Chapter 7
Gamification of SSI's as a Science Pedagogy: Toward a Critical Rationality in Teaching Science

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7.1 Introduction

The complexities of education in contemporary society may be viewed in terms of responses to vocational, citizenship, and individual goals (Winch 2004). Evidence of complexity may be interpreted from vocational contexts where high levels of knowledge, skills, teamwork, and analytical ability are required of contemporary workers. On citizenship, the maintenance of modern nation states requires citizens to be critical thinkers in a context of conflicting interest groups that adds to the uncertainty and complexity of social reality. At an individual level, people need to make choices about their own life goals, and the pathways for reaching those goals, within the context of their vocation and their being a part of society. This societal context of uncertainty and complexity provides grounds for an argument that educational goals need to include some form of *critical rationality* to be explicitly taught and learned in schools (Winch 2004). In science education critical rationality, commonly known as *critical thinking*, involves the ability to evaluate evidence and arguments from a range of scientific, social and ethical perspectives (cf. Simonneaux 2014; Winch 2004).

We suggest that the integration of gaming with authentic contexts involving socio-scientific issues ought to be an important part of science education because gaming enables spaces for student autonomy and critical rationality to become a possibility. The gamification of socio-scientific issues as a pedagogical approach in teaching school science is an emergent strategy. It may involve digital technologies (Psotka 2013), but typically includes a blended approach to gaming across virtual and real (physical) spaces. Daniel Dziob (2018, p. 2) points to the integration of

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these spaces "as game mechanics, esthetics, and game thinking" may be applied to learning science within non-game or authentic contexts. In the context of this chapter we seek to illustrate this integration between elements of gaming, science and technology curriculum, and pedagogical strategies that embrace critical rationality as an essential objective.

Throughout this chapter, we make a case for the gamification of socio-scientific issues as a form of science pedagogy that may shift the focus of teachers and students toward a critical rationality in school science. We establish this case by explaining our own teaching experiences with gamification of SSIs in preservice teaching courses. Our focus in this chapter is around two questions:

1. What strategy and pedagogical tools may assist teachers to become producers of SSI games for implementation in school science contexts?
2. What are the possibilities for our strategy to contribute to critical rationality as an explicit aim in science pedagogy?

7.2 Motivation for This Work

As science educators the gamification of SSIs as a science pedagogy enables us to make science learning relevant and engaging for students. This outcome is achieved by not only connecting science to authentic contexts, but also enabling students to take meaningful gamified actions that are determined by the direction of student interest rather than being teacher directed. Gamification enables the teaching of *activist science* in both the exploration of science and in the meaning and application of science as a human endeavour. The project described in this chapter was initiated by the actions of Alberto in 2011 when he decided to introduce the notion of *Alternative Reality Gaming* (ARG) to a graduate preservice science teacher course focusing on curriculum planning. In the educational context of this study, alternative reality gaming involves an interactive storyline with the real world as its platform and uses a multi-media, multi-technology approach to deliver the story that can be altered by its players. It is played in real-time and can shift across virtual and real spaces where players solve story-based challenges and collaborate beyond their workgroups or classroom to take action in shaping reality. ARG is well suited for activist approaches to science education (cf. Bencze and Alsop 2014, also see Chap. 5 in this book).

Alberto It was around 2010 when I became aware of ARG through social media. I had been a gamer since my pre-teen years, mostly playing video arcade and console games. ARG caught my attention as something novel; the notion of blending a virtual world with real world experience was instantly seductive. Initially, following games mostly based in the US, I observed the basic game-play and then began reading (McGonigal 2011; Szulborski 2005) more about this novel and promising gaming genre, and subscribing to ARG forums like ARGNet (2018). Eventually I managed to enter a game close to the start of play. The game was set in the present and it involved a secret laboratory that was conducting human experiments under the guise of genetics health service. Characters within the game-world included staff working in the facility as scientists and assistants, and patients who had been subjected to suspicious treatments. The game characters interacted to unravel the storyline through the forum and players could participate by reading or contributing to discussion with the characters. Although virtual interactions were globally accessible from an electronic forum site where players and game characters interacted, real elements such as telephone calls and drop sites for material clues were only available to US players. For several weeks, bridging the time-zone divide, I eagerly logged in and contributed to the virtual dimension of play (players in the US received well-designed game artefacts in the mail, collected game clues at drop-zones, and also engaged in telephone calls). As the game was based in the US, none of the real-world dimensions were accessible by me. Nonetheless, play was consuming and the sense of anticipation each day to see how this unwritten story was unfolding become entrancing. The possibility of influencing the play by contributing through various online fora was intoxicating. I even created a fake Facebook profile for one of the characters (played by a player somewhere else in the world, whom I did not know) and started throwing in red herrings for others to deal with. There is no other game, in my experience, as unique as ARG. End-game took place early one morning (EST) in the online forum that supplied the main medium for solving game clues and facilitating character/player interactions. Anyone who missed that final forum was not privy to the game ending. Any player accessing the end-game script on the forum after the fact could not experience the sense of suspense and excitement generated by this in-the-moment aspect of game narrative.

After this experience and further reading, Jane McGonigal's educational ARG, *World Without Oil (WWO),* led me to consider more directly how I could use these concepts in my teaching. At the time, I taught two preservice science teacher courses for second and third year students: *Science, Technology, and Society,* and *Science Curriculum Studies.* The first included content related to SSI and social debates and implications for science (STS). In the second, preservice teachers learnt about high school science curriculum design. Forever the opportunist, I began exploring the possibilities of ARG for SSI/STS and in the development of engaging curriculum design in the second course. Aside from close parallels between ARGs like WWO and SSI/STS curricula, these games involved (at the time) extensive use of Web 2.0 technologies and social media; technologies I was seeking to embed in my teaching. Despite some enthusiastic claims about current generations, experience taught me that few of my preservice teachers really knew about these technologies, let alone how to adopt them meaningfully in teaching.

These explorations led to writing an article focusing on the possible integration of ARG into school and preservice science teacher education (Bellocchi 2012).

Some of the structural features of ARG surfaced complex ethical questions for my university teaching, which informed suggestions for school teaching. In some ways, I felt that the idea (only a short 7 years ago) was too far ahead of its time: Better access to social media technology in schools and university would be required; policies about use of software would need revision in the university; preservice teachers were very unfamiliar with ARG, location-based gaming, and mixed-reality.

In James, I found a willing participant. Not only did he entertain my game-based exploration of curriculum in the science curriculum course, but he adopted the ARG game framework in the design of his science curriculum assessment task. This became one of the examples I reported in my article (Bellocchi 2012). Having completed his doctoral studies under my supervision, chance would have it that James took over the teaching of my courses as I embarked on a 3-year research fellowship. His enthusiastic uptake of the gaming ideas I had offered his class were extended when he became the STS and curriculum studies lecturer. The year was 2016 and, given the fast pace of gaming progress, mixed-reality, ARG, and location-based games had received greater public attention.

James As a preservice teacher in Alberto's course I found the notion of ARG as offering a provocative approach to planning that connected well with context. It also provided an opportunity for me to make choices in the direction of my learning. With that opportunity I took a risk in refining a basic framework suggested by Alberto for developing a gamified scenario to situate a plan for teaching a secondary biology class. This was the start of my interest in the gamification of science education.

7.3 Theoretical Framework

Alberto In 2012, under the leadership of Steve Ritchie, a project focused on emotion and SSI in middle-school science was successfully funded. Based in Sadler's (2009) definition, I understood SSI to be social issues that relate to science and contain an ethical or moral dimension (e.g., food shortages, global warming, oil crisis) that could be explored from a scientific viewpoint or having embedded scientific/technological dimensions, problems, or prospective solutions. This view of SSI was also based in some foundational concepts from the STS literature. My approach to ARG, particularly in the STS course I taught, was framed against these scholarly traditions. Some ARGs (e.g., WWO) I was studying at the time were very closely aligned with the SSI/STS academic literature. For instance, WWO explored what social and environmental implications would arise once the last drop of oil had been consumed. Games like this offer ideal models for exploring ethical and moral dilemmas of, for example, government decisions on policies around the oil crises, or climate change a two examples. My preservice teachers developed assignments based on these principals and their own further research.

James By mid-2016 I was teaching and coordinating some of Alberto's courses, and by that time my approach to SSI's was strongly informed by Simonneaux's (2014, p. 104) "Socially Acute Questions" (SAQs). The notion of SAQs as a means for defining SSIs requires the science educator to embrace pluralism in epistemic approaches by engaging in risk and controversy, drawing upon contextualized data and accepting the construction of knowledge as multi-layered and distributive (Simonneaux 2014). For me, this requires an appreciation of non-scientific understandings of SAQs including positions informed by ethics, values and ideologies as well as conventional scientific thinking.

The adoption of SAQs situates my teaching toward inter-disciplinarity between the sciences and the humanities where preservice teachers are encouraged to adopt critical approaches to decision making and activist approaches in the production of outcomes in their course assessment. Simonneaux (2014) described this approach to SSI's as *hot* educational objectives where philosophical values, scientific and political citizenship could be enacted as the vehicle for learning science as an enacted practice. This theoretical approach to understanding SAQs and activist interdisciplinary thinking was a feature of my explicit teaching with preservice science teachers in the first half of their semester-long course.

7.4 Design Case

The design of this study is grounded in a cycle of design thinking and reflective practice where Alberto and I were participant/researchers exploring our own understanding and learning about the gamification of SSIs, and how this may be best taught in an initial teacher education (ITE) environment. This design has reflected our approach to both teaching and learning as teachers through ongoing modifications to our practice and professional dialogue over time. The challenge at the heart of this design process is to develop a pedagogical strategy and practical tools to enable teachers to conceptualise a SSI game and to develop the game for implementation in school science contexts.

7.5 Methods of Data Production

Our methods of data production in this study comprise teaching reflections and artefacts collected through our work in designing and delivering teaching. For Alberto, his journal article (Bellocchi 2012) and a conference proceedings paper (Lloyd et al. 2012) document research activity and data analyses related to the ARG model used in his teaching. Data sources include his teaching reflections, Wiki, blog, and discussion board extracts, interviews with preservice science teachers, and assessment items from two courses. For James, his teaching reflections include reflective notes, the assessment item that he wrote as a student of Alberto, and his PowerPoint materials and planning notes from the courses he taught.

7.6 Findings

Our findings from this design thinking process are summarised here as three episodes of development: Alberto's teaching in 2011, and James's teaching in 2016 and 2017. The first two episodes show the unfolding of an ARG architecture to design the process of a game and the final episode combines the ARG architecture with a unit planning framework to integrate the science curriculum with technology, society, learning experiences and assessment methods.

7.6.1 Episode 1: Immersion into the World of Alternate Reality Gaming

Alberto Our gamification approach (i.e., the one James was exposed to as my student) drew directly on the ARG framework (Bellocchi 2012). *TINAG, This is Not a Game*, is the foundational principle of ARG developed originally by Szulborski (2005). For a game to proceed, players willingly suspend their knowledge of being in a game. ARGs also require a *puppet master* (i.e., game staff); a role that I took on when sharing the idea with my classes. Puppet masters are responsible for creating the *curtain;* a metaphor used to capture the separation of players from the puppet master's true identity as the architect of the game. Curtains could include websites designed to look like some artefact in the game. For example, in a game involving some medical theme, the curtain could be a website designed to look like that of a hospital at the centre of the game. The puppet master's role is to create an environment that upholds the TINAG principle by means of a curtain. This includes playing a major character or a lead character who initiates play, which begins with a *rabbit-hole.* Drawn from Lewis Carroll, rabbit-holes are the entry point of the game that allow players to become lost in a labyrinth of possibilities. Rabbit-holes could be online fora where clues that lead to a website (e.g., the curtain) are planted, or a QR code on a poster that leads you to a game clue. A moment's perusal of ARGnet will reveal the multiple and unique ways in which a rabbit-hole is created. Given the potentially disorienting nature of ARG (rabbit-holes can meander somewhat), *trailheads* are used to keep players on-track with the intended and emerging storyline, game clues, and player discoveries. A trailhead is also a deliberate clue left by the puppetmaster to keep the game play advancing. Online forums offer great locations (i.e., virtual spaces) for trailheads.

I used a WordPress™ page as my rabbit-hole and the university online learning management system (LMS), Blackboard™, discussion board as the trailhead.

A video with me dressed as an older farmer introduced the SSI problem, and during face-to-face teaching, my preservice teachers then explored the scenario. Challenges were posted on the discussion board that forced my preservice teachers to engage with a range of Web 2.0 tools in the LMS. One involved locating an engaging resource in the library's curriculum section, photographing it, and then creating a Wiki page for sharing with other members of the class. In addition to posing the challenge of learning about Wiki's (i.e., functionality, purpose etc.), this task also demonstrated how preservice teachers could find engaging ways for sharing resources; modelling practice they could adopt in future classes. Each challenge could only be completed through self/peer-teaching of the technology involved (e.g., blog, wiki). This strategy again involved my modeling of teaching practices that could be adopted with high school science classes.

7.6.2 Episode 2: Developing an ARG Architecture

James In 2016 I was presented with an opportunity to teach an undergraduate course for preservice science teachers using a STS approach for teaching around SSIs. The assessment for that course involved the development of a course plan in small groups, followed by the presentation of a short lesson from the course plan on an individual basis. I identified this as an opportunity to introduce the ARG strategy that I had previously applied in my work with Alberto in 2011. To illustrate the ARG strategy I developed a flowchart that I have called an ARG Architecture as shown in Fig. 7.1.

The initial ARG architecture shown in Fig. 7.1 shows the basic features, which may play out through an iterative process depending on the duration and complexity of the game. This architecture consists of the following features:

(a) *Puppet Master*. The role of the puppet master is to plan, set rules and manage progression of the game, knowing that players will take the game in different directions. The teacher as puppet master is a good way to start because the future options for game direction can be managed so that various learning objectives may be embedded within the pathways that students choose to explore.
(b) *Rabbit-hole.* The start point for the game is the rabbit-hole, which should be playful, fun, and a little eccentric, as a way of enticing students to get involved and stimulate their imagination. The puppet master could introduce the rabbit-hole with a role play, which may involve brief purpose made video. In the game I developed called *Cool and Covered* my goal was to promote design activities to develop skin cancer prevention solutions. I used a cartoon character called *Sid the Seagull* who is well-known in Australia as the mascot for a skin cancer prevention campaign. I was able to use online videos made by Cancer Council Australia (2018) with this ready-made character to introduce the SSI of skin cancer prevention. I then extended beyond the introduction by Sid the Seagull

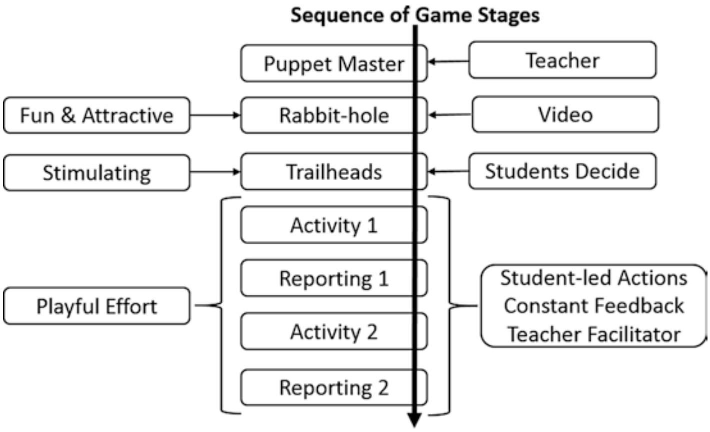

Fig. 7.1 Initial ARG Architecture

with a collection of images to introduce issues of design and shading in public spaces, the design of clothing and cultural practices in Australia that challenged the skin cancer prevention message. These challenges provided opportunities for game participants to appreciate that everyday decisions are not made on scientific grounds, and that the interconnections between what people might know and how they may behave need to be understood from inter-disciplinary perspectives.

(c) *Trailheads*. With my preservice teachers I provided a very open-ended approach with the trailheads, which were revealed sequentially as (1) explore the problem, (2) design a solution, and (3) tell your community. For example, in the trailhead of *explore the problem* each team was to explore one of the sub-issues they identified in the rabbit-hole and come up with a justification and a plan for taking action. I purposely allowed them to explore and find a sub-topic of their choice because this situated to gain an appreciation of the broader topic while selecting one as a specific area of interest. At that point they would report back to the puppet master, and receive points for that stage of the game followed by instructions for the next stage, which was *design a solution*. From an educational perspective these points of interaction with the puppet master are stages of formative assessment, feedback, reward and further guidance. The degree of detail in guidance for each stage will vary with the students and the context, but opportunities for students to maximise creative input and autonomy should be a priority. The number and sequence of trailheads could also be varied and should enable an iterative cycle of engagement throughout the game.

More structure in the storyline would be necessary with children in primary or secondary school contexts. Greater emphasis would be required on the characters such as Sid the Seagull with opportunities for students to develop their own characters within the game. For example, specific problems could be identified such as helping Sid to design a more fashionable hat, or helping Sid improve the shade areas in the playground. To shape the planning of ARGs to this level of analysis the earlier architecture in Fig. 7.1, was further developed in to a planning framework, as discussed in the following section.

7.6.3 Episode 3: Planning Framework for an ARG

James's Teaching 2017 In 2017 I taught another course to undergraduate preservice teachers entitled *Science Technology and Society* (STS), and developed a more detailed approach towards integrating the game with the formal school curriculum. The first half of the semester focused on preservice teachers understanding the principles of STS education and the nature of socio-scientific issues. As part of the reading and teaching, students engaged with the idea of SAQs and interdisciplinary approaches to teaching science (cf. Simonneaux 2014).

Students developed and explored a SAQ that involved getting out of the classroom and interviewing a scientist about the issue. In this context I adopted a broad notion of the term *scientist*, which enabled preservice teachers to explore issues by engaging with people such as ecologists, paramedics, nurses, veterinarians, science related policy makers, geologists, medical practitioners, research scientists, environmental activists and so on. Some of these people were part of the preservice teachers' existing networks, while other scientists were engaged by preservice teachers expanding their networks. This expansion of networks was empowering for preservice teachers as it gave them self-confidence in talking to people outside of their field and it also broadened their own conceptualization of who counts as a scientist. As an example, I recall one primary school preservice teacher who managed to get an invitation to a Department of Health seminar addressing the issue of medical marihuana. That preservice teacher was able to discuss the issue with medical practitioners and policy makers. I was very impressed with the activism of my preservice teachers, evident in the way they acted on the opportunities provided to them.

The second part of this unit involved preservice teachers developing a plan to teach the issue at the focus of their SAQ and in this part of the course I introduced the gamification framework for course planning. I taught this framework over 4 weeks where I explained the reasoning of my planning, demonstrated it with a real issue, and then supported preservice teachers to develop their own plan for a gamified course design in a school context. The conceptual overview of the ARG and course planning framework is shown in Fig. 7.2.

The structure of Fig. 7.2 shows the planning process I undertook in developing a sample game for my students. The sequence of the game flows across the top row from left to right. Consistent with the earlier structure, the game is initiated with a rabbit-hole that aims to spark student interest. This starting point leads to trailheads giving students an opportunity to choose a topic or a direction for their initial activ-

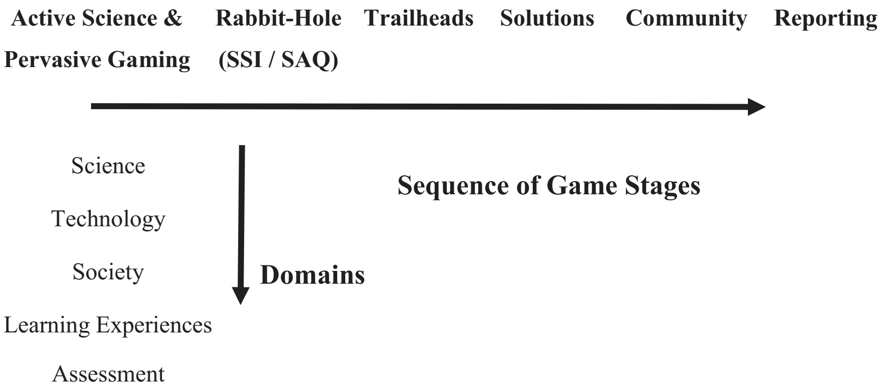

Fig. 7.2 ARG and Course Planning Framework

ity. From here students can explore, inquire, develop and engage with others in the classroom, beyond the classroom or in their after-school community.

I explicitly connected the TINAG rule, introduced earlier by Alberto, with the notion of activist science because the SAQs are real issues about which students could take real action. To enhance this activist science/TINAG factor I added community engagement as one of the cyclical stages of the game planning framework. Taking the game out of the classroom was therefore an important element that students could develop and report about. As students report back to the puppet master it is possible for new trailheads to be explored making gamified learning an iterative experience that jumps back and forth across the stages described in the first row of Fig. 7.2.

To scaffold the planning process for my preservice teachers I developed planning questions for each stage of the game across the domains of science, technology, society, learning experiences and assessment. A summary of these questions is shown in Table 7.1. As an example, to design the *rabbit-hole* stage for the *science* domain I asked questions such as *what is the SSI/SAQ at stake here?,* and *What key science concepts are the focus of the game?* These questions were designed so that preservice teachers could work methodically through the ARG and Course Planning Framework. This process shaped their thinking toward a cohesive summary of the salient features of their game in the context of teaching, and the specific curriculum objectives. This level of thinking and planning, in response to previous feedback, was necessary to ensure preservice teachers would be prepared to respond to future students, and to guide the preservice teacher as both teacher and puppet master. It also enables planning of logistical limitations that may restrain student choices such as the type and amount of materials and equipment available in any particular school.

Cool and Covered: Designing Out Skin Cancer *Cool and covered: Designing out skin cancer* was the topic I used to illustrate the gamification of teaching in science

Table 7.1 Planning Questions

Active Science & Pervasive Gaming	Rabbit-Hole (SSI/SAQ)	Trailheads	Solutions	Community	Reporting
Science	What is the SSI/SAQ at stake here? What key science concepts are the focus of this game?	What science inquiry topics are you directing students toward?	What solutions are feasible for students to develop?	What opportunities are there to build community involvement?	What avenues are available for students to report their outcomes?
Technology	What technologies are involved in the SSI?	What science technologies are involved? What re-design opportunities are possible?	What materials and technologies will students require to implement solutions?	How will students engage the community with their technologies?	What changes to technologies are possible as outcomes of the game?
Society	What are the social, ethical, emotional, economic aspects of this issue?	How might these social, ethical, emotional, economic aspects be addressed?	What social solutions are feasible for students to implement? How could community, school, family contact be implemented and evaluated by students?		How could social impacts be evaluated and then reported by students?
Learning experiences	Develop a rabbit-hole to entice student participation and introduce the topic and context of the game. Determine pedagogical technologies you will use.	What are the possible pathways students could take in terms of experiences in science inquiry or technology design? What are the resource and time constraints? How will student choices be scaffolded?		What are the possible community links that students may want to access and how can these be incorporated into science inquiry, technology design solutions and/or science education beyond the classroom?	In what format will students report? What scaffolding is needed to enable this reporting? What ICT's do students have access to for the purposes of disseminating reports?
Assessment How will each part of the game be scored & linked to assessment?	Define and explain the goals of the game? How does a student win the game?	What guidance, feedback and scaffolding might you need to provide at this point?	What guidance, feedback and scaffolding might you need to provide at each of these stage? For each stage, should the student cycle through another trailhead?		

for my course in 2017. The game I modelled was aimed at the Year 8 and 9 Australian Curriculum (for students aged 13–14 years) where science topics such as energy, materials and cell biology could be integrated with the SAQ and related social and ethical issues. The SAQ at the focus of this game was:

> *How could we design technologies in our everyday life to eliminate the incidence of skin cancer?*

In Australia, skin cancer continues to be a leading cause of death, despite many years of public education campaigns. This SAQ is a question being investigated within the QUT School of Public Health in collaboration with the Creative Industries Faculty. As the rabbit-hole for this game, I introduced the topic with a video that I embedded with supporting assessment documents in a Padlet™ page. Padlet™ is a university supported cloud-based technology designed to elicit online interaction between students. The rabbit-hole is quite a brief presentation and led preservice teachers to a number of trailheads as different pathway choices that could be explored. I located links to the trailheads in my Padlet™ and these links took students to different pathways that they could develop further in Microsoft Sway™ (a digital story telling app). To play the game, preservice teachers created a copy of their selected trailhead in Microsoft Sway™ and this became the online vehicle for recording gaming events as the story of their game-play unfolded over time. When students engaged with offline activities they were able to record these events through images, notes, reports and so on within their Sway™ document.

Within these trailheads preservice teachers were guided toward sun protection *technology design choices* by encouraging them to think about potential technologies such as sunscreen, hats and clothing materials, built shade, and types of building materials that could provide cover by blocking or reflecting UV light. Importantly the design element of these technologies would not only account for science and technology considerations but also perspectives reflecting social, ethical, aesthetic and emotional dimensions to successful design. I provided this level of guidance to enhance their appreciation of the complexity of this problem. For example, hats have been around for centuries, so it is not a lack of hats that prevents people from wearing them. Design choices needed to reflect broader cultural issues so that student designs of protective technologies would promote end user engagement. At practical level, I also needed to ensure that choices were aligned with the resources I have available in the Faculty's science lab, which reflects the resources of a typical secondary school lab in Queensland, Australia.

In the context of this game topic I am able to demonstrate science inquiry possibilities such as testing the impact of ultraviolet (UV) light on different analogues for skin cells. For primary school contexts I demonstrate the use of beads that change colour when exposed to UV light. For secondary students, we are able to incubate non-pathogenic varieties of normal flora from human skin such as *Staphylococcus epidermidis*. For this context I had preservice teachers make and test sunscreens with recipes obtained from the internet compared with commercial sunscreens. I have also had preservice teachers test the protective quality of different clothing materials, based on material type and colour. Other suggested examples could include shade surveys on campus, or addressing issues such as the poor design of our local bus shelter at the front of the university. These examples of science and technology inquiry may also involve technology design solutions and social research about aesthetics or localised cultural practices that could be developed as further trailheads.

In this particular course my focus was on the planning of the game for a school context, and for this reason my preservice teachers did not fully implement these suggested activities. However, in other courses, I have implemented these exact activities, and on this basis I have tested my capacity as a teacher to engage preservice teachers in multiple inquiry and design activities at the same time. There is definitely a level of self-confidence that a teacher needs to develop to be able to deliver such bespoke science learning experiences in the one classroom. This experience reinforces my commitment to ensuring preservice teachers are equipped to plan in detail, by effectively *gaming-the-game* before presenting it in class as the puppet master.

7.7 Discussion

Throughout this chapter we have presented our experiences with our design and reflective evaluations of alternative reality gaming (ARG) as an approach to planning and teaching science through the lens of socio-scientific issues (SSIs) or socially acute questions (SAQs). This study is an historically situated reflective account of our own teaching experiences. Our presentation of these accounts evidences a chronological and cumulative achievement of an ARG Planning Framework that has unfolded through our teaching experiences. The design has unfolded contemporaneously with our teaching from the historical sequence, and periods of discontinuity, of our shared teaching experiences and teaching interests over the past 7 years. The strength of our ARG planning model is in the way it is shaped by our professional growth as science educators and science education researchers. Alberto's original passion for gaming, for integrating technology with his teaching, and for making science education engaging provided the impetus for the initial growth of this teaching focus. In contrast, James was not a gamer, but could see the value in the ARG concept for engaging students in the complexity and uncertainty of socio-scientific issues. The current location of this project enables us to propose an ARG strategy, a small collection of planning tools and experientially grounded advice. In response to our first research question we offer this chapter to assist teachers who may choose to become ARG producers, or choose to engage their students in producing ARGs.

There is much more to be done in the gamification of SSIs as a science pedagogy, particularly in the development and integration of digital technologies such as augmented and virtual reality. This will only become possible as more teachers become involved in game production, alongside software designers so that the expertise of educators and coders can be fully integrated. Such interdisciplinary approaches also need to include the education of teachers so that science teaching is led with SSIs or SAQs. To achieve the hot end of the activist science spectrum, teachers need to be comfortable in teaching around and through controversy, as well as the uncertainty and complexity that arises when adopting multi-disciplinary perspectives with students. In addition, and consistent with constructivist approaches to learning, teachers could invite students to create their own games with or without the support of game designers. Considerations that students would need to make as puppet masters would support their critical thinking, which may be enhanced if the games designed by students are played by peers. As peers engage in game-play and contribute ideas and solutions to problems about, for example, an environmental disaster game, the puppet master students would have to make choices in how to steer the game through their interactions with players. Consideration of the environmental problem, including science and social issues would be required in their critical decision making. Teachers could ask classes to reflect critically on the SSI after a game has been played. Even if students were to play existing games, such as WWO, this kind of reflection could support a critical pedagogy.

What we are suggesting here is the need for teachers to be educated and confident in the practice of critical rationality (Winch 2004). Simonneaux (2014) suggests that the ways in which SAQs are addressed in science teaching typically reflects the rationality of the teacher and that this may also vary from topic to topic depending on the teacher's interests. This is an interesting observation by Simonneaux (2014) because Winch (2004) suggests that critical rationality is context specific and may also be variable in terms of how strong a teacher may want to exercise their own autonomy for critical thinking. For these reasons, while gamification opens the possibilities for students to exercise their autonomy, it is not the only factor that is influencing the degree of critical rationality possible in the classroom. As the puppet master the teacher's sense of autonomy and appetite for critical rationality may constrain the full potential for games to produce a science pedagogy with strong elements of critical rationality. We point to the earlier suggestion of handing over the role of puppet-master to students. By having students' create their own games, they would be engaging with the science while removing the teacher's sense of autonomy as a potential constraint. In this sense the game truly becomes the science pedagogy.

7.8 Implications for Teaching and Research

Our approach in the gamification of SSIs as a science pedagogy has de-emphasized the use of ready-made digitalized games, and instead focused on the application of game thinking to course planning and the integration of common technologies, curriculum, game elements, and authentic socio-scientific contexts. The limitation of this approach is that digital-based gamers may be disappointed with what we offer, but we do welcome greater collaboration between game coders and educators so that digitized games are meaningful and impactful from curriculum perspectives.

The strength of our study is its emphasis on planning across the stages of the game that are integrated across science curriculum, technology, diverse societal perspectives, and the pedagogical features of learning experiences and assessment. The proposed ARG Planning Framework articulates a start point for further research and teaching practice that may stimulate teacher interest in the development of new gaming opportunities in the teaching of SSIs.

A further dimension to this study has been the integration of critical rationality, which is highly dependent on the teacher's role as the puppet master, but could be enhanced by engaging students in that role. We have suggested that gamification of SSIs/SAQs does increase the possibility for student autonomy and in this sense gamification provides a distinct structural possibility for critical rationality to be actively pursued as a pedagogical aim. In light of the current global challenges to science around notions of what constitutes valid knowledge, the time for high quality education in the practices of critical rationality have never been so important to a cohesive and forward thinking global society. Clearly a science pedagogy of gamification as a vehicle for critical rationality in science education, is an area that is ready for further technological development, teacher co-production, and practice-focused research.

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