available as a disaster spatial thinking teaching tool beyond crisis response (Tomaszewski and Griffin, 2016). Finally, as SerGIS work continues, we hope to integrate recent prototypes built in ArcGIS's CityEngine and the popular 3-D game engine Unity to allow for 3-D immersion and real-time motion and interaction.

SUMMARY AND CONCLUSIONS

We presented our work on developing and evaluating a serious GIS spatial thinking game framework called Serious GIS or SerGIS. SerGIS is grounded in practical training needs of crisis management as well as using a theoretical foundation based on existing spatial thinking theory and evaluation research. The paper's main contribution was a spatial think aloud study where ten study participants new to crisis response used SerGIS to address a coastal city hurricane scenario based on crisis practitioner feedback and established literature. Results of the spatial think aloud study revealed four themes that emerged from participant responses — processes of reasoning, tools of representation, overlay and dissolve operation, and geographic information concept learning and knowledge gaps. The first three themes match directly with the spatial thinking theory and evaluation used for developing SerGIS. The fourth theme helped to identify how we can potentially address GIS and spatial thinking educational issues. Insightful aspects of this work were that statistical evidence indicates there is likely a relationship between participants from spatially-oriented backgrounds (but with no GIS experience) performing better with SerGIS than participants from non-spatial background. Additionally, we found that by using a game scenario based on established disaster management practitioner literature, participants were able to focus on spatial thinking tasks and not be limited by understanding the game scenario itself. We also identified several areas for future work such as providing answer option previews and GIS tool recommendation. Ideally, further work in developing, using and evaluating serious GIS spatial thinking games can help advance research on spatial thinking ability measurement, crisis response spatial thinking tasks and learning for novices, and combining gaming concepts with GIS for application domain training and education.

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