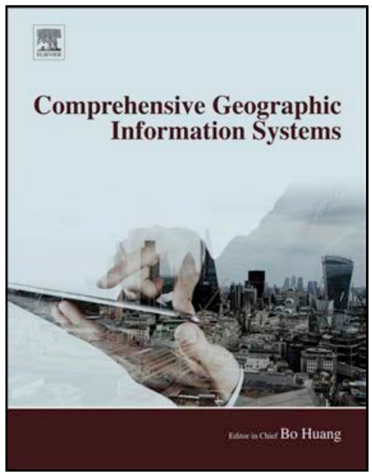

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1.25 GIS and Serious Games

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1.25.1 Introduction

This article presents the interdisciplinary idea of combining geographic information systems (GIS) and serious games. Maps have been integral component of games (serious or not) for many years. In particular, maps are often used as a contextual layer for a gaming experience. For example, the first map that many people in the United States may have encountered was the *Risk*® game board that used a Mercator-based map projection (**Fig. 1**).

In the past 20 years, both the geospatial technology industry and the video game industry have grown in financial revenue and influence (the global video gaming industry had an estimated $99 billion dollar value in 2016 (http://venturebeat.com/2016/04/21/video-games-will-become-a-99-6b-industry-this-year-as-mobile-overtakes-consoles-and-pcs/); a 2013 estimate valued the GIS industry at $270 billion (http://geospatialworld.net/uploads/magazine/Geospatial-World-December-2013.pdf)). For example, maps have become well established and commonplace in diverse fields ranging from medical analysis to disaster response (Tomaszewski et al., 2015). Furthermore, digital games, besides providing entertainment value, are becoming increasingly incorporated into teaching, training, and learning practice (Salen and Zimmerman, 2004).

In this article, we argue that further integration of GIS and serious games can have long ranging impact on learning and advancement of spatial knowledge and expertise in numerous application domains. As previously stated, maps are commonplace in modern-day computer games. However, there is much more that can be done in terms of incorporating the spatial analytical and representational power of GIS into game experiences. Additionally, the integration of GIS into numerous application domains raises interesting and far-reaching research questions on the combination of GIS and serious games. In this regard, we draw heavily, although not exclusively, upon disaster management as an exemplar case study of the integration of GIS and serious games for education, spatial thinking skill development, and problem solving.

We begin the article with definitions to provide context for other parts of the article and to provide readers with background knowledge on important concepts. Specifically, we define *games*, *serious games*, the difference between serious games and simulations, the idea of *gamification*, and spatial representations within serious games. With this background, we provide a literature review focused on the

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Fig. 1 The classic Risk game board.

use of GIS and serious games in disaster management education. We also discuss GIS and serious games in relation to other concepts such as public participation GIS (PPGIS). We then draw on two GIS and serious game case studies to illustrate previous points made in the article. The first is a real-time simulation exercise that incorporates geospatial tools into an emergency response scenario in the context of emergency management capacity building in postgraduate education. Second, we discuss the ongoing research at developing the "serious" GIS or SerGIS system that is designed for flexible creation of serious games using real GIS data and tools. Next, we discuss the important topic of evaluating serious games in terms of their efficacy for learning. We then outline a GIS and serious games research agenda to provide researchers, practitioners, and educators ideas to think about the long-term implications of combining GIS and serious games. The article ends with a summary and conclusion about the integration of GIS and serious games.

1.25.1.1 Games

Although the notion of play and culture was studied in the early 1900s in the classic book, Homo Ludens (Huizinga, 1938), academic game degree programs are a relatively new phenomenon with respect to traditional academic fields. The advent of video games in popular culture and industry since the 1970s has driven a multitude of students to study and make games in academia. UBM Technology Group's (2016) "Game Career Guide" currently lists over 430 colleges and universities. With faculty both responding and furthering this interest, researchers continue to ask seemingly simple questions about games, which have surprisingly complex answers. For example, consider *Tetris*®, which is often considered a "game." In most games, the player overcomes challenges to win or beat the game. But, in *Tetris*®, the player keeps stacking rows of shapes with no final end state, and so, is it really game? And if it is not, then what is it?

At the core of this work in this article, we start with the definition of a *game*. It is an interesting exercise to define this seemingly obvious concept, especially given the dependent relationships of *play* and *fun*. Considering the numerous examples of activities that are fun (e.g., playing with a toy and watching a movie) or could be considered fun for some (e.g., work and school) will usually give pause. For example, if someone has fun in a class, earns points toward a grade, and learns a new skill, is that class at its core a game? We address this idea throughout "**Introduction**" section.

Realizing that researchers needed common ground and terminology for advancing a body of knowledge, Salen and Zimmerman (2004) summarized a multitude of definitions by professionals and academics, which they distilled 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. Consider the Tetris® example above—with a formal academic definition, it is actually considered a "toy" that can be played. Many other experiences and devices fall into a similar category, like Minecraft® and other popular "games." For the purpose of this article, we seek to focus on specific kinds of games that apply to GIS, and so, we drill down a bit into specific kinds of games that are used in education, training, and work, as discussed next.

1.25.1.2 Serious Games

Through Salen and Zimmermans (2004) definition, the example of a student having fun in a class might actually be participating in a game. Their definition broadens a game to include "game-like" experiences, like work, school, and even simulations, where structured experiences provide real rules (e.g., policies) that the participants follow to achieve real goals. Using the example of a class, course material tends to abstract the real world, which presents an artificial "conflict." A student competing with himself/herself, or perhaps the infamous "grading on a curve" are obvious examples of "conflict," but many other aspects of a class present similar challenges: difficult material, abstract concepts, new contexts, or simply juggling multiple courses in school. The artificial aspect of coursework draws highly from educational material abstracting or distilling long-term, complex problems into smaller "chunks" for presentation, homework, and tests. Common examples include business and engineering courses, which borrow heavily from real-world situations, but imagine a student designing an entire luxury cruise liner in a few weeks. There are many similarities of games and education; Bayliss and Schwartz (2009) draw multiple connections between instructional design and game design.

This broader definition of a game also helps extend "games for fun" to "games for work," that is, *serious games*. In the past two decades, there has been a surge of game-related work. Demand for—and by—students has been a major factor, but the lack of early academic scholarship in play and games leads one to wonder about this absence, especially given the vital importance of games and playing in cultures. Perhaps the most obvious answer is the perception of games as frivolous activities—that is, only "serious" human aspects deserve study.

Researchers using games for nonentertainment purposes began to use the term "serious game" in a variety of contexts, especially for work, education, military exercises, and more (Djaouti et al., 2011). Although a broad definition of a game should help convince others of the importance of studying games, applying the adjective *serious* helps elevate the "importance" of such study. When considering serious games, the research community has struggled with the term "serious," as the word implies that such games are not fun for the players. When considering the definition of game, as discussed above, "serious" 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. A variety of categories exist, including health, advertising, military, education, and many more.

1.25.1.3 Serious Games vs. Simulations

A common source of confusion is the relationship of games and simulations. On their own, the importance of simulations cannot be overstated. For example, before performing crash tests of cars, crashes of simulated cars via mathematical and engineering models help narrow the "design space" to save companies a significant amount of time and resources. Fields that involve visualization, like biology and big data, use computer graphics and human–computer interfaces to help display extremely complex systems to improve understanding.

The visualization and interaction of simulations often increase the confusion with games because of the nature of the interactive software with respect to its interface, presentation, and controls. Starting from a game player's perspective, some games offer such realistic environments, as to simulate a real-world location. The worlds of games such as *Assassin's Creed*®, *Fallout*®, and many others use real-world locations that span large areas to explore. This software is marketed as games, released on game consoles, and reflected in popular culture as games. Considering real-time 3D visualizations that offer interfaces, like architectural walk-throughs in a proposed building, these experiences clearly do not represent games and yet, a user's avatar navigating a simulated environment only differs in purpose, for example, not needed to survive an attack while investigating window furnishings in an office building. In fact, Autodesk® is a phenomenal example of how a software company provides both 3DSMAX (animation, games, films) and AutoCAD (engineering, architecture). When simulation and entertainment software, controls, interfaces, and presentation both give strikingly similar interfaces, users unfamiliar with games might assume that their simulated walk-through is somehow a game. This idea recalls a classic question: is the medium the message? In this case, no—the tools used for simulations might actually be the same ones used for making games, but the experiences created might have entirely different purposes.

However, the potential to "blur the lines" between games and simulations becomes possible, given the fidelity is now provided by software tools. 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 to bring more game-like experiences into simulations. The field of wargame design and wargaming provides a useful example (Schwartz et al., 2007), especially given the resources spent by governments to test combat situations. In Schwartz (2008), the classic Tic Tac Toe game is an extremely abstracted wargame, which in itself is an abstraction of real war. The design space between these extremes is dense, given the variety of decisions, scenarios, and models that can influence the design. All of these issues continue to be the focus of academic exploration and debate. For the purpose of this article, we choose to preserve the core definition of games involving rules and goals. With respect to bridging games and simulations, we look to gamification, as explained in the next section.

1.25.1.4 Gamification

The observed similarity of games and classes, serious games, and simulations that "slide" toward game-like experiences all point to the concept of *gamification*. We use the definition from Deterding et al (2011): "'Gamification' is the use of game design elements in nongame contexts." By gamifying an experience, one applies game concepts to that experience, which should (theoretically) drive interest, engagement, and passion. For example, the more fun work is for an employee, the better the productivity, retention, and more. Although many people might naturally assume nongame experiences as games for themselves, Coonradt and Nelson (2007) documented the concept in "The Game of Work." An interesting example is our work vernacular. Although informal, one may often hear about how a worker "games the system," as in finding loopholes in rules and policies to exploit advantages. In a more productive sense, using rewards to encourage achievements is a common workplace strategy.

Part of the drive of gamification is observation of gamers "glued" to their platforms (TVs, mobile devices, computers, etc.), fixating on overcoming the challenges the game provides. If companies, schools, the military, and others could somehow map the interactions, rules, and challenges—all of which a game comprises—then somehow the workers, students, soldiers, and others would all engage more deeply. At least that is the theory (e.g., Egenfeldt-Nielsen et al., 2016). For the purpose of this article, we focus on the aspects of serious games to explore spatial representations.

1.25.1.5 Spatial Representations and Serious Games

The comparative effectiveness of several methods of spatial representations in serious GIS games is an important research question. More than ever, interactive platforms that allow for 3D visualization of geographic environments have been proposed to accommodate experts in retrieving and interpreting spatial data in a variety of fields, including but not limited to disaster response and urban planning. 3D city models, 3D spatial data, and virtual reality simulations are currently being used to accomplish essential tasks such as on-scene assessment, optimal path calculation, and disaster response training.

However, how 3D graphical representations compare to traditional 2D displays is a key consideration. Chen (2011) notes that one of the major disadvantages of 3D GIS and city models is the high cost of production. Despite appearing more technically and visually impressive, what advantages do 3D mapping and visualization offer over their 2D counterparts? Are 3D models worth the cost of production? Many have answered the first question, addressing the gap of knowledge between 2D and 3D visualization. Unlike traditional 2D maps, which rely on symbology, 3D maps include illumination, shadows, texture information, and the ability to change perspectives (Chen, 2011). Tiwari and Jain (2015) argue that in the context of disaster management, 3D graphical representation "reduces the cognition effort needed to interpret the situation," thus improving the efficiency of decision-making. Herbert and Chen (2015) reported a study evaluating the perceived usefulness of 2D and 3D visualizations according to urban professionals. The study suggests that the usefulness of 2D or 3D depends on the specific tasks undertaken. 2D visualization was perceived to be more useful by urban professionals for "simple, measurement-based tasks" such as assessing building height, footprint, and setback.

However, 3D visualization is suggested to help urban planners determine the "context" of a proposed building in its terrain and how it interacts with surrounding buildings from many perspectives. Additionally, 3D was considered useful for performing more complex urban planning tasks such as assessing a building's recession plane. These complex tasks are described as tasks that "involve more imagination and mental manipulation" (Herbert and Chen, 2015). Shen et al. (2012) address the 2D versus 3D comparison in the context of emergency management information systems. Similar to the Herbert and Chen (2015) study, Shen et al. (2012) suggest that 3D displays do not guarantee superior decision-making for all tasks. Rather, decision performance is determined by the specific task, not the dimensionality itself. For example, 2D visualization may be better suited for tasks involving judgments on relative position and orientation. Shen et al. (2012) suggest a hybrid EMIS for toggling between 2D and 3D displays as well as training to enable decision makers to choose the most appropriate display format based on the current situation. Although more research needs to be done on comparing 2D and 3D visualizations, it seems that the relative usefulness of each dimension display may be task dependent.

From the above literature, it is suggested that 3D GIS may be an effective tool in disaster management. 3D displays and models could provide responders with essential geo-information necessary for responding promptly to events. Additionally, 3D visualization is useful for developing simulations that could improve disaster preparedness and virtual training procedures for first responders. However, it is still unclear how the 2D and 3D displays compare for decision performance, especially in the context of serious games. For a potential disaster simulation using a 3D city model for navigation, it may be advantageous to include an option to view the 2D map.

1.25.2 GIS and Serious Game Literature Review

GIS and serious games have seen a small but growing body of literature. In the following sections, we present a literature review of GIS and serious games from the perspective of disaster management and serious gaming and also look to other examples of research focused on combining GIS technology and serious games.

1.25.2.1 Disaster Management and Serious Gaming

In the field of disaster management, serious games are being introduced as a means of eliminating the shortcomings of traditional training tools such as simulated drills. In addition to lacking realism, these drills often require large investments of time and money to arrange and execute. These shortcomings make these training tools impossible to repeat in short amounts of time. Recent introductions of serious games into the disaster management training routine allows upcoming first responders to optimize their training by achieving the most effective results with less of a need to invest great amounts of time and money. The following are reviews of several released serious games that include either a mapping tool or a GIS component as well as common mechanics seen within these games.

Many existing serious games in disaster management include a GIS component as a means of providing spatial awareness in the gaming scenario. The presentation of maps, context for the scenario, specific locations, and the ability to interact with the environment are all examples of spatial awareness as presented in a gaming context. A gaming scenario that presents this exceptionally well is C3Fire, a microworld simulation for emergency management (Granlund, 2001). Using the tool both as a means for the leader to communicate to his personnel and as a means for the personnel to keep record of their findings, this game relies heavily on the graphical interface that a GIS is capable of providing in order to enhance their communications between players. Granlund (2001) revealed in his findings that those participants who selected to use the GIS and mapping tools provided to them had a higher rate of accurately identifying fires than those who simply chose to use the diary and standard communication tools. He elaborated as well by stating that the data from the GIS tool were much more beneficial for debriefing of the game since it provided the instructors with quantitative data rather than just simply qualitative feedback.

Several other disaster management games effectively provide spatial awareness without necessarily including real GIS functions. BreakAway Ltd. (2012) presents *Incident Commander* (**Fig. 2**), a game created in conjunction with the US Department of Justice, that also considers spatial context for their game, giving users a map of the surrounding area where the disaster is located. As people work through the situation, they are able to reflect on the context of the emergency and make decisions based on what's present in the area.

Hazmat Hotline uses maps in a slightly different way, still giving context to their users, but on a much more local level (Schell et al., 2005). Giving them locations of victims, of the source of the hazardous material, and of their crew, this game allows users to think about how to best handle the situation, given where everything is located in relation to each other.

Although GIS and spatial components are critical components of disaster training serious games, there are other factors seen within released games that strengthen a game's viability as a training tool. One of these factors is the inclusion of a stress component to portray the reality of the situation at hand. There are several ways to address the stress component within a gaming context, one of which is using time as a key game mechanic. Haferkamp et al. (2011) demonstrates how each is portrayed within the game, *DREAD-ED*. *DREAD-ED* works based on limited time for team discussion and decision-making, giving the team between 30 and 45 min to reach a decision. To introduce a stress component as well, the game displays four scales to the players which change based on decisions they make to give real-time feedback after every more. Both poor and wise decisions come with feedback. The tactical decision games created by Crichton and Flin (2001) reflect upon similar components, allowing only an hour and a half for participants to completely work through their game, and introducing contingencies throughout the entire duration. The time component emphasizes the need for emergency responders to act quickly in light of a disaster. In addition to a time limit, stress is also factored into serious games through the inclusion of an unpredictable factor. Created in conjunction with VSTEP and several agencies around Europe, *RescueSim* is a flexible gaming environment that is controlled strictly through an instructor toolbox (VSTEP B.V., n.d.). The instructor not only creates the original scenario that will be presented to the players but also is capable of changing the weather in real time, showing the progression of an incident as it would look in real life, and introducing secondary events off of the primary one. Each of these changes is not known or able to be predicted by the players. SPOEL, a virtual environment created for the management and training of mass evacuations, allows for stress to be portrayed in a slightly different manner, working with the changes in human behavior as well as resource distribution and management as their primary sources of stress (Kolen et al., 2011). Victims within the game are able to change their opinions and actions based on media and decisions of the emergency crews.

Fig. 2 Screen shot of *Incident Commander* from https://youtu.be/Gc1CnfQKkZc.

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Road systems are also a limited resource, as they are capable of degrading within the game, or becoming too congested to use as viable evacuation routes.

Another component present in released disaster management games is the use of news stories or information recaps within the game scenario. Information provided to the players throughout the game scenario is another crucial piece to their ability to fully understand about what is going on as the incident revolves around them. IMACSIM provides this through use of waypoints (Benjamins and Rothkrantz, 2007). As the users make their way through the simulated environment they are able to visit numerous waypoints which provide information on the current state. These waypoints are flexible with scenarios, meaning that they can fit to a variety of different conditions and emergencies, and they are also able to accurately reflect any changes that occur throughout game play. Disaster in my Backyard also takes advantage of the opportunity to introduce information throughout the game, using QR codes and victims as the information source (Meesters and van de Walle, 2013). Set up as a live walk-through game, this scenario is much more hands-on in their information presentation. As players make their way through from start to finish, they are able to interact with actors who are playing victims within the game, receiving various amounts of information as they interact with them. Similarly, participants are also given an app which allows them to interact with QR codes that are placed throughout the game environment. These QR codes contain relevant information and allow communication between people as the game plays out.

1.25.2.2 Other Examples of GIS and Serious Games

GIS and its many tools have several applications in serious games outside of the disaster management field as well.

For example, Ahlqvist et al. (2012) is an excellent example of using GIS technology to incorporate real-time data streams in a massive online simulation geared for student learning about human–environment relations. Additionally, serious GIS games are not necessarily only for student learners or professionals in training but can also target the general public. Qamar et al. (2014) present a unique example of such a game with a novel idea for an "immersive map navigation experience" for patients undergoing physical therapy for hemiplegia. This gaming environment involves map navigation influenced by both the Leap Motion controller and the Microsoft's Kinect. Its 3D motion sensors are able to noninvasively detect hand therapy motions and joint movements while converting them into movements seen within game interface. The serious gaming environment is advantageous for both patients and therapists because of its lightweight web interface and its use of cloud-based storage that allows patients to use it anywhere and anytime. The GIS game interface consists of either a 2D or 3D map that can be browsed by the patient's gestures. The different dimensions of spatial representation require different controls to navigate the map interface. To navigate the 2D interface, the user must "grab" the map by clenching the fist and moving the fist in the desired direction (up, down, left, or right). 3D navigation, which is represented by a freely moving kite on the screen, is influenced by more specific hand gestures that enable controls such as zooming out. Serious gaming environments such as this one show major potential for making therapy sessions more entertaining and immersive for patients.

Serious game environments have additionally been implemented with PPGIS. Conceptually founded in the 1990s, the purpose of PPGIS is to enable communication between decision makers and local groups through the GIS and geographical education (Poplin, 2012). Poplin (2012) has studied a specific implementation of web-based PPGIS within an online questionnaire for residents of Wilhelmsburg, Germany. In this questionnaire, participants were asked questions concerning their relationship with the canals of the quarter. These questions involved having participants drawing points and lines on an interactive map interface, marking locations such as a participant's favorite place in Wilhelmsburg. Within the conclusion of the study, Poplin (2012) questions if serious games could be integrated in public participatory processes to hold participant interest in the decision-making process. The integration of serious gaming in PPGIS has been implemented in recent years. In a later study, Poplin (2014) studied the design of a serious PPGIS game called "B3—Design Your Marketplace." This serious game provides a playful environment in which citizens are able to submit their own designs of a public space based on current information received about the city district. In addition to submitting designs, citizens can vote for their favorite designs and communicate with fellow participants as well as urban planning experts. Serious gaming environments such as "B3" integrated into public participatory processes not only facilitates citizens' interest in urban planning and decision-making, but also has pedagogical value in their ability to educate participants on geospatial technologies in an engaging manner.

1.25.3 GIS and Serious Game Case Studies

In the following sections, we draw upon two GIS and serious game case studies based on the research of the authors of this article. These case studies can serve as examples of both the incorporation of GIS Technology into real-time live simulations and development of digital GIS serious games.

1.25.3.1 Emergency Simulation Exercises for Capacity Development Within Postgraduate Education

Disaster risk results from environmental hazards of diverse nature interacting with social-ecological systems and the different vulnerabilities of societies and populations (UNISDR, 2015). Policy makers and practitioners are increasingly realizing the importance of bringing together the disaster risk reduction (DRR) and the climate change adaptation (CCA) communities around the globe, as well as the sustainable development goals (SDG). Mainstreaming CCA and DRR into SDG activities is considered as a strong and valuable measure to reduce vulnerability and to progressively increase resilience (Harris and Bahadur, 2011).

A key barrier though, to improving resilience to disaster risk and climate change impacts at the national level has been identified as a lack of sound scientific knowledge, operational capacity, and technical expertise often resulting from the absence of sustainable and quality assured formal training programs in the area of DRR- and CCA-related sectors (Jordan et al., 2010). The increasing complexity of operational environments in global DRR and Emergency Response in general, in combination with the growing challenges of the humanitarian system at large, also reinforces the need for knowledgeable, skilled, and readily available personnel.

Since 2013, the United Nations University Institute for Environment and Human Security (UNU-EHS) in Bonn, Germany is offering the Joint Master of Science (M.Sc.) Program "Geography of Environmental Risks and Human Security" together with the Department of Geography, University of Bonn, as an international degree program with a research-oriented profile. This program provides an in-depth introduction to problem-oriented research methods, theories, and concepts as well as real life challenges and problems that international and UN organizations are facing. The curriculum includes research areas such as vulnerability assessment, resilience analysis, risk management and adaptation strategies within linked human–environment systems, and environmentally induced internal displacement and transboundary migration.

Among these major subjects students are also trained in the field of emergency response and preparedness. A small-scale emergency simulation exercise has been designed as a fictional disaster event with the purpose of understanding the implementation of standards and procedures that come into effect during a real emergency as well as training the application of geospatial tools for mapping and assessment purposes in the field. Basic geospatial tools are used to practice an emergency assessment as well as to improve coordination and communication among different stakeholders. At the same time, this simulation exercise was the basis for the development of the digital serious games approach, as outlined by a number of former publications (Blochel et al., 2013; Mathews et al., 2014; Tomaszewski et al., 2014, 2016) and further discussed in "**"Serious" GIS (SerGIS)**" section of this article.

1.25.3.1.1 The simulation exercise scenario

On June 9, 2013, a thunderstorm, heavy rainfall, and storm caused large-scale flooding along the Rhine River, in particular the city of Bonn was affected (**Fig. 3**).

The river level increased to 8 m, which is almost 4 m above normal. The game scenario narrative is as follows:

Two children have been reported drowned, numerous persons injured, and hundreds of people displaced. A first rapid assessment reports that infrastructure was heavily affected and several roads, railways, and bridges are closed due to flooding and collapsed trees. Detailed GPS data of the reported sites are not available. A hospital located nearby the river is overcrowded and does not have the capacity to receive more patients. A water treatment plant has been severely flooded and all electrical systems including back-up pumps have stopped working. The city's water authority is already receiving costumer complaints regarding cloudy, poor-tasting drinking water. Strong wind gusts cut down power lines seriously paralyzing communication and transportation networks.

In addition, a ship carrying 200,000 gal of crude oil and barrels of toxic chemicals has been reported wrecked at the South Bridge, connecting Bonn Rheinaue with Bonn—Oberkassel, with oil spilling from the damaged cargo tank into parts of the Rheinaue park area (**Fig. 4**).

Details about the toxic content of the barrels are unknown. According to technical experts the toxic chemicals may reach the water treatment plant within a short time due to the rapid current of the Rhine River. The official German Weather Service is forecasting the continuation of heavy rainfall combined with strong winds over the coming days.

The game player then engages in the following roles. Specifically, in support of the German government the United Nations Office for the Coordination of Humanitarian Affairs has deployed a United Nations Disaster Assessment and Coordination

Fig. 3 The Rhine River in western Germany has a long history of flooding as seen in this 1930 image from Cologne, Germany which is north of Bonn.

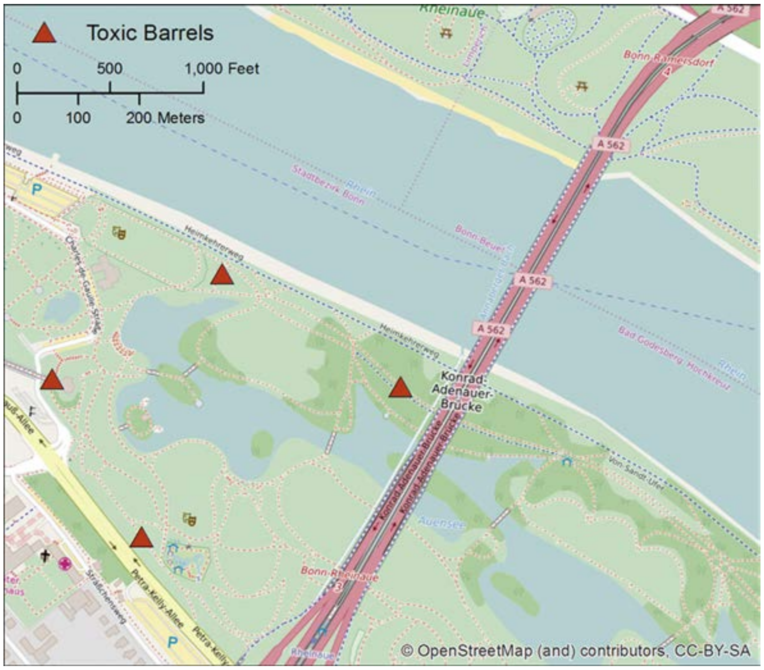

Fig. 4 The Bonn Scenario: toxic waste barrels that have washed up on shore from the flooded Rhine River.

(UNDAC) team. UNDAC has established an On-site Operations Coordination Centre (OSOCC) and the team supports the activities of German authorities in charge of disaster management and civil protection, such as fire fighters, emergency medical personnel including public health authorities, the Federal Office of Civil Protection and Disaster Assistance (BBK), the German Federal Agency for Technical Relief (THW), federal agencies such as the Environmental Protection Agency, state drinking water agencies, the German Red Cross, as well as local law enforcement. An additional CBRN Team (chemical, biological, radiological, and nuclear defense) from Rotterdam, The Netherlands, arrived on-site to support the team from BBK with regard to the identification and rescue of the hazardous materials (HAZMAT).

1.25.3.1.2 The simulation exercise (SimEx)

The students in the simulation exercise SimEx are divided into different groups and represent members of the UNDAC team. Their task is the assessment of four hot spot sites that are of particular high risk to affect the environmental system and population: water, biohazard, oil spill, and infrastructure. Equipped with GPS devices the students have to locate the four hot spots and assess the extent. Specific GIS functionalities, such as buffer, and further tools to combine buffered areas (union, intersection etc.) are used to display varying dissolve types. Collected GPS data (way points and tracks) will be analyzed, reproduced, and visualized in a map. Regular injections by the exercise control team additionally challenge the students, also turning the exercise into a more realistic setting. Finally, an emergency assessment report including a map of the affected area is requested for submission to the OSOCC.

1.25.3.1.3 The pedagogic value

Simulation exercises, including role-play activities, form part of a broader set of learning techniques (Shaw, 2010), in particular, relating to approaches on experiential and evidence-based learning (Petty, 2009). The United Nations University Bonn recognized the high pedagogical value of simulations and the fact that role-play exercises can be used to achieve a variety of different learning objectives, ranging from content and substantive knowledge to critical thinking and problem solving. From an educational point of view, the integration of an active learning exercises into face-to-face classroom allows instructors to achieve several different objectives that are beneficial to the students: (1) promoting student's interaction and input; (2) promoting students creativity, curiosity, and interest; (3) creating an alternative way of presenting course material; and (4) applying theories and concepts introduced in class in the field.

Within this particular scenario the teams involved exercise coordination, information management, needs assessment, safety and security procedures, cultural awareness, communications/media management, logistics, personal preparedness and self-sufficiency, as well as the individual organization's tasks and mandates. Of particular importance is the awareness and understanding of their own individual roles and responsibilities and to be reasonably comfortable with them (UK Cabinet Office and National Security Intelligence, 2014). The latter aspect is also crucial with regard to the serious games approach based on the scenario: when persons gravely adopt their roles and responsibilities within such a game, the exercise becomes more realistic and turns into an appropriate learning experience. In this respect, such a teamwork training conducted within simulated environments, either physically or virtually, may offer an additive benefit to more traditional didactic concepts as it enhances the performance of actors involved, and possibly also helps to avoid or reduce errors during real events.

1.25.3.1.4 The added value of geospatial applications in the field

For most people, a mobile phone with in-built GPS and geo-browser functions has become an everyday tool. But how can we use geospatial data as tangible sources of information for disaster response and preparedness? How can we collect geospatial data appropriately in the field? How can we interpret and analyze data even under adverse conditions and time pressure? The students will find answers for these questions during the exercise. "The faster emergency responders are able to collect, analyse, disseminate and act on key information, the more effective and timely will be their response, the better needs will be met and the greater will be the benefit to the affected populations (Van de Walle and Turoff, 2007)." GIS professionals directly supporting response operations in the field, such as the skilled humanitarian volunteers from the UK NGO MapAction (http://www.mapaction.org/), are collecting accurate and timely information that is extremely relevant especially in the initial, time-crucial phase of an emergency. Large amounts of up-to-date primary data can be rapidly gathered using adequate field equipment and quickly shared among relevant actors. Final products, such as visualized maps, will help stakeholders and responders to better estimate the impact of a disaster and therefore limit damages, understand the root causes of the event, and finally facilitate the decision-making process. Emergency response exercising is therefore a favorable way to build upon lessons learned from previous events, to progressively improve the understanding of prospective emergency events, and to learn how to better protect populations and societies from adverse consequences in the future.

1.25.3.2 "Serious" GIS (SerGIS)

The SerGIS project is an ongoing effort to develop a system for creating and playing games based on Geographic Information Systems (GIS). It is different than the previous case study in that it is a purely virtual environment. SerGIS has been developed with a particular emphasis on using gaming concepts to both demonstrate the capabilities of GIS tools and build spatial thinking ability (Tomaszewski et al., 2016). This is an important point as SerGIS is not like a GIS software training tool—although the usage of SerGIS could provide a basis for GIS software training.

Another important feature of SerGIS is that it has been designed to allow for custom authoring of game scenarios. As an educational device, this is important as it allows for high level of flexibility in developing a wide range of serious GIS game types. To develop a serious game in the SerGIS environment, the user creates a series of game question/answer prompts (Fig. 5).

The order of these prompts, which can be rearranged, determines the flow of the game itself. Each SerGIS prompt consists of four customizable properties: Map, Content, Choices, and Actions. The map section allows game authors to customize several properties of the map displayed in the prompt, such as its latitude, longitude, and the zoom level. Using Esri's ArcGIS accessing to web-based GIS data, the author can edit the basemap into any of ArcGIS online's provided reference layers. Additionally, authors can add map layers by entering the URL of the layer uploaded on an ArcGIS server. In addition to map properties, the game author can edit the

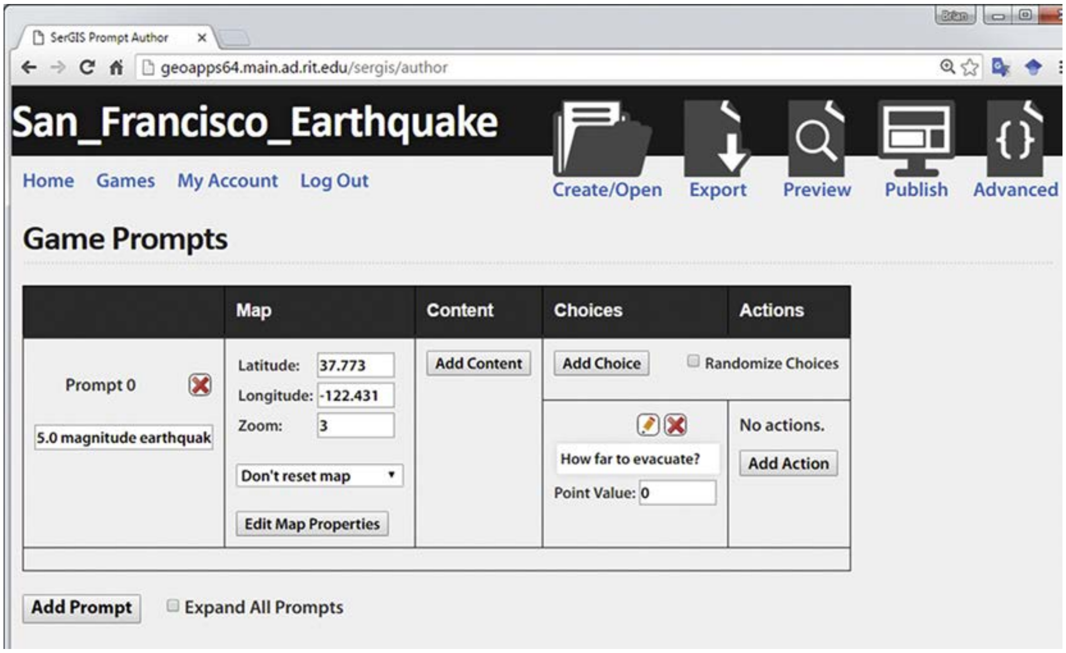

Fig. 5 The SerGIS game authoring prompt.

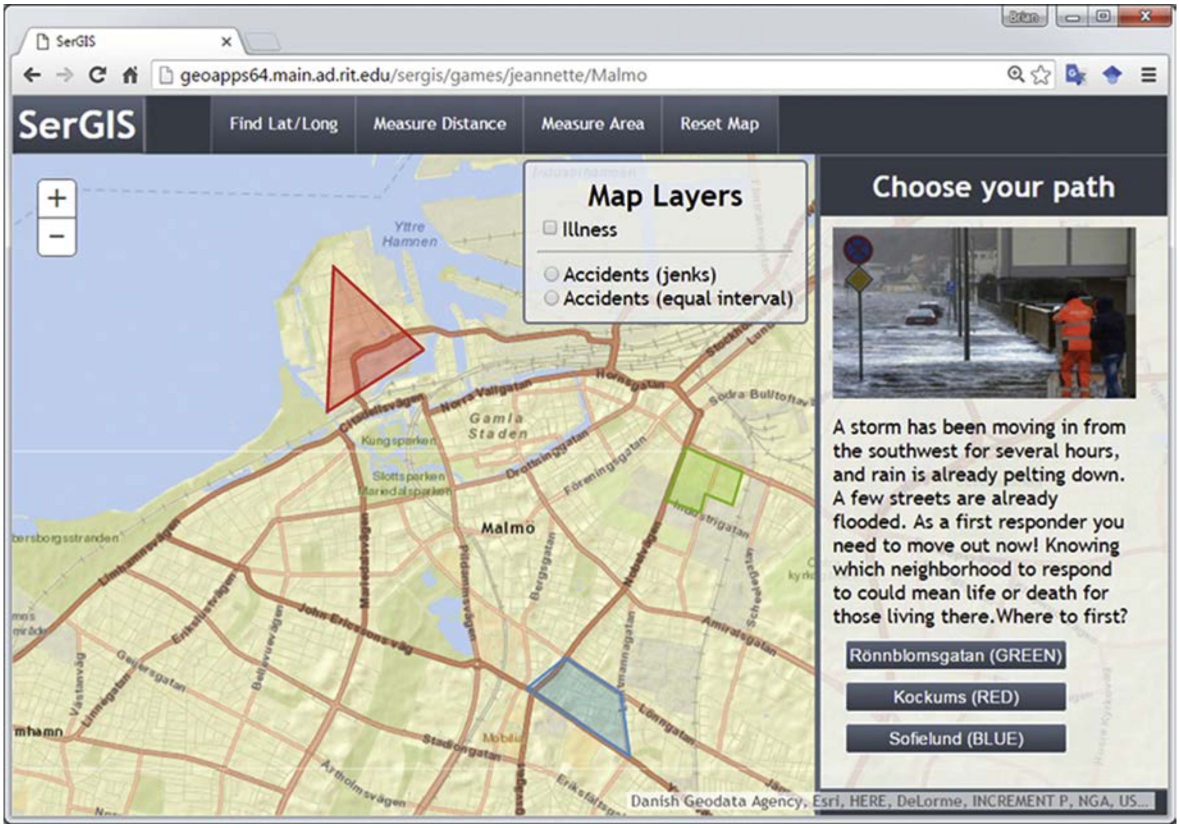

Fig. 6 The opening prompt of a SerGIS game.

context, choices, and actions segments of each prompt. These changes are then reflected in the JavaScript Object Notation game data file, which the author can preview, save, and publish.

Upon loading the game, the user is presented with a visual representation of the first prompt. This representation contains the current game scenario as well as the accompanying map (Fig. 6).

Drawing from the map data as well as the question posed by the game scenario, the player is then prompted to select from the choices displayed underneath the context. When the player makes a selection, the results of the decision are conveyed to the user. These actions range from an explanation of the choice made by the game player to using ArcGIS to draw map features or layers. The decisions a player makes may change his or her score, depending on the point values the game author assigns to each choice. The user then moves on to the next prompt, repeating the process until all of the authored prompts are finished. At the conclusion of the game, the user's accumulated score is shown, as well as the maximum amount of points that could have been scored on each prompt.

A particularly exciting aspect of the SerGIS environment has been the use of SerGIS as a way for student-to-student learning about GIS technology, games, and hazards (Tomaszewski and Griffin, 2016). In this regard, a group of GIS technology students from the Rochester Institute of Technology (RIT) in the United States conducted a collaborative learning activity about GIS technology via SerGIS with a group of undergraduate hazard students from the University of New South Wales (UNSW) in Canberra, Australia (Fig. 7).

With only a minimal amount of instruction, the UNSW students were able to utilize the authoring prompt of SerGIS to create a wide variety of game-related hazards (Fig. 8).

This led to a significant learning outcome that the UNSW students were able to think spatially about disasters, gain better understanding of spatial representations in GIS, and develop ideas for further training and education for development of GIS software technical skills.

1.25.4 Evaluating Serious GIS Games

From the case studies and reviews outlined earlier in the article, GIS serious games have been acknowledged as a viable tool for education and training in professional fields. However, in order to advance GIS serious game design and assist both educators and professionals in selecting appropriate games for instruction, it is necessary to evaluate the effectiveness of serious games. Several

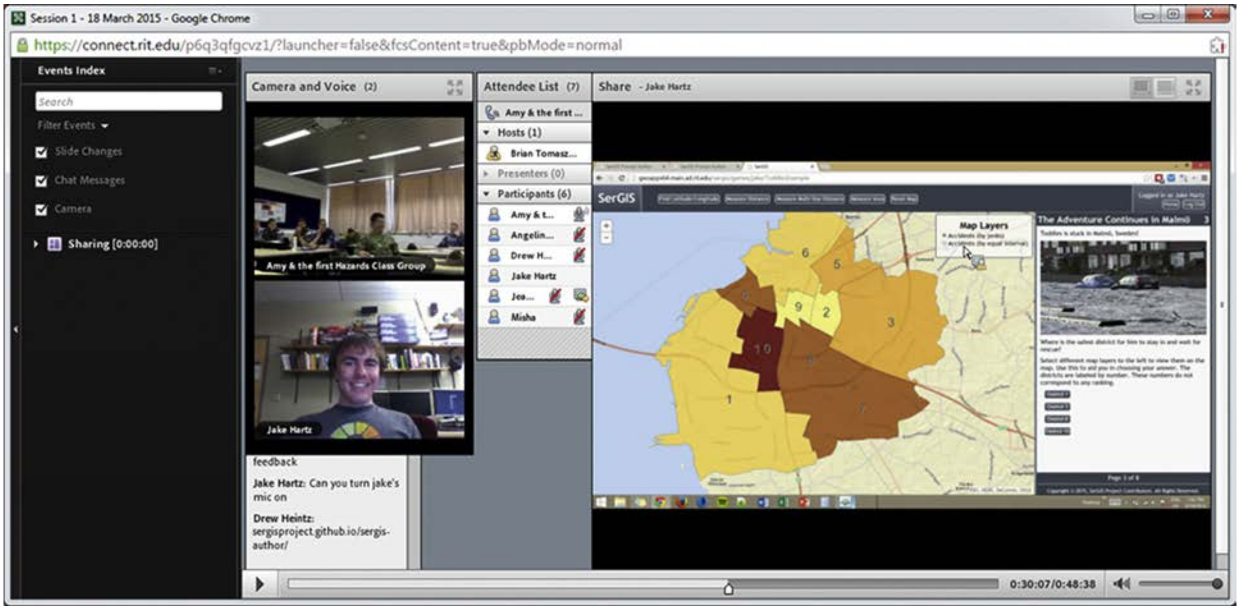

Fig. 7 A student-to-student learning exchange about GIS for Hazards using the SerGIS environment. In this figure, students from RIT are teaching students from UNSW on how to author games in SerGIS.

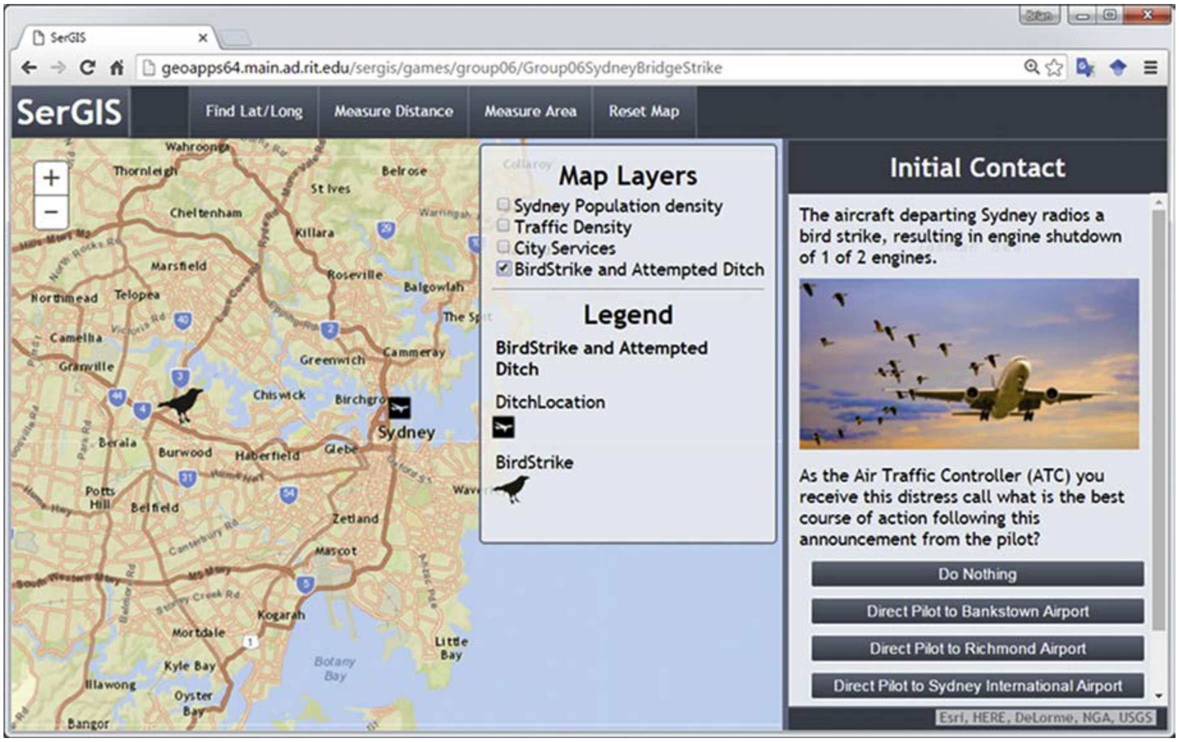

Fig. 8 A serious GIS game created by an undergraduate student. This particular game is related to an air traffic control situation in Sydney, Australia. The student who created this game had no experience with GIS but was able to quickly build a game that utilized numerous GIS functions in order to learn about the capabilities of GIS for disaster management.

evaluation frameworks and methodologies have been proposed and utilized to help determine if a serious game produces the desired learning outcomes. It is necessary not only to review these approaches but also to check whether they have been applied to existing games in the fields of GIS and crisis management. Key considerations for this section will include: factors common to serious game evaluation, how these elements are present in proposed evaluative frameworks, and how these evaluative practices have been applied to existing crisis management and GIS serious games.

First, in describing the process of evaluating serious games, learning assessment has been defined as "using data to demonstrate that learning objectives are being met" (Bellotti et al., 2013). The flexible nature of video games makes such data collection a rather difficult and time-consuming process. Bellotti et al. (2013) discuss two common types of assessment with respect to serious games. Summative assessment refers to evaluating a learner's achievements at the conclusion of an instructional process. A familiar method of summative assessment in educational research is using pre- and posttesting to measure learning outcomes. In a serious gaming context, pre- and posttesting plays a role in tracking a player's knowledge about a particular subject before and after playing the serious game. A case study of the United Nations International Strategy for Disaster Reduction (UNISDR)'s disaster management serious game Stop Disasters! demonstrates this evaluative process. Stop Disasters! is a free-to-play serious game developed by UNISDR that simulates disasters in five scenarios. The intended pedagogical goal of the game is to raise the player's awareness of the underlying causes of these disasters, as well as measures for preventing and mitigating the disaster's impact. In order to address the gap in studies for evaluating the impact of social awareness serious games, Pereira et al. (2014) conducted an evaluation study of Stop Disasters! using several evaluative methods, one being summative. The user study had 27 people play through the wildfire scenario of the game twice on easy difficulty. The study used a pre- and posttest design to measure the difference in the participant's knowledge before and after playing the game. The questionnaire asked four questions to assess the player's knowledge in four topics: vacant land management, inhibited land management, community management initiatives, and community mechanisms. The evaluation found statistical evidence suggesting that the game had a positive impact on the player's awareness in the four topics used for the pre/posttest questionnaire. Summative assessment is generally easy to implement and provides statistical, quantifiable evidence of a serious game's effectiveness. However, it should be noted that methods of summative assessment, such as pre- and posttesting, are alone not a clear indicator of a serious game's effectiveness. Summative assessment fails to take into account that players can cheat or simply guess the correct answer (Bellotti et al., 2013). Additionally, evaluating learning outcomes based on whether or not a player has completed the game does not answer whether he/she has actually learned the content or has merely learned how to beat the game (Bellotti et al., 2013).

Although summative assessment alone cannot adequately evaluate game-based learning, it can be used with formative assessment to develop a comprehensive evaluation process. Formative assessment is implemented throughout the learning process and continuously monitors a learner's progress. Bellotti et al. (2013) suggest that the immediate feedback provided by formative assessment is useful particularly to the domain of serious games evaluation. According to the general evaluation framework proposed by Mayer et al. (2014), methods of in-game assessment and data gathering should be unobtrusive to the player experience. Shute et al. (2009) describe unobtrusive evaluation in serious games as "stealth assessment," which integrates player performance evaluation in a way so that the player is unaware of the process. Stealth assessment indirectly measures a player's learning progress by requiring a player to use knowledge from previous areas of the game to advance farther. Unlike traditional questionnaires, in-game assessment does not directly measure player knowledge and is less disruptive to the user experience. Player performance can be discreetly evaluated through objective measures such as "information trails" introduced by Loh et al. (2007) that transform in-game data to observable player actions. These player actions are then analyzed to gain a greater understanding of a player's thought process during the game (Loh et al., 2007). In the field of GIS games and training, Metello and Casanova (2009) emphasize that geospatial games must provide the tools necessary to evaluate player performance during gameplay. On the most basic level, these tools would provide a timeline of the player's decisions in accordance with each of the game's scenarios. In scenarios with predefined procedures, the game can compare the player's decisions against these procedures, although these predefined procedures and plans are, similar to the serious game, subject to evaluation.

In addition to a game's educational value, one must assess its qualitative aspects. One of the primary challenges for serious game design is striking a sufficient balance between pedagogy and learner engagement (Rooney, 2007). Favoring pedagogy in serious games risks a loss of interest and motivation by the player (Boughzala et al., 2013). Playtesting with end users, an essential aspect of the game design process, is an effective means of assessing the value of its qualitative features such as challenge, enjoyment, and narrative. When playtesting, providing the participants with detailed questionnaires is one common method of qualitative evaluation. These questionnaires often use a Likert Scale to ascribe a relative quantitative value to qualitative data. In addition to summative assessment, Pereira et al.'s (2014) Stop Disasters! case study also measured the subjective experience of the game using a questionnaire. Participants answered a modified version of an Intrinsic Motivation Inventory (IMI) questionnaire which measured user experience in five dimensions: interest/enjoyment, perceived competence, effort/importance, value/usefulness, and pressure/tension. Players rated sentences pertaining to each dimension on a seven-point Likert scale. At the end of the procedure, users were permitted to express any free comments about the game. While players praised the interface, concept, and the informative feedback of Stop Disasters!, they criticized the game's lack of a zoom mechanism and the absence of the ability to test fires in certain locations. The qualitative evaluation (the IMI questionnaire) suggested that Stop Disasters! is an enjoyable and useful game in a low tension gaming environment (Pereira et al., 2014).

Playtesting in the context of qualitative serious game evaluation also requires receiving feedback from a diverse range of users. These end users may differ in many variables, including but not limited to age, gender, experience in the general knowledge area, and experience with computers and digital games. In her paper detailing the development of "B3—Design Your MarketPlace!," an urban planning serious game in the emerging field of PPGIS, Poplin (2014) notes that the game's finalized playtest was conducted with two groups. One of the groups consisted of entirely senior citizens with varying degrees of computer experience, while the other group consisted of university students studying urban planning. Both groups were asked to perform two tasks in this urban planning game and answer a questionnaire concerning the game's qualitative aspects. From the evaluation, it was concluded that most of the participants appreciated the concept of a serious game for participating in the urban planning process, as well as the game's graphics.

However, the playtesting group of senior citizens had several notable problems accomplishing the two designated tasks, which related to the computer skills of the participants. This study of the serious GIS game "B3—Design Your MarketPlace!" suggests that if a serious game does not target a niche, concrete audience, usability testing of the game should be conducted with a diverse set of users.

Another method proposed for qualitative analysis of serious games is De Freitas and Oliver's (2006) Four-Dimensional Framework. Designed to assist teachers in evaluating the worth of serious games, the framework consists of four dimensions: context, learner, pedagogic considerations, and modes of representation. In particular, the "modes of representation" dimension focuses on the subjective features of the game, as well as the game's overall diegesis. De Freitas and Oliver (2006) acknowledge that video games are unique in the central role diegesis (the world within the narrative) plays. Relevant considerations concerning the diegesis of a serious game include the game's interactivity, fidelity, and realism. This remains especially true in the field of serious GIS games involving training scenarios, in which the overall effectiveness of the game's instruction depends greatly on the realism of the scenario's simulation. It is necessary to evaluate the level of these qualitative aspects required to support learning outcomes.

An evaluation process commonly applied to serious games research is the facilitation of debriefing sessions postgame. According to De Freitas and Oliver (2006), it is essential to distinguish immersion into a virtual world from the processes used to reflect the experience. In other words, one must not only play a game but be critical of the process in order to reflect on their relationship with the diegesis outside of it. This "double" identification approach highlights the importance of debriefing as an evaluative tool for serious games (De Freitas and Oliver, 2006). Citing a study in which student learning facilitated by the game Savannah did not match the curriculum, De Freitas and Oliver (2006) argue that a reason for this mismatch was the lack of a clear debriefing session during the pilot project. Andrés et al. (2014) address a similar fault in their evaluative study of TimeMesh, stating that omitting a postgame class discussion of the learned material limited the learning outcomes. Bellotti et al. (2013) note the potential of video and screen recordings in facilitating debriefing sessions. Participants can reveal additional information concerning why he or she chose to take specific recorded gameplay actions during the debriefing process.

There is little difference in the processes used for evaluating serious games specifically in the area of GIS compared to serious games in general. To maximize the effectiveness of serious game assessment, however, multiple methodologies should be integrated into the evaluation process. For example, the learning outcome of a serious GIS game should not be evaluated by pre/posttest design alone, but should also be evaluated through debriefing sessions and qualitative analysis. An evaluation study or framework that evaluates the educational value, game design quality, and in-game player performance of a serious game may prove essential to educators seeking to integrate serious games into both education and professional areas.

One significant difference in the evaluation of serious games for GIS would be evaluation of how the serious GIS game enhances spatial thinking. GIS has long been recognized as a spatial thinking support device (National Research Council, 2006). Tomaszewski et al. (2016) is some of the first research to consider the relationship between the serious GIS gaming experience and spatial thinking. In this research, while playing the game, subject participants were asked to "think aloud" spatially or verbally describe their spatial thinking process. Results indicated that students with spatially oriented backgrounds such as engineering performed equally, if not better, than students from nonspatially oriented backgrounds but with GIS classroom experience.

1.25.5 A GIS and Serious Game Research Agenda

The vibrant and exciting world of GIS and serious games has numerous research directions. The following is a research agenda that ideally can guide and inform basic and applied research on GIS and serious games.

1.25.5.1 Geo-Gamification

Further research should be conducted on incorporating gaming concepts with GIS analytic and representational capabilities. Such research could start with further examination of current gamification best practice such as use of virtual reality, scoring, and rewards and incentives within the gaming experience that can potentially influence learning, training or outcomes of a serious game. Beyond this could be deeper ethnographic research on how people in various domains interact with spatial data, representations on various virtual and computing platforms, and how those interactions could then be gamified into a serious gaming experience.

1.25.5.2 Spatial Representations and Serious Games

As discussed in "**Spatial Representations and Serious Games**" section, 2D and 3D spatial representations critical aspects of the GIS serious gaming experience. Further research should be conducted on the appropriateness of 2D versus 3D for specific gaming tasks, and how those representations contribute to the overall serious gaming experience and learning outcomes. Research on spatial representations in serious games should also investigate how decision-making is affected by the type of spatial representation provided in the serious game.

1.25.5.3 Expert Knowledge Incorporation Into Serious GIS Games

As was demonstrated in this article, serious GIS games are closely coupled with application domains such as disaster management. This close coupling to application domains creates numerous research opportunities for incorporating expert knowledge into serious GIS games. For example, the SerGIS environment outlined in "“Serious” GIS (SerGIS)" section provides the ability to provide feedback on individual game choices made by players. This feedback is critical to both the learning experience provided through the serious game and validating the relevancy and efficacy of the game as a training and learning tool. Incorporating expert knowledge can be conducted in a variety of ways such as literature reviews of practitioner materials, participant observation, interviews, and other knowledge elicitation techniques. These techniques are basic research methods themselves that can be taught to undergraduate and graduate students. Thus, serious games can also serve as an indirect way for building research methods and skills that are related to a broader and more engaging purpose (from a student's perspective) of building and creating serious games.

1.25.5.4 Evaluating Serious GIS Games

Evaluation methods should be developed that account for the unique spatial aspect of serious GIS games. These methods should not only incorporate summative and formative assessments used in evaluating serious games in general (as discussed in "Evaluating Serious GIS Games" section), but also should consider how the nascent field of spatial thinking evaluation (Kim and Bednarz, 2013; Lee and Bednarz, 2012) can be incorporated with serious game evaluation.

1.25.5.5 Technology Research

Numerous technical research directions exist for serious GIS games. The case studies provided in section three demonstrated the use of existing commercial GIS tools to develop a serious GIS gaming experience. This is important as the data sets and tools used by the game players are the same as those used by GIS professionals. These gaming experiences relied on desktop and web-based GIS tools to create a gaming experience. However, much more work can be done on incorporating real GIS tools with real GIS Data on mobile platforms, wearable computing, and as of yet unknown forms of computing that will emerge in the next 5 years. For example, (a) developing serious GIS games that incorporate real data streams collected from an actual disaster and where (b) the game is played on a mobile device while in the field like discussed in "Emergency Simulation Exercises for Capacity Development Within Postgraduate Education" section.

1.25.6 Summary and Conclusions

In this article, we introduced the idea of GIS and serious games. We provide context to this idea through definitions of games, serious games, the difference between serious games and simulations, the idea of gamification, and spatial representations and serious games. Given the close coupling of serious games to application domains, we drew heavily upon the domain of disaster management in terms of literature review and case studies to provide specific examples of GIS and serious games. In particular, we provided GIS and serious game case studies drawn from the research experiences of the authors. The first was an example of capacity development using emergency simulation exercises that incorporated geospatial tools with a real-time simulation exercise. The second was a virtual serious GIS game environment called serious GIS or SerGIS that has been developed to allow for flexible creation of gaming scenarios using real GIS tools. We then provided discussion on evaluating spatial games as a means for further research on development and evaluation of new serious GIS games. We concluded the article with a GIS and serious game research agenda that ideally can provide ideas on further developing both the theoretical and methodological basis of GIS for serious games.

Although maps have been, and will continue to be an important part of gaming experiences, we argued that the analytical and representational power of GIS combined with the ideas of serious games can provide a powerful and novel method for training, learning, spatial thinking development, and problem solving in a wide variety of application domains. Ideally, further research and development on GIS and serious games can take advantage of the ever-expanding volume of spatial data being created combined with new technological platforms that can address pressing societal problems.

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