Design and Implementation of Mobile Educational Games: Networks and Innovation

Rob Harrap, Sylvie Daniel, Michael Power, Joshua M. Pearce, Nicholas Hedley

THE ADDED VALUE OF SCIENTIFIC NETWORKING:

Perspectives from the GEOIDE Network Members

1998-2012

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Edited by Nicholas Chrisman and Monica Wachowicz

GEOIDE

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Cover design: MS Communication

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Contents

Chapter 8

Design and Implementation of
Mobile Educational Games:
Networks for Innovation

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Abstract: Research networks foster creativity and break down institutional barriers, but introduce geographic barriers to communication and collaboration. In designing mobile educational games, our distributed team took advantage of diverse talent pools and differing perspectives to drive forward a core vision of our design targets. Our strategies included intense design workshops, use of online meeting rooms, group paper and software prototyping, and dissemination of prototypes to other teams for refinement and repurposing. Our group showed strong activity at the university-centered nodes with periods of highly effective dissemination between these nodes and to outside groups; we used workshop invitations to gather new ideas and perspectives, to refine the core vision, to forge inter-project links, and to stay current on what was happening in other networks. Important aspects of our final deliverables came from loosely-associated network members who engaged via collaborative design exercises in workshops, emphasizing the need to bring the network together and the importance of outside influences as ideas evolve. Our final deliverable, a mobile educational game and a series of parallel technology demonstrations, reflect the mix of influences and the focus on iterated development that our network maintained.

Keywords: mobile educational game, collaborative design, augmented reality, mobile technology, Energy Wars Mobile Game.

1   Introduction

Between 2007 and 2008 a group of researchers came together to work on the design of educational games, under the direction of one of the authors (Daniel). The GeoEduc3d network aimed to use mobile and desktop hardware and software to build games where children - both in classroom and in informal settings - experience urban space and learn about sustainability, climate change, and how geomatics is used in these fields and in game design. The project was brought to the GEOIDE network - 'Geomatics for Informed Decisions' - and subsequently funded with ten core researchers at three institutions. This Chapter focuses on three issues: how the group fused geomatics and game design to produce a game to teach children about gaming, technology, and sustainability, how the game and side-projects reflected that approach, and what the organization and execution of the project has to say about network based science.

1.1   From Vision to Project

GEOIDE is a network funding organization under Canada's National Sciences and Engineering Research Council (NSERC); a specific program at NSERC creates Network Centres of Excellence (NCE's) that focus on areas of common interest to industry, government and academia. The GEOIDE network, headquartered at Laval University, has existed since the late 1990's and completes its mandate in 2012.

The NCE overarching philosophy is that networks of researchers who are geographically distributed between regions of Canada will offer unique perspectives on *what to do* and *how to do it*. The NCE structure requires that projects have industry and/or government partners who will set the context and then take up the results of research, and a strong collaboration with specific partners is encouraged. GEOIDE itself has a Board of Directors and a Scientific Committee which combine to set direction and oversee individual projects, with at least yearly feedback to all project leaders on their direction, productivity, and on possible linkages to other projects. The Scientific Director of GEOIDE (Dr. Nicholas Chrisman since 2005) plays a central role in communicating opportunities arising to project leads and so encouraging a truly networked science community.

Again, the core idea of GeoEduc3d from the onset was that there is a place for gaming in the classroom of the future, and that geomatics has a clear and significant role in such games. Mobile games, where players move around using devices such as cellphones, are especially relevant in that they balance game play with physical activity. Such games could educate about a theme - such as global warming, or urban development - while simultaneously informing about underlying methods - such as geomatics and computing.

With this as a vision, the project lead (Daniel) worked with an initial team of researchers and partners to establish a domain of common interest and to ensure that the

size of the network and expectations of the members was consistent with the NCE rules and GEOIDE mandate. The project lead then wrote an initial proposal and the deputy-lead (Harrap) made minor changes; at this point the major groups (four institutions, ten researchers) in the research network and their proposed roles existed on paper. The question of which would be active or inactive, and of whether GEOIDE and the partners would be agreeable, remained to be discovered.

At the time of application for funding, GeoEduc3d had strong commitment from industry and government partners, as well as excellent international links to European academic groups with an interest in geomatics education and game design. In terms of the network structure of GEOIDE, it did not exist in a vacuum, as two projects with complementary goals were funded at the same time: one, on climate change visioning, included one of the authors (Harrap) and one, on social media and collaborative geomatics, had a similar interest in networked tool design. As a network of networks, GEOIDE encourages collaboration and cross-fertilization of ideas between groups; one of the things the project would be tasked with is ensuring that other GEOIDE projects were aware of our efforts; another would be to take key outcomes from other projects and put them to good use within the GeoEduc3d initiative.

GEOIDE funded the GeoEduc3d project with an initial pilot year as the network itself was undergoing a re-funding phase with the NCE. When GEOIDE was approved for an additional phase ('Phase IV') GeoEduc3d would go on to full funding and activity.

1.2   Network Science and GeoEdu3D

The advantage of team-based science is, of course, that multiple disciplinary perspectives and multiple minds can be brought to a problem. The range of perspectives increases as teams become larger, but teams of any size face issues that only get worse with larger teams: communication barriers around collaboration, context, and shared vision.

Communications between team members sets the stage for what a project is about, whether the vision starts out top-down from a project leader or is developed within a group. As work towards a vision or visions proceeds, collaborative work requires communications of the common context of work, lessons learned, and emerging opportunities. These issues are significant when a group can meet in person, for example, when members are within a university department or a university as a whole. The issues become much more significant when a larger community is involved.

A second, complementary, set of issues arise from the evolving group mindset, often referred to as 'groupthink.' There is a danger over time that a group will see a drop in innovation because of a lack of outside criticism, new ideas, and new understanding of context. For a project like GeoEduc3d inside a network like GEOIDE, outside groups like the GEOIDE leadership, like other GEOIDE projects, and outsiders from

other national or international groups of relevance could all provide insights to keep an evolving project evolving in a useful direction.

The GeoEduc3d group used a number of networking mechanisms to address context, collaboration, and inspiration issues, and is perhaps unique in GEOIDE in that network science studies were discussed among the project members as part of planning and project execution. The specific mechanisms used are discussed below in historical context followed by a discussion of lessons learned from this larger meta-project. First, however, we provide technical background on the scope and foundations behind the project itself, and review the relevant concepts from network science that inform that history and discussion.

2 Project Scope and Foundations

2.1 History, Focus, Appeal

Games have long been a motivator in the development of new technologies and techniques, particularly in the areas of computer graphics and artificial intelligence. One recent area of investigation has been pervasive games, which offer different styles of interaction than traditional board games or desktop-based computer games [1]. The term "pervasive games" embraces the employment or application of Pervasive and Mobile Computing technologies either to augment traditional games or to create new games that are impossible to realize with traditional media [2]. Pervasive games take the player away from the computer and bring him in the real world, which is richer, more diversified and challenging than any made-up game world. This new generation of games uses information and communication technology to overcome the setting and interactional boundaries of conventional games, creating new, enhanced environments, and making the real environment an intrinsic component of the game [1]. Such games are attractive for education since they combine the appeal of games with environments that can engage and support situated learning, and additionally can be designed to encourage team-based problem resolution strategies.

Spatial context has become an important factor in people's everyday life. GPS is no longer the domain of specialized equipment: car navigation systems and smartphones both use location to provide service to average consumers. While there has been a dramatic spread of such uses of spatial technology, for example driven by Google and its API to online mapping technology, the geospatial and geomatics domains are still relatively unknown by people: they use the technology without being aware that anyone would study it or work at it!

One of the goals in the GeoEduc3d project is to address geomatics awareness via situated mobile games, specifically educational games which use state-of-the-art geospatial technology and which address themes relevant to teenagers such as climate change and sustainable development [3]. Through immersive, reactive and interactive

serious gaming, GeoEduc3d's purpose is grounded in mobility and in the use of mobile platforms in real geographies.

The project rational relies on the following observation: if geographic information use is to continue to grow, future university students must have a more sophisticated understanding of the field. The current supply of geomatics professionals comes from traditional land surveyors or geo-information specializations, yet these fields have poor visibility among young students. Effort needs to be invested in finding people to work in geomatics, to develop and to use these new technologies, and on finding new perspectives and ideas on what geographic technology should be in the future. By designing and implementing gaming and learning-oriented tools based on geospatial technology, tools developed within the GeoEduc3d project immerse teenagers in games that use geographic information and technology, and highlight how these tools are designed, implemented, and delivered to open the eyes of the next generation to opportunities in geomatics.

Our goal has been to engage students with rich user experiences set in real geographies. The project adapts proven visualization and interaction solutions to enhance game based learning, with a focus on methods from augmented reality (AR). Augmented reality is a newly emerging technology by which a user's view of the real world is augmented with additional information from a computer model [4]. An augmented reality application is said to be mobile if the user is his own avatar and his position in the synthetic world follows his displacements in the real environment [5]. Mobile augmented reality games are a special type of pervasive games. Several mobile augmented reality applications based on smartphones have been released (ex. Layar, http://layar.com), but mobile AR solutions offering realistic visualization and interactions with the real world still remain research prototypes [6]. The GeoEduc3d project is concerned specifically with the geomatics challenges inherent to mobile AR solutions (ex. 3d modeling of the environment); the limitations of technology and AR are discussed below.

2.2   Mobile Technology

The newer models of mobile phones used in location based or mobile augmented reality applications (i.e. iPhone4, Nexus One) have built-in cameras, Global Positioning System (GPS), accelerometers capable of rough orientation (tilt) estimation as well as bearing orientation (which way the user is facing). The iPhone4, for example, tracks 6 degrees of motion (3 for orientation, 3 for shift) for the phone using microsensors. Even with such advanced devices, there are still challenges remaining when using mobile technology for mapping or serious gaming purposes. These range from hardware issues, to development platform and geospatial infrastructure complexities: the main challenges include battery life, GPS positioning accuracy and availability, and complex and incompatible development requirements for different devices. Mobile games require long-lived devices with precise orientation and positioning and with seamless access to multi-scale content, and the team would prefer to develop

applications for multiple hardware and software platforms to allow wider uptake of our tools.

2.3   Augmented Reality in a Geomatics Setting

Augmented reality applications require accurate tracking in order to superimpose computer-generated information upon the user's view of the real world in a precise and realistic manner. Most of the efficient tracking techniques rely on prepared environments to ensure accurate results. These are environments where the designer has complete control over what exists in the environment and can modify it as needed [7]. Such methods cannot be applied outdoors, where the context is more fluid and where control over setting is less likely. Tracking in unprepared environments is challenging, especially when using a mobile platform. The positioning devices available in mobile platforms are still not accurate and reliable enough for AR. Computer vision approaches, where a sensor in the mobile device observes the scene and calculates orientation and alignment factors are generally necessary to complement GPS and internal positioning sensors. However, computer vision algorithms are sensitive to outdoor conditions (ex. moving objects and people; lighting conditions) and robust solutions have not yet been achieved [8].

The limited computational power of the mobile device is an additional and important hurdle to overcome if mobile augmented reality applications are to be used in an outdoor environment, especially when computer vision methods are involved. Algorithms need to be highly optimized and efficient solutions generally exploit the characteristics of the device processor. Innovation at the hardware level is required to be able to offer an immersive and rich mobile AR experience to the users.

2.4   World Construction

The purpose of mobile location-based or AR applications is not only to situate the user in the world but ultimately to allow them to interact with this world. World augmentation and interaction in current mobile solutions is limited, and there is abundant interest in improving these areas. Both interaction and augmentation require accurate knowledge and representation about the environment, and this world model, or set of models, must exist at a variety of scales – corresponding to the scales at which the user navigates a region (blocks) down to the scales of fine-grained interactions (centimeters). Model features must also have rich annotations that support a variety of interaction styles, search, discovery, and community annotation [9]. Accurate geometric and semantic models of the real world are required. Support for situated activity [10] as well as high resolution urban mapping demands models where features down to 'doorknob scale' are represented. The overwhelming problem to tackle is that of data acquisition at this level of detail. This exceeds the difficulty in fields such as game world building and computer animation where models must be precise (detailed and photorealistic) but not accurate (they don't match any real world setting precisely). Research is needed both in how to construct such a world model, and in where

simplifications are possible - for example, re-use of models - that will not break the fidelity of the model or adversely affect the user experience.

This, then, is the scope of research and perspective of the GeoEduc3d project, to use existing technology to build mobile games incorporating ideas from augmented reality in order to engage and educate young students about technology, geomatics, and sustainability, while also engaging in research about supporting technology and methodologies for such games. We now turn to the issue of networks of researchers before examining how the network aspects of the project evolved and what that evolution informs how future network science might be carried out.

3 Perspectives on Networks

GeoEduc3d is about networks on several levels: first, it is funded by a research network, and comprises a mini-network that spans institutions and disciplines. Second, the project deliberately uses sub-networks to foster innovation. Third, in recent years network science in itself has become central to game design, especially social game design, and ultimately this change has dramatic implications for what motivates students to engage, a key component in our goal of delivering educational experiences via games.

The idea that humans form social networks for collaboration, idea-sharing, and inspiration is intuitively obvious: it underlies such long-standing structures as professional societies, research conferences, and even peer-reviewed publication. The idea remained largely intuitive until the 1960's, when pioneering work on the structure of social networks was done by mathematicians and computer scientists [11] and subsequently and famously demonstrated by an experiment with hand-delivery of mail (often erroneously referred to as the 'six degrees of separation' experiment) [12,13].

Another significant perspective on networks is Metcalfe's Law, originally stated by Metcalfe and documented by Gilder (reported in [14]) and attributed to the architect of the Ethernet networking standard: the value of a communications network is proportional to the square of the number of connected users in the system. Unlike the small world approach, which emphasizes who knows who in a chain, Metcalfe's Law emphasizes that the 'macro' value of a connected network as connections is strongly related to network size.

With the rise of socially-rooted Websites such as MySpace, Wikipedia, and especially Facebook, the idea of a social network of creators and sharers received significantly more attention, and this more or less coincided with the publication of a popularized account of small world networks by Watts [15] a highly active researcher in the field. Some attempts were also made to directly link innovation in science to the nature of a scientist's social network (e.g.[16]). No group has done more to make the idea of the

social network and its representation as a graph more visible than Facebook, who directly refer to their company as one focused on innovation around social graphs.

As researchers, we might care about these results for a number of reasons:

– our ability to connect with each other as directly involved researchers is a function of the connectedness of our network, and the overall size of the network
– we might draw resources from those in our social network
– we might draw inspiration from those in our extended social network, in other words, use social networks to enhance our research
– we might directly make use of social networks in things we design, either by exposing them explicitly (as does Facebook) or implicitly (as does a community such as bloggers or Wikipedia authors).

One key result from academia that informs the last two points, and was central to how the projects described in this Chapter were designed and run, is the relationship between social network membership, connectivity, and innovation. Uzzi and Spiro [17] describe an in-depth study of creativity and success on Broadway as a function of the strength of members of a small network (producing a Musical). After continued success, the productivity and success of a semi-stable group will begin to falter, and innovation returns after substituting a 'new player' from the larger network, especially when that new member was only weakly associated with the original team. In other words, as a group works together, they may be highly successful to a point, but eventually new ideas, preferably quite different new ideas, are needed to renew the creativity of the group. This result is an example of the highly active, emerging field of *science of team science studies* [18] which explicitly examine the effectiveness of multi, inter, and trans-disciplinary teamwork via statistical and network-theory based examination of research publications, patents, and the like. These approaches are driven by recent studies that show the impact of team science [19] and how these are mitigated by organizational structure and geography [20].

The group that comprises the central research team of the GeoEduc3d project includes education researchers and geomatics researchers spread between three universities and spanning Canada. Faced with a diverse and geographically distributed group, the project leaders used a number of measures to manage the project and especially to ensure innovation within the group, and this approach was integral to the formation of the project.

Finally, subsequent to the initiation of the project, a dramatic shift took place in the area of game design and publishing: the most profitable and visible games of 2009-2011 were not graphics-intensive, innovative and immersive experiences, but were instead very simple and highly addictive games that operate within Facebook and directly rely on the social graph and principles of social psychology [21]. This has somewhat influenced what our industry partners are interested in pursuing.

Given the objectives of our project - to design innovative mobile games that educate children about environmental issues and geomatics - and the nature of our distributed and multidisciplinary team, we took advantage of a number of methods, grounded in network science, to keep shared context, collaboration, and innovation alive. These are discussed in detail in the next section.

4   The Design Process: Applying Network Science to Games

A number of tools exist to support team-based work; in fact, there is an entire area in information science and computer science centered on the design and implementation of such tools - 'computer supported cooperative work. These tools range from what is now mundane - telephones, email, and documents sent or shared online - through to newer and less established techniques - web meetings, design workshops, and wiki-based collaborative writing. A number of related methods to extend cooperative work also exist, such as design by variation, bringing outspoken outsiders into design sessions, and 'extreme development' methods.

Our shared design practice was rooted in human-centered design principles such as the use of personas, scenarios, and early testing of prototypes with clients; while these methods were important, they don't relate directly to the network structure that is the focus of this discussion.

A number of specific techniques *were* applied. These individual techniques all contribute to design, shared context, shared visioning, and rapid innovation. They include:

  – Design workshops
  – Web-based meetings
  – Inter-project networking
  – Inter- and Intra-project shared prototypes
  – Critical review and guidance from partners
  – Critical review and guidance from outside critics

Each of these methods also addressed the institutional, disciplinary, and geographic barriers to collaborative science to a degree.

We focus here on the larger-scope and more effective elements, namely design workshops, shared prototypes, and the use of outside critics and 'inspirers'. These are discussed in chronological order below to give a sense of the evolving priorities and state of the overall game design project. Note that the group held regular web meetings before and after these individual activities, and that the discussion below only includes about half of the actual meetings, emphasizing the early, key, workshops and innovations.

4.1   Project Initiation – Building a Network

As discussed in Section 1.0, GeoEduc3d was proposed as a network project to GEOIDE and funded based on strong central goals, relationships to partners, and relationships to other networks. The initial funding was for a pilot project year.

During the initial pilot phase, a number of key activities took place: communication with other groups inside GEOIDE, refinement of relationships with partners, and a preliminary design workshop. In particular, one initial research (and hence one institution) chose not to participate in the evolving project, and several new researchers at the other institutions became engaged in the process.

4.2   Workshop 1 - Game Design by Analogy

The first network-centric activity undertaken was a workshop to refine the overall direction and scope of the project, in other words, to decide on the *specifics* of the project given the general objectives under which the initiative was funded. The workshop was organized at Queen's University (Kingston, Ontario, Canada) in June 2009 and included researchers from inside the project as well as interested researchers and students from the related field of energy sustainability. The group was broken up into design teams and tasked with challenges to address. All our teams involved high school students, undergraduates, graduate students, and faculty researchers with different backgrounds, including geomatics, sustainable design, climate change science, and education. The range of participants broadens the sources for ideas and inspiration; the inclusion of young students provides a strong tie to the culture and interests of our target audience.

The leaders realized at this point that game design is an established discipline although not a traditional academic one; the real evidence of excellence in game design is in the form of existing, classic games. As a result, the design strategy we applied was to take existing board games, have the teams play them, and then to try to infer why the specific elements of the games work.

Figure 1 shows researchers and students participate in scenario-development exercises designed to foster the emergence of original gaming ideas based on a frame game approach [22]. Frame games are, in essence, game shells which have had their original content removed and for which only the structure - the game pieces and game mechanics - remains. Game authors use the shell to build a new game by adding their own content and making minor changes to the game mechanics. During the workshop, participants looked at a variety of board games and analysed them through a variety of lenses [23] such as game content, game mechanics and game dynamics in order to better understand what makes a game work, whether the game mechanics have to be altered to accommodate new content, and the degree to which game dynamics are affected by such changes [24].

Fig. 1. Scenario development using a frame game design approach

Following the framing exercises, the group met in break-out groups to design three independent games, all set in an urban space - the area around a typical school or campus - but still board-based. Variants that were proposed included a mystery game with the participants as investigators, and two variations on a game of capturing buildings to control the overall 'field.' The resulting ideas were discussed, and the exercise was re-run, this time assuming game play would be mobile and would use devices such as smart phones, and perhaps could integrate augmented reality elements.

One key outcome of this process was that some of the younger participants who had a background in game programming and especially game 'modding' (where an existing game is modified to serve a new purpose) began implementation of the design ideas as simple prototypes. The idea of rapid development through experimentation, termed 'extreme development,' allowed the group to see which ideas would be easily realized and which might be a challenge. This also concretized some of the emerging ideas, and gave the group a way forward: instead of starting with a low level game implementation task, we could instead start by developing a 'mod' and use that as a basis for testing and refinement. The downside of this approach was that our first experiment would be desktop, not mobile, computing-based.

The impetus for this direction was from students outside of the actual research group: inspiration and collaboration from the larger network had a significant role, enabled via participation in an intense and enjoyable workshop-based game design process.

4.3 Prototype 1 - Making Design Ideas Tangible

The workshop resulted in the design of two games scenarios, since two of the breakout teams designed very similar games. Out of the two scenarios, one was selected as the foundation of the first GeoEduc3d modding-based prototype. The proposed prototype, *"Energy wars – Rise of the Chimera"* (see Figure 2), is an educational game situated in a real environment: the first version takes place on the Queen's University campus. The goal in the game is to explore the area and then capture and upgrade buildings to make them more energy efficient. The goal *of* the game is to teach students about energy flows, about cost-effectiveness of upgrades, and about timeliness of acting on evolving situations with energy and sustainability.

Gamers have access to two roles: an engineer and a security officer. In the role of an energy engineer, players can survey and modify campus buildings. Meanwhile, enemy agents are interfering with building occupants and damaging building systems; the security officer can block these attempts. Buildings consume or produce energy resources which are the currency of the ongoing game. Since one player must control both characters as well as manage resources, the result is a game with no single winning strategy and opportunity for repeat play to explore alternatives.

The Energy Wars game is built on top of Blizzard's Warcraft III engine using custom development tools from the game modding community. The buildings in the virtual campus are 3d models of the relevant campus buildings; constrained by mobile terrestrial LiDAR (Light Detection And Ranging) data acquired using Terrapoint (http://www.ambercore.com) TITAN technology and checked against photographs. A workflow was designed to input 3d models into the Warcraft III environment, including the use of CAD and 3d Modeling tools.

Since stealth learning (i.e. learning while playing) is one of GeoEduc3d objectives, the energy angle in the game relies on realistic simulation. Information related to the building state of repair, technologies to propose to upgrade the building and the "green energy" the building can generate was provided by an expert in solar photovoltaic systems (Pearce) from outside of the GeoEduc3d network. The results for that research group are discussed in Section 6.4. The renewable energy and energy conservation content in Energy Wars was founded on treating sustainability improvements and upgrades as supported in the technical literature [25].

The actual development of Energy Wars was carried out by a high-school intern and an undergraduate student working for one summer, with input from members of the GeoEduc3d team at key points.
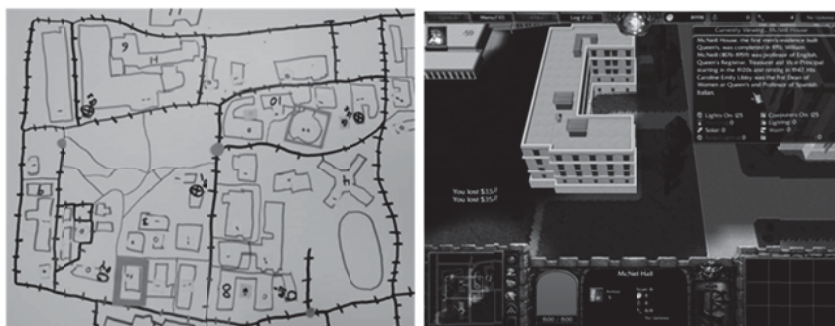
Fig. 2. Game prototype "Energy wars – Rise of the Chimera"; a) Drawing of the game scenario during Queen's Game Design workshop; b) Screen capture of the game prototype built on top of Blizzard's Warcraft III engine.

There were two key results from the prototyping process: first, the team now had something concrete to experiment with, modify, and learn from, and second, the game was a deliverable in its own right, albeit a desktop game.

The Energy Wars prototype was submitted and ultimately selected as a finalist in the 2009 Serious Games Showcase & Challenge (http://www.sgschallenge.com/), rated there as the best game by an undergraduate developer group.

4.4   Workshop 2 - Refining Perspectives and Directions

The Energy Wars process demonstrated we could work as a successful research network, engage with other partners and other networks, and deliver an interesting and testable product. However, Energy Wars was a realization of only a small part of the overall project vision, lacking a distinct mobility component, use of augmented reality methods, and with a single-player focus. Context had been established, collaboration had taken place, but inspiration to move the project forward was necessary.

The next approach taken was to host an open workshop with partners from industry and government to show off the project to date, and to use this opportunity to bring in outside views. We reached out across the individual personal 'social networks' of the members invite outsiders to attend and present viewpoints on the state of educational gaming, the future of gaming technology, and to take part in our next phase of development.

The workshop included break-out sessions similar to those held at the first workshop, again exploring existing ideas and brainstorming on how to extend these, perhaps incorporate them into further developments of Energy Wars, and discussing side projects that were being developed to test other ideas in parallel.

The specific focus of the meeting was to examine how to blend the 'fun' aspects of a next-generation game with educational aspects. Different approaches were investigated, including game play through a series of staged, low-content activities, and another being social activism to create a long-lived experience that might persist beyond the student-in-classroom setting. Participants in the workshop played an outdoor mobile game with existing technology to get a better sense of the benefits and difficulties of mobile gaming; this framed our next generation design in realistic terms.

The outside visitors, or 'inspiration agents,' were active researchers in educational gaming with experience in developing games for high school students. Again, they both pointed out new directions and framed realistic expectations of what could and could not be achieved in a research group of our size. This demonstrates that network interactions can simultaneously affect what you do and how you manage a project. The workshop also included participation of five representatives of partner groups including two talks framing new technology (e.g. 3d scanning) and game design methods (e.g. computer graphics in urban settings) from within the partner organizations.

4.5   Prototype 2 - Innovation and Refinement

Given the strong interest drawn by "Energy Wars – rise of the Chimera", and given the overall objective of mobile, team-based games with augmented reality components, the results to date were used to launch what became the main focus of the GeoEduc3d project: "Energy Wars Mobile."

Energy Wars Mobile features a revised game scenario, with player persona and game mechanics adjusted to take advantage of the mobile environment. The game was reframed to have multiple mobile roles to be played by different students including roles for students who have mobility issues. The revised prototype is situated on Laval University campus (Quebec City, Canada) but can be repurposed to any site with reasonable geographic data access and networking infrastructure. It was developed by the subnetwork at Laval (Daniel, Hubert, Badard [Geomatics team]; Barma, Power [Education team]) over the course of two years (2010-2012).

The student players are members of the *Quebec City Emergency Measures Crisis Team*. They have been requested to take action after a nuclear accident has occurred in Quebec and, as a result, a state of national emergency has been declared. Since local hospitals are already full and can no longer receive patients, a new treatment centre is needed as soon as possible. Public Safety Canada, working with Laval University, needs to determine the best area on campus to base a new emergency treatment center.

This is the main objective of the team of players: they need to find the best located building on campus to open a radioactive-contamination treatment centre and a refugee service area. They have three primary objectives to fulfill in order to meet this

main goal namely, 1) to conduct in-depth field exploration to find contaminated areas around campus and to decontaminate them, 2) to identify the best building on campus to serve as refugee service area, and 3) to retrofit the chosen building to make it more energy efficient, given that there is an energy shortage due to the generation plant failure.

The latest version of the game scenario involves three levels to be completed successively: once the area is decontaminated, the best building on campus to serve as refugee service area is highlighted; once the building is "captured" by the team, they can start to retrofit it. Money accumulated during the decontamination phase – assigned as a reward for carrying out tasks efficiently - is used to buy technologies to retrofit the building such as solar panels and wind turbine.

Figure 3 shows a view of radiation hot-spots spread over the game space, the main control panel of the expert app, the budget tool informing players of their current money status, and the list of technologies available for retrofitting the chosen building.

The multi-level approach adopted for Energy Wars Mobile prototype complies with the recommendations expressed during the second workshop, wherein a series of low level activities where suggested as an approach to better engage the players. The nuclear event context has been chosen to foster the player engagement in the game since a rapid response is required. In addition, the regional risk included in the scenario has been considered a key element to trigger their interest and awareness around environmental issues.

The game involves a team of six players with individual roles, forming a network:

- the commander, guiding the team;
- the scout, wandering around the campus to detect radiations;
- the radio operator, relaying information between the players on the field and the commander;
- the energy expert;
- the material expert;
- the environment expert.

The commander can guide its team either from a remote desktop or directly on the field using a mobile tablet (i.e. an iPad2). This role might best be assumed by a teacher since tools are provided to monitor how the players manage to face the problems presented to them and how they collaborate as a team to overcome them. A smartphone is provided to each player on the field in order to track his position and to allows him to complete his dedicated tasks; the technical challenge in implementing Energy Wars Mobile was to have the individual capabilities work on the relatively limited devices used, and to coordinate the overall game-flow between them.

Specific elements of the game play address the various research focii of the Ge-oEduc3d group: mobility, augmented reality, and sustainability and environmental issues. Energy Wars Mobile allows discovery and exploration of environment and space through location-based and augmented reality tools. Decontamination of the campus is carried out by roaming the game space and detecting radiation hotspots: these are georeferenced (i.e. geotag) nodes spread strategically over the gaming area. Since the location of each player is tracked, various interactions occur according to position and vicinity to radiation hotspots: some hotspots incur immediate money loss, whereas others provide immediate gain. Some zones trigger quizzes to be solved by the player to be able to proceed with the game. Such an approach takes fully advantage of the mobility side of the game, the network of players, and the notion that repeated simple tests can promote learning and retention [26].

The interaction can contribute to improve the visual and spatial thinking skills of the player. To further develop such competency, radiation zones are displayed using augmented reality visualization methods (see Figure 4). The player can switch from a bird's view of the campus where hotspots are displayed in 2d to an augmented reality view where they are displayed as 3d graphics. This representation change trains the mental associations of the player between the 2d and 3d spaces, allows different types of spatial reasoning, and promotes immersion in the local environment.

Fig. 3. Energy Wars Mobile displays and information: a) game map with geotag database (display in yellow); b) main screen control of the expert app; c) information about the player budget and building sustainability gauges; d) list of available technologies to upgrade for buildings.

Fig. 4. Energy Wars Mobile prototype: visualisation of the virtual radiation markers using augmented reality markup.

Developing the underlying architecture of Energy Wars Mobile exploited researchers – nodes in the immediate network – that until this point had had relatively little input, given that their expertise was not in design but in mobile solutions development and deployment. Energy Wars Mobile relies on a client-server architecture (Figure 5) built using the PhoneGap open source framework (http://www.phonegap.com), which allows rapid cross-platform development and provides support for both mobile and desktop platforms. This allows, for example, the Commander persona to deploy either on a desktop or on a tablet computer depending on the teacher's specific needs. The underlying content is stored in a PostgreSQL database and conveyed through an Apache Tomcat server. The Expert and Radio personas are deployed on iPhones currently, and the Scout (which ultimately is to employ Augmented Reality ideas) is implemented on Sony Ericsson Xperia with Android.

The notion that a research network – GEOIDE – funded a group of researchers – GeoEduc3d – to do research that ultimately resulted in a game that uses a network of players – scouts, experts, … – shows the degree to which network thinking permeates the entire approach taken, from administration to application.

GeoEduc3d involved a number of other meetings and refinement stages similar to those described above, incorporating outside feedback, design sessions, and chances for students especially to show their work to a wider audience. For the sake of brevity we mention only that in each case we brought in the external commentators that we felt would most seriously critique our ongoing efforts.

Fig. 5. Architecture of Energy Wars Mobile prototype.

4.6 Workshop 4 – Testing and Refining Deliverables

Given a new prototype, the network met to carry out preliminary testing; unlike the earlier workshops, which had involved and in fact centered on external input, the testing workshop involved only core researchers and one industry representative; since most issues of the design were not 'on the table' and since testing opportunities are limited, keeping the group to a subset of the entire network was desired.

Preliminary testing of the prototype highlighted several shortcomings. The main one was the impact of a general lack of precision of the GPS in the mobile devices. The players had to deal with the uncertainty related to their position and the radiation hotspot location. Players spent a fair amount of time trying to locate hotspot focus areas while the augmented reality tool indicated they were on the right spot. The trigger distance to radiation hotspots had to be tuned accordingly. Testing also showed that the players required more feedback to better understand what was going on in the game. The Expert app interface was subsequently redesigned to include a control panel with information about the current status of the game. All mobile roles were modified so that the phone vibrates each time the player is in contact with a radiation zone, which in subsequent testing received very positive feedback.

Some early experiments were also conducted with educators from high schools. The prototype raised a lot of interest and positive comments from them. The use of mobile devices and the augmented reality tool were key contributors to the positive feedback – the issues that the core researchers in the network thought were interesting and ef-

fective did not completely correspond to what educators, distal nodes in our network, placed value on!

The development of Energy Wars Mobile is ongoing; it is our intention to both continue the development ourselves and to share the work done to date with interested parties so that the project has larger impact and permanence; we are also seeking new members for the research network and actively taking our results to other networks so that they may benefit from the project.

4.7 Reaching out to Other Research Networks

The GeoEduc3d team engaged in internal networking and, as discussed, constantly brought in outside critics to workshops to challenge assumptions and refine the research and development direction. The group also took part in significant outreach both within the GEOIDE network and in the larger domains of education, game development, and geomatics.

Within GEOIDE, the GeoEduc3d team sat in on workshops by other research networks with related interests, such as the Climate Change Visioning project. We also prepared and presented a GEOIDE Summer School Course on game development and geomatics (presented 2010 and to be presented 2012).

Outside of GEOIDE proper, team members interfaced with the public and research sectors through participation in game and education events, with other research networks internationally through shared use of tools and presentations at conferences, and with the larger academic community via conferences and publications. We hope that the open access we provide to our tools will result in uptake that further continues outside linkages and shared exploration of ideas.

5 Secondary Experimentation in the Research Network

With a geographically distributed and thematically diverse network there is the danger – if not the strong likelihood – that a research network like GEOIDE will end up funding teams that implement different solutions in a vacuum, and that *within the GEOIDE projects the same will happen*. GeoEduc3d used workshops and constant online communications (net-meetings, email, and shared files) to instead focus on the shared development of a few research prototypes as discussed above. While this meant all researchers had input on a few strong deliverables, it also meant that many ideas that didn't fit into the central design theme might have been left unexplored.

The danger of a lack of centrality is of course that nothing coherent comes from a project – the network produces essentially a series of projects that are no different than what would have resulted if the researchers were funded individually. The danger of overly strong centrality is that higher risk ideas and issues that might, but might not, be relevant are left unexplored. As a result, in GeoEduc3d the management team

deliberately encouraged experimentation in the early project and created an internal vetting project for higher-risk 'mini-projects' in the later project phase. Many of these side-projects informed the development of Energy Wars Mobile, and many delivered ideas and code that are ready for incorporation in future versions.

While history could be rewritten and these aside, or 'secondary,' experiments be presented as if they were obviously and initially central, this would misrepresent the intent and furthermore misrepresent one key issue with innovation in networks, which is that different levels of innovation happen in parallel, some high risk and some low risk, and the advantage of this parallelism is that successful side-experiments can be folded into the main development effort while those that are less successful can provide useful lessons learned without endangering the main effort. This is, in fact, one of the key approaches used in Open Source development efforts.

5.1 Building the Augmentable Environment

The Energy Wars Mobile prototype involves three mobile augmented reality applications.

The first and the second application augment the environment at the campus scale. They aimed at visualizing 3d graphics (such as radiation hotspots) in the field; the locations of these are not known by players at the beginning of the game. The approach implemented in these two applications differs. The first one relies on the geographic coordinates of the items to be displayed to overlay the virtual graphics of the items on the real world at those coordinates. This was ultimately incorporated into the 'Scout' role in the Energy Wars Mobile game. The second one addresses building the local environment for augmentation. Augmented Reality requires geometric models of an area so that the computer graphics calculations can be done to determine how augmentations overlie (or underlie) viewed objects. The experiment (Figure 6) involved a fast and easy way to create 3d models of buildings to manage occlusion and offer a realistic rendering of the virtual graphics [27].

The third application augments the environment at the player scale. More specifically, it targets augmentation of user interaction at the scale of hands and hand tools. The purpose is to superimpose graphics showing virtual tools the players (i.e. the experts) will have previously selected according to the task they have to achieve. The AR approach relies only on computer vision algorithms (i.e.OpenCV open Source library) used to detect and track the player hand on the smartphone camera feed; an example is shown in Figure 6.

$$dh = d \cdot \tan(dz)$$
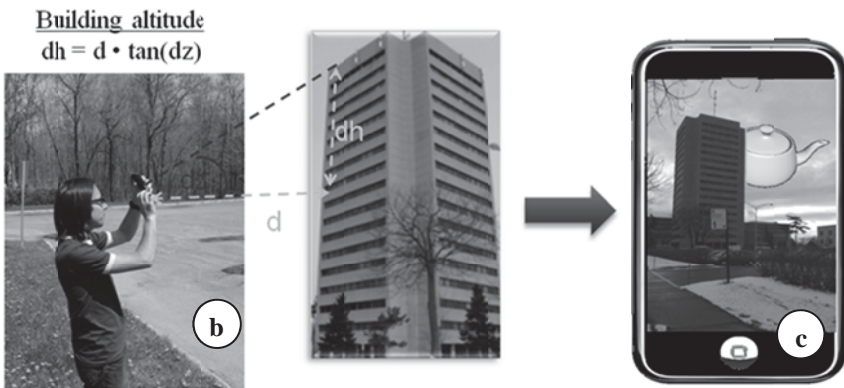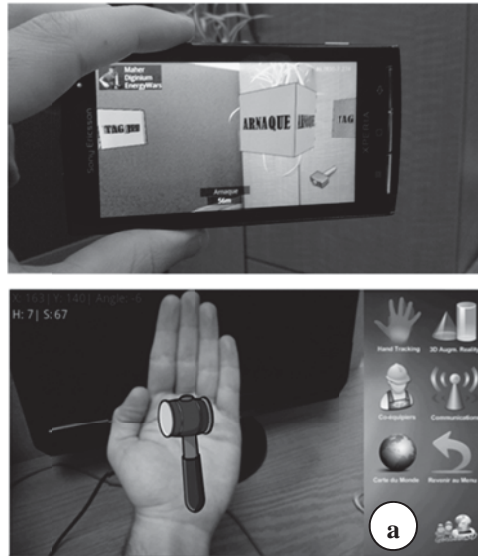
Fig. 6. Mobile Augmented Reality applications used in Energy Wars Mobile prototype: a) Mobile AR apps using geographic location; b); AR apps to augment gamer hand with virtual tools; c) iModelAR apps involving fast and easy 3d modeling of buildings.

5.2 Situated Augmentation of Urban Environments

Beyond the scale of Energy Wars Mobile, the group recognized that urban gaming in the large might involve relatively simple, but high volume, annotations of urban features with simple text and graphics. Starting with a conceptual plan [28] a mobile-device based application was built that allowed landmarks to be identified and described with stories and photographs. The 'Situated' application relies on a client-server architecture, is multi-platform, and can be extended with new data collection requirements as needed to address specific study requirements. Situated (Figure 7) supports both shared content and named groups with private content, has roles such as

administrators and content creators, and has geographic locales supporting the idea that regions may have different communities of interest who wish to document their environment. Ultimately *Situated* has a strong relationship with the idea of hotspots in Energy Wars Mobile: in a future game scenario those hotspots might be anything that a community in *Situated* wished to document, meaning that *Situated* communities could transition to game communities.

Fig. 7. A Landmark in Situated on an iPhone. The new Landmark supports storytelling, photo documentation, and ultimately game creation.

5.3 Augmented Reality Landscapes

Researchers at the Spatial Interface Research Lab (SIRL) at Simon Fraser University, led by one of the authors (Hedley), have designed, built and evaluated a constellation of situated, mobile and augmented reality visualization interfaces for distinct problem spaces aligned with GeoEduc3d objectives. Based on Hedley's [29] concept of 'real-time reification' (RTR), these interfaces combine the capabilities of geospatial virtual environments, augmented reality and geosimulation connect students to spatial data, simulations, and abstract concepts in real spaces, in new ways. Their research has integrated partnerships with local government, regional environmental programs, and provincial agencies.

The first collection of interface prototypes combine 3D physics, geosimulation, geo-visualization, geomatics, tangible spatial interfaces and mobile augmented reality (MAR) to allow students to interactively explore precipitation, watershed topography,

and hydrology in everyday spaces. A *Touch of Rain* is a multi-modal geospatial interface that combines location, orientation and motion sensor data with tangible user interface capabilities, allowing users to interactively position and move virtual clouds over terrain, control virtual rainstorms, and see where water particles flow on virtual topography. *A Situated Virtual Touch of Rain* is a situated portable virtual environment that allows the user to look 'through' location aware mobile devices as portals into parallel virtual geosimulation spaces at the same time as standing on the equivalent real location. *An Augmented Touch of Rain* is a MAR interface that allows users to switch seamlessly between situated virtual environment and situated augmented reality. Users can create virtual clouds, position them over topography in virtual space, and see the precipitation simulation fall (or flow over topography) in *real* geographic space.

Fig. 8. (L-R) *A* Touch *of Rain; A Multi-Touch of Rain; An Augmented Touch of Rain* All images copyright Nick Hedley and Chris Lonergan/SIRL 2010-2012. All rights reserved.

Throughout this initiative SIRL researchers have networked with regional watershed education groups, and are collaborating with GeoEduc3d researchers to create localized versions of *A Touch of Rain* for parallel usability testing in Quebec in 2012.

A second set of interfaces explore the potential of situated citizen sampling, mobile augmented reality (MAR) and geospatial game design for tsunami education – in collaboration with real communities. *EvacMap* allows users to interactively browse user-specific location-aware evacuation maps of Ucluelet. *VAPoR* is an iPhone-based mobile interface tool that can capture and map community perceptions of risk and evacuation – enabling the collection of mental maps of risk perception and evacuation from permanent residents and visitors. *SMARTEE* demonstrates the potential of MAR to augment real communities with GIS-derived risk overlays and evacuation information. This research has raised a number of issues that challenge us to think carefully about the design of geographic augmentations using MAR.

Fig. 9. (L-R) *VAPoR field testing; SMARTEE field testing; collaboration in real community* All images copyright Nick Hedley and Calvin Chan/SIRL 2010-2012. All rights reserved.

5.4   Spawning New Research Networks

Outside critics and influencers had significant impact on the development of both the core Energy Wars project and on side projects. This was nowhere more true than in the interaction with energy experts during initial (phase 1) game development.

As outside influencers less familiar with both the technical tools used in the project and with gaming in general, Pearce and his mechanical and materials engineering students that participated found the team-based design and prototyping exercises to be, in their own words, both fascinating and enjoyable. The exposure and guidance from GeoEduc3d network members in the use of technical tools and design methods spawned productive new research directions for Pearce's group - e.g. the use of smartphone technology to assist in building energy audits [30] and a spin-off company to commercialize it (Envirolytics: http://www.envirolytics.ca/).

The experiments in the scope of energy solutions within GeoEduc3d led us to realize that a sub-network focused on energy modeling of the environment, comprising some of the members of GeoEduc3d and some new members, was worth exploring. The new network, 'Bedrock to Blue Sky' (Harrap, Pearce, Daniel, Badard, Cascante, Hutchinson) was formed in 2009 and approaches similar urban spaces from a quite different perspective. The new network includes three members from GeoEduc3d, one of our external critics, and two new researchers.

6   Discussion - the Social Network, Innovation, and GeoEduc3d

The GeoEduc3d project has had a number of impacts both in the subject areas and as a research network, as discussed above. We now discuss those impacts, strengths and weaknesses of the approach, and ways forward.

6.1   The Intersection of Games and Geomatics

Within the field of geomatics, the work demonstrates the very strong and largely un-explored link between methods in geomatics and in game design. Many issues that are a challenge in game design – construction of large and realistic urban worlds, for example – are within the normal purview of geomatics. Many issues that are a challenge in geomatics – moving from a two-dimensional and static conception of our subject to a dynamic, three-dimensional one – are within the normal purview of game design. Perhaps more importantly, whereas in game design the idea of design is central and crucial, in geomatics application design and experience design (as opposed to cartographic or aesthetic design) are relatively underused, and in particular a focus on user affordances is underappreciated. Finally, our work demonstrates that in the shared space of gaming and urban geomatics, access to reliable positioning even outside is a critical barrier to effective game play.

In the field of gaming proper, the work demonstrates that highly engaging experiences can be shaped out of networked teams with relatively simple roles, and that spontaneous interaction and team building arise when players realize how roles mesh. We have demonstrated that engagement arises from local context, and that there is a relationship between gaming in the local environment and experiencing that environment dynamically (as in augmented reality) or in documenting that environment. Outside of gaming proper, the side-experiments on *Situated* and AR interfaces demonstrate innovative and accessible ways to engage with citizens about spatial problems.

This of course bridges to the educational aspects of the project, where we hope that the game play, the game subject matter, and the context-setting before and after game play together contribute to meaningful learning. We have also demonstrated that informal methods such as game modding, popular with many students, have a role in the classroom and may in fact allow students who would otherwise be unengaged to find a niche for meaningful participation in shared work.

6.2   The Value of the Networks

The GeoEduc3d network was created and informed by a direct consideration of the strengths and weaknesses of stable networks of researchers, of the advantages of connecting across social and scientific networks, and especially of the challenge of creating a network where three different focii – education, gaming, and geomatics – must meaningfully mesh. As noted, we realized that an overly stable network would stifle innovation but an overly fluidly network might prevent any real work at the collective level from being accomplished. We also were very concerned with the possibility that the research network would be a community of interest where individuals share ideas but not necessarily strongly collaborate on specific projects, and our focus on a few central and shared projects as meant to encourage that type of strong collaboration. These reflect the recognized issues with networked science identified by the studies discussed above: geography, disciplinarity and institutional barriers. The problem

with network research is that it usually isn't a network for research, but merely one for distribution of funds under an artificial and temporary network structure.

Our approach as discussed above centered on three elements:

- We used a small number of key prototypes and asked all researchers to contribute directly to those at a design, development, testing, and application levels.
- We encouraged side projects to explore key ideas with significant risk in the context of the core projects.
- All of our communications activities, and especially our workshops, involved central roles for outside critics to present their own work, to criticize our work, and to forge new links of collaboration.

The result, overall, was a number of areas where our approach proved strong, and a number of areas of relative weakness.

First, students in the network were educated in a way that was deliberately more collaborative and intertwined with other disciplines and other approaches. For some students, their involvement was part of graduate training, for others it was part of summer internships, but all contributed as equals during design sessions. All students were kept aware of the other disciplines involved in the larger project. And we took this approach out to a GEOIDE Summer School course to broaden the interdisciplinary reach. This links to the idea from network science studies that show that mentoring is perhaps the area where networks of researchers can have the largest impact [18,19].

Second, we managed to incorporate several elements from outside of the traditional research community, partly by incorporating members of outside groups and partly by participating in outside activities and encouraging outsiders to participate in our activities. For example, our early work relied heavily on links to the game modding community, an informal social network of self-educated but highly motivated game designers who collectively know a huge amount about what does and does not work in game design and implementation. Our use of critics is discussed in detail, below.

The original formation of the team was also an indication of a fundamentally networked view of the world: three communities that were relatively unknown to each other took part.

On the other hand, a number of weaknesses emerged, some of which are simply realities of network science in our view and some of which might be handled differently in a future project of this type.

First, the network approach taken was not for everyone. Some researchers, realizing that the project did in fact centre around shared work on a small number of prototypes, drifted out of the network. They clearly saw the purpose of network science as

being to build a community that discusses ideas around private projects, or perhaps projects carried out by a few members of a network, and the idea of working on a larger team didn't engage them.

Second, geography was a significant challenge, as has been recognized in science studies [20]. Although we made every possible use of online meetings, design often involves being in the same space, and more distributed members of the network had a harder time staying engaged and collaborating meaningfully. In particular, we might have done a better job of shifting students between sites to give them more exposure to different perspectives, although our tradition of at least three shared meetings a year did result in some opportunities for sharing results if not early work.

Finally, our use of critics could have been made much stronger if at least some of the critics were re-engaged to provide renewed feedback and a stronger push in interesting directions. The administrative push of the GEOIDE project administration kept us thinking about publications and the like, but those external science and development critics who we so successfully engaged in a one-off manner might better have formed a project-specific oversight committee with continued involvement.

6.3 The Value of Cycles of Criticism

As pointed out, our use of outside critics included those from partner organizations such as game companies, geomatics tool providers, and social groups interested in the dissemination of tools, and these outsiders had a strong interest in influencing what direction our development took. These criticisms took place throughout the development cycle of our project, including criticisms of early prototypes, of speculative parallel projects, and of our final core deliverable.

The normal model in the academic community is that work is done by an individual or group and then this is delivered in verbal or written form to the community who respond with (often anonymous) feedback. There are strong merits to this system, especially during the later parts of a project: it provides assurance of community standards, it provides corrective advice on communications styles and approaches, and it provides insulation between critics and (perhaps irate) authors of work. Guidance of projects is provided up front, when a grant is given, and at the very end, when judgement is rendered, although in some projects interim reporting is done. GEOIDE is a good example of a structure in which up-front, interim, and project completion guidance is provided.

There are two substantial problems with this model. First, who is providing the feedback? Second, at what level of inspection is it happening, and with what resulting impact. In many projects feedback is provided at a managerial and an academic level. In GeoEduc3d we purposefully brought in critics that were *not* from these communities, but were instead from the practitioner community. In GeoEduc3d the inspection by critics happened throughout the life of the project, and at a deep level: the critics

played the prototypes, they showed alternatives, they led visioning exercises to provide insights rather than commentary, and these had a significant impact throughout the development, long before academic papers were being written, and while there was still time for substantive change.

As with other aspects of our project, this again shows the wisdom of some aspects of the open source community, where the idea of fast prototypes and fast feedback are central. Extreme programming, at its core, pushes developers to work with others to gain shared insights, to face repeated criticism on the project rather than on secondary products (such as documentation), and to let a project to some degree evolve rather than be pre-planned. Clearly a middle ground is wise between emergent and highly structured science, but in GeoEduc3d the role of critics, or perhaps 'extreme commenters' was central to the projects success.

7   Conclusions

The GeoEduc3d project designed a networked game to educate students about geomatics, game design, climate change, and computer science. The early prototype of the game - Energy Wars - and the later prototype - Energy Wars Mobile - both relied heavily on student - faculty networking, critiques from professionals from outside of our research network, and intense workshop-based design sessions.

The role of workshops with external critics both informing the core research group about outside developments and challenging our design and development approaches and direction was the largest network innovation taken. Geography is a strong barrier to network science, and involvement in the workshops turned out to be a strong predictor in long-term involvement in the overall research network.

Realizing that a balance was needed between the central development targets and individual interests and strengths, we funded relatively high-risk but also high-impact side projects involving individual researchers and students, continually challenging these side-projects to show relevance at workshops. The mix of central and distributed innovation proved fruitful, and several initiatives arising from this process appear to be the keys to ongoing work by the research network beyond the life of GEOIDE, who funded the GeoEduc3d project.

Finally, the results of science-of-team-science studies, although at first perhaps seen as outside of the interest of specialized researchers in geomatics, augmented reality, and game design, are in fact central to how we conceive of new projects, manage those projects, and in fact manage science in the future. Network-based science is now common, and will likely be the rule for the most important sub-network we engaged with in this project, our students.

Acknowledgements

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Does it make any difference to organize multi-disciplinary, multi-institutional projects? What is the value-added by the network form of collaboration? These questions are frequently asked but rarely answered.

Over the past fourteen years, the **GEOIDE Network** *(Geomatics for Informed Decisions) has mobilized 84M$ in research effort across Canada. All participants in the Network over this period have a story to tell; and this book is the collection of these stories. Participants in the network have collaborated to contribute their viewpoints and their assessments. Some come from long-term participants whose activity spans the whole fourteen-year history, while others come from one particular moment, at the start or the end.*