Open source software and design-based research symbiosis in developing 3D virtual learning environments: Examples from the iSocial project

Abstract

Design-based research (DBR) and open source software are both acknowledged as potentially productive ways for advancing learning technologies. These approaches have practical benefits for the design and development process and for building and leveraging community to augment and sustain design and development. This report presents a case study of a software project using a design-based research approach and Free/Open Source Software (FOSS). The project is developing a 3D virtual learning environment (3D VLE) for youth with autism spectrum disorders (ASD) to develop social competence. The potential of FOSS when implemented within a DBR framework is highlighted using examples from our process of designing and developing the 3D VLE, and the design principles resulting from our processes for fostering social interaction in the medium are presented. Using findings from five studies performed over the course of our DBR process, this article illustrates how the flexibility and community features of FOSS fit with the iterative nature of design-based research to benefit the development of our project and to forward understanding of how to support social interaction in the 3D VLE for individuals with ASD. Limitations of the approach are discussed.

1. Introduction

This article is a work with two emphases. One emphasis is on the fit of free and open source software (FOSS) for conducting design-based research (DBR). The other is on individuals with autism spectrum disorders (ASD) using multi-user three-dimensional virtual learning environments (3D VLE) for social competence instruction. We forward
the general argument that the open and flexible nature of FOSS strongly complements the principles of design-based research DBR and contend that the combination of the two for instructional systems design represents a symbiotic ecosystem in which design theories can be readily advanced and innovative learning technologies can be designed, developed and sustained in a way that benefits all involved in that ecosystem, from learners to instructors and from designers to developers. We illustrate and support this argument using examples from our own project, a multi-year effort to design and develop a 3D VLE focusing on social competence instruction for individuals with ASD, as well as with findings from multiple usability and usage studies we have performed using this system. Focusing on expansions to curriculum, enhancements to virtual world design and software tools to support learners' social interactions with others, we illustrate how we have leveraged DBR as a general methodological framework to guide our design, development and evaluation, how we have systematically used findings from usability and usage studies to address unforeseen issues that affected social interactions in the 3D VLE and how we have improved these designs over multiple design and development iterations.

This article is primarily situated in the field of instructional technology and illustrates how FOSS allowed us to maintain extreme flexibility in designing and deploying our instructional system as we were performing DBR. The processes and findings in this regard will be of interest to instructional technologists, designers and developers interested in leveraging FOSS and DBR in their projects. However, at the same time, the 3D VLE that we have created is designed for individuals with ASD, and, as such, is situated in the growing literature supporting the use of innovative technologies
for individuals with special needs. We feel the design principles that have emerged from our design-based research will be of particular interest to those working on developing technology interventions for individuals with ASD, but also to a more general special education audience who might be interested in learning about how others have approached and overcome real-world challenges pragmatically.

1.1. Background

The topic of online learning conjures images of course management systems like Blackboard and Sakai, in which course materials are made available to students, students can submit their assignments to instructors and the class can discuss topics using discussion forums, text chat and in some cases audio and video conferencing. Given remarkable enrollments in online courses (Picciano & Seaman, 2008) and predictions that over 10% of all K-12 classes will be offered online by 2013 (Christensen, Horn & Johnson, 2008), it is clear that educators and educational institutions see enormous value in online learning. However, course management systems are but one medium to enable learning via the Internet. Other mediums such as multi-user virtual environments (MUVEs), virtual worlds and serious games are gaining traction as viable learning technologies in educational institutions (Dalgarno & Lee, 2010; Livingstone, Kemp & Edgar, 2008; McLellan, 2004). Arguably, the affordances of these technologies can provide for more social learning than traditional CMS, which can be socially isolating (McInerney & Roberts, 2004).

Researchers in general education are exploring a variety of MUVEs in order to learn how to best leverage the characteristics and capabilities of the medium to impact learning outcomes. For example, applications built using MUVE technology such as
Quest Atlantis (Barab, Gresalfi, Ingram-Noble, Jameson, Hickey et al., 2011; Barab, Sadler, Heiselt, Hickey, & Zuiker, 2007), River City (Ketelhut, Nelson, Clarke & Dede, 2010; Dede, Clarke, Ketelhut, Nelson, & Bowman, 2005) and EcoMUVE (Metcalf, Dede, Grotzer, & Kamarainen, 2010) are showing the potential of MUVE technologies as teaching and learning tools. Given the promise of learning benefits such as enhanced motivation and engagement attributable to media like three-dimensional virtual learning environments (3D VLE), MUVEs and serious games, interest is growing.

This interest reaches beyond the field of general education. Researchers in special education are also beginning to look to these media as viable instructional technologies (e.g., Cheng & Ye, 2010; Wallace, Parsons, Westbury, White, & Bailey, 2010). Although research in this area is still in its infancy, some promising studies that leverage 3D VLEs for delivering social competence training and instruction to individuals with autism spectrum disorders (ASD) have begun to emerge. ASD is a pervasive developmental disorder which is manifested by impairments in social interaction, communication impairments and restricted, repetitive and stereotyped patterns of behavior, interests and activities (American Psychiatric Association, 1994; Wing, 1997). In particular, individuals with ASD experience severe difficulties with social interactions, which can result in them having a higher likelihood to exhibit problematic social behavior and become socially withdrawn (Bacon, Fein, Morris, Waterhouse, & Allen, 1998; National Research Council, 2001; Weiss & Harris, 2001). Failure to address these social deficits can ultimately affect quality-of-life for these individuals, leading to low self-esteem, impaired self-concept and depression (Myles & Simpson, 2002).

A number of potential benefits have been attributed to 3D VLE-based instruction
for individuals with ASD such as predictable task repetition, the potential to adapt to the individual and control of input stimuli (Parsons & Mitchell, 2002). 3D VLEs offer the potential for role-playing in a realistic and compelling environment that may be intrinsically motivating, safe and completely controlled (Dautenhahn, 2000; Parsons, Mitchell & Leonard, 2005; Rizzo et al., 2000). Indeed, individuals taking part in instruction in 3D VLEs have shown potential learning gains (Mitchell, Parsons, & Leonard, 2007; Moore, Cheng, McGrath, & Powell, 2005; Parsons, Leonard, & Mitchell, 2006), although it is not yet clear the degree to which skills learned in the virtual world generalize to the physical world. Some research indicates that individuals with ASD are able to generalize skills learned in the 3D VLE to training scenarios using videos (Parsons, Leonard & Mitchell, 2006; Mitchell, Parsons & Leonard, 2007) and that they accept that what happens in immersive virtual environments could happen in real life (Wallace, Parsons, Westbury, White, White, & Bailey, 2010). However, the issue of generalization remains a significant issue, both in special and general education (Dalgarno & Lee, 2010). Nonetheless, given the prospect of social interaction in virtual contexts which mimic the real world, in environments in which risk is negligible, and mediated by technology which has the capacity to be deeply engaging and motivating, 3D VLEs show promise as a viable instructional technology for individuals with ASD.

1.2. The Three-Dimensional Virtual Learning Environment

According to the Twenty-fifth Annual Report to Congress on the Implementation of the Individuals with Disabilities Education Act (2003), identification of and intervention for social competence deficits needs to be a focus of instruction in order to help individuals with ASD achieve increased success and independence. Our project
(Authors, 2010a; Authors, 2010b) is an Internet-based, three-dimensional virtual learning environment to support social competence acquisition for youth with ASD. The purpose of developing this system is to expand access to specialized training for developing social competence from a local program requiring physical access to a national program that can be accessed via the Internet. The project seeks to translate a traditional face-to-face curriculum of over 30 hours of training in five units (with six 45-minute lessons per unit) of instruction into a format that is amenable for delivery in a 3D VLE. The face-to-face version of the curriculum (Social Competence Curriculum for Adolescents: SCI-A) has demonstrated impact for improving social competence (Stichter et al., 2010) and specifically targets the following social competency areas: 1.) awareness of emotion, 2.) facial processing, 3.) non-verbal communication, 4.) theory of mind, 5.) perspective taking, 6.) conversation skills and 7.) problem solving (Solomon et al., 2004; Stichter, Randolph, Gage, & Schmidt, 2007; Webb, Miller, Pierce, Strawser, & Jones, 2004). The SCI-A curriculum is based on the same premise as cognitive behavioral interventions (CBI) that thoughts, emotions and actions are inextricably linked and that changing one of these necessarily produces changes in the others (Gresham, 2005). The targeted skills are not taught discretely or in isolation but, instead, are scaffolded from low- to high-complexity with the more complex skills building on less complex skills learned in earlier units.

In the 3D VLE, participants in groups of four to six take part in curriculum activities by logging in to our virtual world over the Internet and interacting with an online guide (OG) and other participants in the environment. They are represented as avatars and communicate verbally using audio speech and non-verbally using text chat,
avatar gestures and keyboard/mouse controls. Participants perform curricular activities which promote the discussion of social competence collaboratively with the OG and allow for the negotiation of social norms between users. Activities range from highly structured, instructor-centric activities to more naturalistic activities which are more student-oriented. Examples of more structured activities would be participants taking part in a trivia game or a board game. A less structured activity would be participants being given the task to interactively build a restaurant in the virtual world. Participants take on roles such as menu manager or interior designer and take part in reciprocal discussions about the color, architecture and food options of their restaurant while they build the virtual restaurant. The OG helps to keep the lesson on track and ensure participants are adhering to the principles of reciprocal conversation that they have learned in prior lessons. Participants are rewarded for appropriate behavior by receiving points from the OG. If the group earns enough points, they are awarded free time at the end of the lesson which they can use to freely explore the virtual world, play games or chat with one another.

1.3. Design Challenges

The challenges of teaching and learning in a 3D VLE are multifaceted and complex. All interaction in such environments is technology-mediated, pedagogies for teaching and learning are still nascent and experimental and, as designers, the translation of effective real-world strategies into a virtual world is often complex. In order to approach these and other challenges, methods of designing, developing and sustaining 3D VLE as viable and effective instructional technology are needed. In order to establish strategies and methods for effective 3D VLE design and development, especially given
our unique users, a particularly flexible design framework is needed. We have chosen design-based research as a framework which provides the opportunity to advance our theory of how the learning of youth with ASD can be supported in the 3D VLE as well as to advance the 3D VLE system so as to implement the curriculum and support social competence acquisition.

While DBR provides us with a conceptual framework and describes general process guidelines, it does not provide explicit instruction as to how one goes about implementing changes in design. Instructional technology both constrains and affords learning, as the unique tools and capabilities presented by the technology allow for novel and innovative learning approaches, yet the limitations and tradeoffs that are part of technology implementations circumscribe the range of learning activities which can be performed. How often do instructors desire that a software suite could perform a certain desired function or that it were easier to access certain functionality? When required design improvements necessitate changes to underlying software, such changes are typically not possible unless the software licensing allows for inspection and modification of the underlying source code. While the majority of purchased, off-the-shelf software does not allow for this, FOSS does.

Our 3D VLE has been built using the Open Wonderland virtual worlds toolkit (http://openwonderland.org/), an open source, Java-based virtual worlds platform licensed under the GNU General Public License (GPL) v2. The flexibility afforded by Open Wonderland has allowed us to follow a DBR trajectory through early work of building theory and testing pilots and prototypes to current work of iterating through the design and development of five units of the curriculum with usage tests for each unit. The
ability to examine, modify and freely distribute FOSS has provided substantial flexibility in the design and development of our system, has enabled us to forward innovative and pragmatic approaches to enhancing the technological constructs which support instruction and learning and to improve existing design principles and discover and implement new ones.

2. Conceptual Framework

2.1. Design-Based Research

Design-based research is theory-driven design, wherein the goal is not only the iteration of a product but also the advancement of a design theory for optimal learning and performance within a naturalistic context, usually in relation to the use of technology (Design-based Research Collective, 2003; Brown & Campione, 1996). In addition, DBR addresses specific, complex, and important educational problems (Reeves, 2006) by systematically testing designs in context with each implementation and analysis informing the next iteration of the design theory. It has been called an iterative cycle of design and enactment or implementation, followed by analysis of the implementation, theory iteration and redesign (Wang & Hannafin, 2005). These iterations of design and implementation have the goal of establishing the relevance of the implementation and ultimately its impact (Amiel & Reeves, 2008). DBR has implications for design, development and implementation and thus shares similarities with iterative approaches to software development such as agile and extreme programming. However, DBR distinguishes itself from these other approaches in that it is at its heart a research methodology with a primary focus on educational relevance and impact.

While there is no one way to conduct DBR, a number of general principles are
typically used to guide the methods employed. Reeves, Herrington and Oliver (2005) forward a series of principles which focus on developing solutions to broad, complex educational problems by integrating known and hypothetical design principles with technological affordances. These solutions are reflected upon and tested to both refine learning environments and reveal new design principles that ultimately contribute to construction of theory and explanations in the process. Key features of these principles are a strong focus on collaboration between researchers and practitioners and continual refinement of processes, questions and protocols. Given DBR’s focus on iteration, collaboration, consistent refinement and improvement, it may seem obvious that agility, adaptability and flexibility are essential to a successful DBR process. To be sure, when implementing a design in a complex system, many (and in fact, most) contextual variables are not known a priori (Barab & Squire, 2004). The DBR process allows for discovery of additional contextual variables, thereby further informing design theory through subsequent design and testing iterations that address these variables. For example, in our project we found that participants sometimes had difficulties navigating our environment and would get “stuck.” This was unanticipated and led us to redesign our spaces to be more open, with fewer obstructions, and therefore easier to navigate.

The capacity of the DBR process to uncover previously unknown or unaccounted contextual variables underscores the importance of DBR to our design and development trajectory. Research that specifically addresses individuals with ASD undertaking instruction in a 3D VLE is sparse. Many articles are descriptive and do not report specific learning gains (e.g., Charitos et al., 2000; Dautenhahn, 2000; Kerr, Neale, & Cobb, 2002; Max & Burke, 1997; Parsons et al., 2000; Parsons & Mitchell, 2002). The focus is
primarily on single-user experiences of practicing discreet skills, and does not consider how such instruction might be experienced mutually by multiple users. However, adding a collaborative dimension to the experience has ramifications for design, implementation and learning outcomes. Collaborative 3D VLEs provide a number of benefits that are not realizable with single-user environments such as using peer groups with a facilitator to discuss social competence collaboratively (Cobb et al., 2002; Kerr et al., 2002), negotiating and developing social norms between users and flexibly facilitating communication (Parsons et al., 2005). What is known about individuals with ASD learning in 3D VLEs focuses on limited skill sets often taught in isolation of other skills and does not specifically address structures and mechanisms for actually being social in a 3D environment. Given that there is limited understanding of individuals with ASD learning collaboratively in 3D VLEs, we have adopted DBR as our framework for design since it embraces incomplete knowledge and allows us to iteratively expand our design and learning theories to provide more relevance and impact in our implementation.

2.2. Free/Open Source Software

Free and Open Source Software is an approach to software development and distribution that includes source code and forms of licensing which permit ready customization and evolution while preserving the software as a common good. FOSS’s ability for ready customization and evolution, to meet local needs, to be iterated loosely in regards to special requirements of target users and free access to source code makes it a natural partner for design-based research, which requires flexibility to control iterations and to approach unknown contextual variables. FOSS accommodates the needs of DBR to agilely revise, adapt, make changes and re-implement to fit the target context.
FOSS provides opportunities for designers, developers and users to participate in the community development effort that simultaneously contributes to meeting local needs (Lin & Zini, 2008; Carmichael & Honour, 2002). Open source software is particularly useful for educational application development in that it helps to establish a closer relationship between development communities, educators and users, so that the software can be iterated based on the needs and special requirements of the target users. The integration of the practices of teaching and learning with the flexibility and freedom to develop makes FOSS a suitable alternative to commercial software.

FOSS is gaining traction for its potential benefits over proprietary counterparts in the development of multi-user 3D VEs both for educational and enterprise applications. This interest is spurred by the flexibility, customizability and extensibility of FOSS 3D VE platforms such as Open Cobalt (http://www.opencobalt.org/), Open Qwaq (http://code.google.com/p/openqwaq/), Open Wonderland (http://openwonderland.org/), OpenSim (http://opensimulator.org/) and others. For example, Young (2010) discusses the decision to use the NSF-sponsored FOSS platform Open Cobalt over the proprietary Second Life platform due to educators’ lack of control of the proprietary environment. In Kappe and Guetl (2009), the researchers discuss development of a virtual conference room for knowledge transfer and learning purposes and their preference for FOSS software toolkits due to the ability to customize and add functionality to such virtual worlds as well as their ability to interoperate with other virtual worlds, including Second Life. Zutshi and Sharma (2009) compared the usability and acceptability of two proprietary platforms, Second Life and Qwaq Forums (now Teleplace), and one FOSS platform, realXtend, for collaboration within an enterprise. While the authors reported
success with the realXtend platform, they were unable to achieve their goals with the proprietary platforms. The authors note the flexibility of realXtend enabled building an environment that users found more consistent with their real work situation than was possible with the other platforms.

Such reports of successful FOSS implementations underscore the benefits of the FOSS approach for development of 3D VLEs. However, FOSS software solutions bring with them unique challenges. The authors (2010c) maintain that while FOSS allows for profound flexibility, it can also result in difficulties due to great diversity in implementations and the need for highly knowledgeable local staff that have the capability to participate in broader FOSS communities. This sentiment is mirrored in other researchers’ (Kappe & Guetl, 2009; Young, 2010; Zutshi & Sharma, 2009) assessment of their particular FOSS implementations. Indeed, those studies note the high requirements of hardware and professional knowledge of the personnel in the implementation. This challenge could well be the primary impediment to implementing FOSS 3D virtual environments.

Given the challenges presented above, FOSS may not be a good fit for everyone. Not all institutions or projects have the capacity to fund or train staff to support and extend FOSS. Nonetheless, FOSS made sense for our project for many of the same reasons as DBR. Given incomplete understanding of the field, we expected that we would need to iterate our technical and learning designs multiple times, but we were unable to anticipate what specific changes would be necessary or the extent of those changes. For this reason we chose to use the Open Wonderland 3D VLE development toolkit because it was released under a FOSS software license and had a vibrant development
community. FOSS licensing allows us maximum flexibility in terms of our unit and lesson implementations and the vibrant community affords us the ability to rely on developers, users and other members to forward the greater Open Wonderland project in general and our collaborative 3D VLE implementation specifically.

3. Method

The ultimate goal of our design research trajectory is both to inform design principles and develop a system that supports learning behavior and social interaction in the 3D VLE. Since there is no substantial nor sufficient research base for us to draw upon, we needed to learn how to make the user experience social for youth with ASD through our iterative DBR process.

3.1. Participants and Sites

All participants in all studies described below met a set of pre-defined qualifications: they 1) were between 11-14 years old, 2) had a medical diagnosis of autism determined by the Autism Diagnostic Interview Revised (ADI-R) (Rutter, Le Couteur, & Lord, 2003) and/or the Autism Diagnostic Observation Schedule (ADOS) (Lord, 2002), 3) were verbal/capable of speech and 4) had an intelligence quotient within one standard deviation of the mean for the typical range (e.g., a score of 85-115). If participants met these criteria, they were considered to be high functioning. Participants were recruited through a large Midwestern autism research center and offered a small honorarium for their participation. The studies were fully explained both verbally and in a letter to all participants and their parents. Those who wished to participate provided signed assent forms and their parents provided signed consent forms. Sites varied between a large midwestern autism research center and a large midwestern university. All
studies were approved by our university’s institutional review board. An overview of the sites at which the studies were performed and participants is provided in Table 1.

Table 1
Sites and study participants

<table>
<thead>
<tr>
<th>Study</th>
<th>Date</th>
<th>Site</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability</td>
<td>Fall 2008</td>
<td>Usability lab at large Midwestern university</td>
<td>Two boys with ASD; one 11 and one 13 years old</td>
</tr>
<tr>
<td>First usage</td>
<td>Fall 2008</td>
<td>Large Midwestern autism research center</td>
<td>Four boys with ASD; one 12, three 13 years old</td>
</tr>
<tr>
<td>usability</td>
<td>Spring</td>
<td>Usability lab at large Midwestern university</td>
<td>Two boys with ASD, one 13 and one 14</td>
</tr>
<tr>
<td>test</td>
<td>2009</td>
<td></td>
<td>Two boys with ASD, one 13 and one 14</td>
</tr>
<tr>
<td>us</td>
<td>Spring</td>
<td>Large Midwestern autism research center</td>
<td>Three boys and one girl with ASD; one 12, two 13, one 14 years old</td>
</tr>
<tr>
<td>usage test</td>
<td>Fall 2009</td>
<td>Large Midwestern university</td>
<td>Six boys with ASD; two 12, three 13 and one 14 years old</td>
</tr>
</tbody>
</table>

3.2. Procedures

3.2.1. Iterative design and development of prototype

We started in the Fall of 2008 with a pilot prototype of a single unit in the curriculum that focused on turn-taking in basic conversation. The prototype was created in a multi-phase process in which we performed front-end analysis, designed the initial implementation, developed the prototype, ran internal quality assurance and regression tests, performed expert reviews, made final changes and then executed a usage test with four youth on the autism spectrum (Figure 1). During the front-end analysis we reviewed objectives and generated an initial set of design principles to guide the design of the 3D VLE. The guiding and foremost design principle was to promote appropriate social interaction among participants and engagement with the curricular activities in the medium. From this we derived subsets of design principles, for example, 1.) making the space minimalistic and not including objects which might detract from social interaction or be distracting, 2.) writing all learning materials at an appropriate level for participants
for simplicity, 3.) keeping the learning environment uniform throughout lessons and lesson sections for predictability, 4.) making learning activities that promoted reciprocal interactions among participants, etc. We anticipated these principles and others would set the stage for social interaction in that they were intended to keep distractions to a minimum, encourage on-task behavior, make learning supports highly accessible and ease transitions between contexts.

**Figure 1. Multi-phase, iterative design and development process**

We then began designing student supports, learning activities and the virtual world itself. Designs were reviewed within the design team, revised based on feedback and redesigned until a consensus was met and the designs were approved for development. These designs were also reviewed by two faculty members, one in special education with over 20 years of experience delivering behavioral interventions in clinical and professional settings and one in educational technology with over 20 years of experience in design, development and evaluation of learning technologies. Functioning prototypes were then built and regression tested. Data from regression tests were used to reflect the design principles and improve designs. The two faculty member experts were
consulted periodically to perform cognitive walkthroughs of the virtual space, utilizing a think aloud method for capturing their perceptions of the working prototype and for providing input for improvements. The outcome of these multiple design and development iterations was twofold: 1) a virtual world with all of the needed technical, student and instructor supports for delivering a single unit of the social competency curriculum and 2) a more refined set of design principles with which to further guide design and development.

The prototype was tested for usability in Fall of 2008 in a usability laboratory at a large Midwestern University with two youth with ASD. Findings indicated 1) participants were able to complete all assigned tasks, 2) participants found that using the 3D VLE was easy and 3) participants would be willing to come back again. Participants did need assistance completing some tasks, for example, taking control of a web browser window. No usability issues were presented regarding the general design of the environment and the incorporated curricular content. Participants intuitively understood how to navigate, were able to read instructional content in the environment, play games and watch videos. They were also able to successfully navigate with their avatars to different areas of the environment and use avatars' gesturing features. A number of areas for improvement were identified. Participants had difficulty taking control of windows in the virtual world due to an unfamiliar key combination. This finding led us to the principle that learning supports in the environment must be simple to activate. To realize this design principle, we examined Open Wonderland's source code that controlled window activation and modified it so that a student could click with the mouse anywhere on a window to activate it. We also found that participants were confused by the number of control
buttons for operating shared slideshows and video players. We extrapolated from this the
design principle that as few controls as necessary should be used on interactive objects.
To realize this design principle, we reported our finding to other developers in the Open
Wonderland community and provided design mockups for how interfaces might be
improved with fewer controls. Those developers incorporated our feedback and design
mockups into the next version of the software. In addition to changes made to software,
more orientation to the system and opportunities for participants to use the tools and
interfaces were needed. Providing additional training materials and extra time in lessons
for orientation and training became an additional design principle, and we were able to
make changes to the curriculum delivery method to account for this.

The multi-step process described above illustrates how we used a DBR
framework to establish a fully-featured functional prototype for usability testing. Because
we chose to use a FOSS toolkit for building our 3D VLE, we were able to modify the
software to address identified usability issues. In addition, we were able to participate
with the FOSS community to make additional changes to the system, which benefited our
users as well as all users of the Open Wonderland virtual worlds toolkit.

3.3. Usage Test of Prototype

The purpose of the usage test was to investigate participants' behavior across time
and space in the 3D VLE in order to better understand the degree to which they engaged
in behaviors that were desirable and that aligned with instructional objectives, under what
conditions these behaviors occur and the characteristics of the behaviors. Our goal was to
use the data gathered during the usage test to 1) identify areas for improvement in our
virtual world design, lesson activities, learner supports and general usability 2) to iterate
our current design principles and 3) identify variables which impacted our design that had not yet been defined or accounted for. The unit we had prepared for the prototype focused on turn-taking in basic conversation. In this unit participants both learned about appropriate ways to take turns and practiced the skills in various contexts.

Four youth in groups of two (boys on the autism spectrum, ages 11-14) undertook the instruction with assistance by the OG. The study was performed at a large midwestern autism research center. Youth sat in different rooms, but in the same building, during the sessions. The unit consisted of two training sessions of one hour for learning to use the 3D VLE system and then four one-hour lessons from the curriculum unit delivered over a two-week period. Screen and video camera recordings were captured of four participants taking part in the unit's lessons and then coded with high inter-observer agreement (>80%) by four trained graduate students. The coded data accounted for participants taking part in long chains of back-and-forth interactions which require both verbal and non-verbal communication, thus providing a lens through which to interpret their turn-taking behavior in the 3D VLE. Axial and open coding were also performed on the data in order to look at the nature of participants' interactions with one another and the online guide. For this, the data were reviewed using constant comparison, temporary codes were assigned using causal and generic relationships, codes were iteratively reviewed and refined and the entire coded data set was finally reviewed and codes were re-assigning where appropriate.

3.3.1. Findings from usage test

A summary of major findings are presented here. We found strong evidence that participants were engaging in turn-taking with each other and with the online guide, and
that the majority of their turn-taking was socially appropriate. Our analysis allowed us to
determine the activity the participants were engaged in, the virtual world tools they were
using and the mode of interaction they were using (e.g., voice chat, text chat, avatar
gestures) while they were engaging in turn taking. We found participants perceived
others' avatars as being controlled by real, thinking people as opposed to being just
computer graphics and that participants preferred avatars that had human-like behaviors
like gesturing and walking animations over those without these features. We also
observed inappropriate behaviors like interrupting, leaving the group without permission
and bumping into one another’s' avatars. Participants showed some difficulty navigating
the environment and would sometimes bump into walls, get stuck in doorways or become
disoriented. We also observed that there was sometimes a disconnect between what
participants' avatars were doing in the virtual world and what the participant was doing in
the real world. For instance, a still avatar could mean that a participant is paying attention
and keeping a calm avatar body. It could also mean that the participant has walked away
from her computer. Participants also had problems using their microphone-equipped
headsets, such as accidentally muting themselves, and they complained that the headsets
were uncomfortable.

While participants were able to use the affordances of the virtual world to
successfully engage in turn taking, their turn taking took place in a multifaceted activity
context in which undesirable outcomes like interrupting and getting stuck in walls were
observed. We recognize that some degree of undesirable behavior and challenges using
the software are to be expected; however, we also realized that many of the problems we
observed could be mitigated and behaviors that promoted social interaction could be
enhanced and amplified with better design, improved software supports improved activities. For instance, we added the principle that software tools should be incorporated into the environment to promote desirable social behavior like taking turns and constrain undesirable behavior like interrupting. We found that avatars with highly realistic behavioral capabilities might have the potential to positively impact instructional outcomes. From this we adopted the principle that avatars should be more realistic, with multiple human-like behavior capabilities. Given that headsets were problematic, we adopted the design principle that participants should be provided lightweight and simple headsets for communication and that alternative devices such as external microphones and speakers should be provided as needed. Because of the disconnect between real world and virtual world activities, we developed the principle of providing a way for users to be aware of others’ activity and status in the real world while operating in the virtual world, such as webcam video and pictures. Finally, participants had many difficulties with transitioning, like getting stuck in walls, which led us to the principle that the least number of transitions should be used in any given lesson.

4. **Cases of DBR and FOSS symbiosis**

Following the procedures outlined in the previous section, we performed the entire design and development process two more times using the unit on turn-taking, executing a usage test at the end of each iteration. Data for both studies were collected by recording participants' screens as well as by capturing webcam video. In addition, field notes were created by the online guide and support staff after each lesson. The second and third usage test continued the same macro-level design-based research phase as the first usage test and shared many similarities. Because of this, we do not go into as
specific of detail regarding the design, development and implementation aspects of the second and third usage test as with the first. We do discuss the areas in which our processes, implementations and outcomes differ, however. In addition, we provide examples of some, but not all, of the changes we made to the 3D VLE and our design principles during the DBR iterations that led up to the second and third usage test. While there would undoubtedly be value in documenting the many changes to the 3D VLE and to our design framework, our goal is to highlight those changes which best illustrate DBR and FOSS being used in symbiosis.

4.1. Activity Monitoring and Representation

One example of symbiosis had to do with our data collection processes. An issue we identified after the first usage test was that coding video data was extremely time consuming and labor-intensive. Each hour of instruction, would yield up to seven hours of video (six students and one instructor) and taking approximately 160 human hours for our team of researchers to analyze. This was problematic because research outcomes are a primary driver of our design and development process, but the amount of time between finishing a usage test and completing analysis overlapped with subsequent design phases. As a result, we began to look for ways to gather data that would not require as much human input to make sense of and would allow us to more quickly answer questions of how students use the learning environment and interact with one another. We were able to investigate how to capture data other than screen recordings by analyzing the underlying source code of Project Wonderland to determine how user interactions were generated and communicated between the server and clients. This analysis resulted in the development team creating a way to write representations of user interactions to plain
text log files. The interactions included avatar gestures, entering/exiting virtual spaces, speaking, moving one's avatar, clicking on items in the environment and so on. These interactions could then be plotted on charts and used in similar ways to the coded video data to investigate how users were using the system over time. For example, Figure 2 shows the amount of seconds that participants' spoke in one-minute intervals over the course of one lesson. This chart not only provides an indication of how much a participant was speaking, but also presents a representation of the flow of conversation, with peaks in the chart representing when a speaker is speaking and valleys indicating silence. The chart presents the fluctuations in durations of speech per minute for five participants. At minute 17, the online guide's chart indicates a valley, while Student 2 shows a peak and all other participants show a slight upward trend in the slope of their charts' lines. This could be interpreted to mean that the online guide was speaking less in minute 17, while Student 2 was speaking more and others were increasing their participation.

*Figure 2.* Participants' speaking behavior in one lesson represented as total duration of speech in one-minute intervals.
The ability to track, record and graphically represent participants' behavior in the 3D VLE is important because it allows us to identify areas in the data that are interesting or unexpected and examine those areas more closely. Using information from these investigations, we are better able to determine if our designs and design principles are effective or if they need further refinement. This exemplifies one way to leverage FOSS for design-based research. Using FOSS allowed us to examine and modify the source code of the Open Wonderland system to track and record participants' behavior in the 3D VLE. In turn, these data can be used to inform our designs and design principles. Above all for our project, incorporating a way to more quickly gather and analyze data from usage tests better equipped us to generate recommendations for revisions to our designs and design principles.

4.2. **Virtual environment design**

Due to changes to the underlying curriculum, instead of four one-hour lessons as
in the first usage test, participants took part in six 45-minute lessons for the second and third usage tests. The content of the turn taking unit remained largely the same but, given the shorter amount of time for each lesson, was restructured in some areas to allow for overlap between lessons or shortening of some activities. These curricular changes required changes to the virtual world. In addition to this, participants had a number of challenges using the initial virtual world we had built to implement the curriculum. The new timings, amount of lessons and the problems that participants had using the initial virtual world were key design considerations as we set about envisioning the design a new virtual world.

The initial space was an enclosed, round lighthouse building. The building consisted of multiple levels. Each level contained content for a given lesson within different rooms. Participants would move between levels and rooms as they undertook curricular activities. However, transitioning from one activity to another was time-consuming, especially when a student became disoriented, got stuck or left the group. This observational data led us to the design principle of creating an open and spacious environment, in which there would be fewer things to interfere with navigating one's avatar and in which it would be easier to see where the group is, should one become disoriented or leave the group. Figure 3 provides an illustration of the initial environment and the redesigned environment, using the design principle of openness, with both exterior and interior views.

*Figure 3.* Initial environment (1) and redesigned environment (2) exterior (a) and interior (b) views
Iterations of our virtual environment designs led us to the design principle of more open and spacious spaces. Data from a usability study and field notes showed that participants were better able to navigate through the world and be social when it was easier to see and move across virtual landscapes when this design principle was implemented. These lessons helped us advance our understanding of building and designing virtual learning to include the tangible nature of the environment as something that provides both opportunities and constraints. The example of redesigning our environment to better meet the needs of participants again underscores the complementary nature of FOSS in conjunction with DBR. As is evident in this example, the changes made to the virtual environment were quite extensive. While it can be argued that such extensive modification could also be accomplished using a proprietary system like Second Life, the amount of effort involved would likely be much greater. The open nature of the Open Wonderland toolkit facilitated tremendous flexibility and ease in this
process due to Open Wonderland's use of open standards, open file formats and an open content creation pipeline. Because of this, we were not constrained to using prescribed tools for creating our virtual world but instead had the option to choose any number of tools. While we used FOSS tools to create the virtual world and its contents, we were free to use proprietary software to do the same, had we so desired. In this sense, the example of our virtual world design underscores the flexibility of FOSS for making the changes necessitated by the discoveries and subsequent modifications of our design theory brought about by the DBR process.

4.3. Learning activity design

One of the major benefits of learning in a 3D VLE is the ability to have an intrinsically motivating and engaging environment. Over the course of the design, development and testing iterations, we were able to change many curricular activities so that they became more engaging for participants. One such activity helped participants learn turn taking communication strategies by collaboratively building a restaurant. This activity was prototyped and implemented in the second usage test. In this first iteration of the activity, participants shared a web browser window in the virtual world to make decisions about the style and decorations in their restaurant, as well as to create a menu for the restaurant. For the most part, participants engaged in very little off task behavior while undertaking the restaurant building activity. However, review of the video data showed that participants required frequent prompts by the online guide in order to engage in reciprocal conversation. In addition, participants did not move their avatars much other than to turn to speak to their partner. This finding is similar to Rutten and colleagues (2003) discovery that users within their multi-user 3D VLE needed support initiating and
maintaining interaction or else their interaction quickly halted. While this finding is somewhat expected, given the difficulties that individuals with ASD have initiating and maintaining reciprocal conversations, it does underscore the need for providing scaffolding to promote conversation. Rutten and colleagues suggest human support as one form of scaffolding. Another type of scaffolding can be the activity itself. In the current example, while the activity engaged the participants on one level, it was not effective at promoting interaction among participants without the intervention of the online guide, nor did the activity take advantage of virtual world affordances such as being able to navigate the virtual environment with one's avatar and interact with others' avatars in naturalistic ways.

Given that our guiding design principle was to promote social interaction, we revised our requirements for the activity in an effort to make it more engaging and encouraging of participant interaction without so much prompting by the online guide. For the next iteration of the restaurant building activity, we used the design principle of participants actually building a restaurant in the 3D environment instead of in a web browser window and in which they could negotiate choices, for example, for the building type, furniture, types of food and decorations. Figure 4 illustrates the initial, browser-based restaurant activity and juxtaposes it with the redesigned activity. Making it possible for participants to build a virtual restaurant in the 3D environment required developing functionality into the Project Wonderland toolkit to support the activity enhancements. While our developers were able to investigate the underlying source code, it was not initially clear exactly how they would go about creating this new functionality. However, because Open Wonderland is developed in the open by a community of both
paid and volunteer developers, the developers on our team were able to contact other contributors and discuss the challenges presented by our new design, gather ideas and opinions about how to move forward and in some cases even receive specific guidance about how to perform a given development task.

*Figure 4.* Early, browser-based version of the restaurant activity (1) and redesigned, in-world restaurant activity exterior (2a) and interior (2b)

Videos from the sessions in which students used the redesigned restaurant activity indicated that the activity was highly engaging. Participants were excited to take part in the activity and clearly enjoyed taking turns to choose how they wanted to build their restaurant. Data from logs show that after the online guide had provided instructions for the activity, the majority of conversation was between participants. In addition, participants moved throughout the restaurant area, exploring their choices and discussing them as a group. Using these data, we iterated our design theory to include the principle of using interactive components that were embedded within the 3D virtual world to facilitate reciprocal interactions and collaboration among peers. This example again underscores how we have leveraged the symbiotic nature of FOSS and DBR. The iterative process of DBR made possible the identification of variables which impacted the user experience in the original restaurant activity such as being less engaging than intended and requiring frequent prompts from the online guide. The flexible nature of
FOSS allowed us to make the radical changes to our design with relative confidence that these changes could be realized. And the open nature of FOSS allowed our developers to engage with a community of other competent developers who were able to provide direction and support for realizing our design.

4.4. Learner supports

A finding from the first usage study was that participants had difficulty staying with the group and not invading each other's space. Non-verbal aspects of group interaction such as staying with the group and keeping appropriate personal distance are required by the curriculum. Indeed, these are areas in which individuals with ASD may struggle, given the challenges they have with social interaction. Social norms like appropriate body distance and remaining oriented to a speaker are skills which often must be taught explicitly, as individuals with ASD do not necessarily pick up on them implicitly. To approach this skill area, we adopted the design principle of using software mechanisms to help users manage group interaction. We conceived of a software tool that would help users to manage their adjacency and distance from others' avatars while also staying with the group. Adjacency is how close users’ avatars are to one another, for example, an avatar directly in front of or touching another would not be desirable, whereas standing approximately one meter away would. Distance is the area between users’ avatars, for example, an avatar across the room from another would be undesirable, whereas within two or three virtual meters would not. The software tool took the form of grouping mechanisms. One form was lesson spaces which could be locked or unlocked for entering and exiting by multiple participants. Another was personal spaces for maintaining appropriate adjacency and distance to others. Group and personal spaces
were conceived as circular areas for groups and individuals that could be embedded in the virtual environment to both indicate to participants visually the area in which they are allowed to move their avatar and to limit participants’ ability to navigate their avatar away from this area until given permission. The group and personal spaces operate on the principle of constraining undesirable behavior and inviting appropriate behavior such as maintaining appropriate distance with one's avatar from others and the online guide and staying together as a group. These tools provide indicators of what behaviors are appropriate and inappropriate at a given time, invite social behavior related to the curricular content and signify when it is appropriate to enter a space or when it is not appropriate to exit. Once participants are in the spaces, they can be locked, thus restraining the mobility of their avatars.

4.4.1. Prototype grouping and personal spaces

The initial, prototype iteration of group and personal spaces took the form of a green, dashed circle that floated at approximately avatar waist height (Figure 5). Personal spaces were large enough for one avatar to occupy, whereas group spaces could accommodate multiple avatars. These early prototypes did not have any functionality beyond providing a visual cue for participants to know where to stand. Findings from a usability study in May, 2009 with two boys with ASD (one 13 and one 14), showed that they noticed the group and personal spaces but did not intuitively understand their utility. When asked about the group spaces functionality, the participants said, “I am lost” and “I give up.” Once the purpose of the spaces was explained, participants described the spaces as “easy.” This led us to design training on the functionality of the spaces and to design the spaces to be more intuitive.
4.4.1. Second iteration of grouping and personal spaces

The next iteration of spaces was also represented as circles that were located at about avatar waist height. We redesigned these spaces to glow green when they could be entered and exited and to turn red when they could not be exited. We also trained participants in the color coding using a stoplight analogy of "green means go, red means stop." In addition, when the space was entered, participants were presented with a pop-up notification informing them whether they could freely exit the space or whether they needed to wait for the online guide to unlock it before they could exit. An illustration of this version of the group spaces is provided in Figure 6.

Feedback was gathered from participants on this iteration of group spaces during the second usage study. Opinions varied from "They're easy." to "I hate them!" Observations from video data showed that one participant would sometimes not pay attention to the lesson but would instead try to escape from the locked personal space. As the group spaces were faded out over time, we found that this participant tended to try to leave the group and not participate in lesson activities in general. Other participants found the group spaces to be helpful in terms of showing them where to stand with their avatars.
and keeping appropriate body proximity, but also said that they were "weird," although they did not provide explanations as to why. We also found that participants rarely paid attention to the pop-up notifications.

Figure 6. Second iteration of group spaces

Since it was not clear why participants' responses were mixed, we reviewed the videos of them using the group and personal spaces as they undertook the unit. Investigation of the videos showed that participants used the group spaces as intended for the most part. However, as the grouping spaces were being phased out as part of the unit's scaffolding, we used a more neutral, blue indicator to show participants where to stand. This indicator was represented as a pod that sat just off of the floor of the virtual space. It did not lock or change colors (Figure 7). During the lesson in which the blue pod was used, all participants moved their avatars to the pods and stood on them without prompting from the instructor, including the participant who was reluctant to join the group. This seemed to indicate that participants may be more accepting of a space that is represented in a more naturalistic way. We reasoned that group and personal spaces were
foreign-looking. Because they floated in space, it was not clear what their purpose was. However, the blue pods sat on the floor and appeared to invite the user to stand on them. This finding inspired our next iteration of group and personal spaces and provided the basis for the design principle of using naturalistic cues for supporting participants.

*Figure 7.* A blue pod indicator showing where to stand

4.4.1. Third iteration of grouping and personal spaces

The third iteration of grouping spaces drew from the design principles derived from the first two implementations and extended the prior designs. While the mechanism of the space boundary floating at avatar waist height did not appear to be effective, the use of green to indicate that a space was open and approachable and red to indicate that a space was closed, occupied or not able to be exited seemed to be both intuitive and valuable. Coupling this with the lessons learned from the prior usage study, we combined the color and locking/unlocking scheme that we had used with prior versions of grouping spaces and applied them to the blue pod that was used in the prior usage study. We dubbed these spaces "personal pods" and conceived of them as being similar to a
student's desk in the real world. We extrapolated the idea of personal pods to work with larger spaces, which we dubbed "group spaces". We conceived of group spaces as being analogous to a table or common work area in a classroom. Instead of using pods which sat slightly above the floor, we created group spaces to be semi-transparent circles on the ground. Group spaces used the same mechanisms as personal pods of using red and green colors to invite and constrain behavior and locking and unlocking to keep participants from exiting a space before given permission. Personal pods and group spaces are illustrated in Figure 8.

Figure 8. Avatars standing on locked personal pods (1) and avatars approaching a group space (2)

Personal pods and group spaces were implemented during the third usage test. During this usage test, field notes were recorded by the online guide, the online helper, participants' helpers who physically sat with them, technical support staff and a faculty member in special education. Following the study these field notes were open coded by two graduate students looking for triangulation in the data. The triangulated data were then condensed and categorized, and these categorizations were used to develop
descriptions of overarching themes. Findings from the field notes reflected participants being compliant in the 3D VLE, understanding and accepting the purpose of group spaces, doing well staying together as a group and using the group spaces and personal pods as indicators of where to stand and orient. The group spaces and personal pods seemed to be less obtrusive to participants than in prior usage tests, and they did not seem to discuss the spaces as much. In addition, the assertion was made that having participants' avatars use the personal pods may have been effective in shutting down distractions and getting lessons started quickly. Participants reported that they enjoyed taking part in the usage test and were disappointed when lessons ended.

In addition to these positive and encouraging reports from the field notes, a number of areas for improvement were discovered. For instance, the arrangement of personal pods was such that some participants' avatars got in the way of others' view. Participants whose avatars were on the most distant pods could not hear the online guide as well as those who were closer. Participants' avatars also had a relatively wide range of motion within the pods, and would explore just how much they could move their avatars. Some participants were able to exit pods even when the pods were locked. When others observed this, they also attempted to exit the locked pods. Their behavior was playful and game-like, but nonetheless distracting and off-task. These areas for improvement have served as input for enhancement of existing design principles and development of new ones. For example, pods should be arranged such that participants can see and hear clearly. In addition, avatar motion on pods should be restricted. These and other design principles served as input for the next generation of recommendations to enhance group spaces and personal pods.
The three iterations of usage testing described in this section have led to the development of software supports intended to promote desirable behavior and discourage undesirable behavior and that have evolved significantly from our initial designs and prototypes. The result of this process, personal pods and group spaces, serve as a strong example of how FOSS can complement the DBR process. Development of the initial grouping spaces prototype required being able to modify Open Wonderland to add functionality to support the grouping spaces. This prototype was used for usability testing, the data from which helped us to reflect on our design and generate new and modified design principles. These design principles were realized by again modifying the Open Wonderland source code to support new design, which resulted in improved grouping spaces. The improvements were investigated in a usage test, and data from the usage test allowed us to generate recommendations to enhance our solution. In turn, these recommendations were incorporated into our designs for personal pods and group spaces and subsequently programmed as extensions to Open Wonderland. Personal pods and group spaces were once again investigated in a usage test, which we used to generate recommendations for the iteration of design for these software supports. The example of group spaces and personal pods serves as a longitudinal example of FOSS and DBR symbiosis, illustrating systematic evolution of instructional technology through use of DBR principles and how continual refinement is facilitated by FOSS.

In addition, this example shows how FOSS and DBR can be leveraged to contribute to the building of theory. While we began with a certain model of how participants would behave in the 3D VLE and how the online guide would manage their behavior, we found that participant behavior did not conform to our expectations, with
participants having difficulty staying with the group, maintaining appropriate adjacency to others and so-on. The systematic evolution of our software supports allowed us to test our theory of learning and instruction in a 3D VLE, adapt it to the realities manifested by participants using the software supports in actual learning and instructional scenarios and ultimately improve it based on the outcomes of our iterative processes. Such an approach to development of theory is flexible and sensitive to the myriad contextual variables (both known and unknown) associated with the completely technology-mediated nature of learning and instruction in a 3D VLE and is needed in this burgeoning field which still lacks concrete theoretical guiding principles.

5. Discussion

We have argued that the open and flexible nature of FOSS makes it a good fit for implementation of DBR by allowing for significant customization and design flexibility. In addition, we situate the need for these customizations and design modifications within the pragmatic challenges that we faced when attempting to create a 3D VLE that was highly conducive to social interaction for adolescent students with ASD. DBR informed our multiple design iterations and was likewise informed by these iterations, allowing for the discovery unknown variables that impacted our designs. This, in turn, facilitated the development and enhancement of design principles to guide future design and development iterations of our software. Ultimately, the ability to modify FOSS based on the design principles developed using a DBR process informed our design theory for supporting youth with ASD in virtual worlds and allowed us to build and expand our general theory of learning and instruction in 3D VLE.

The results of the combination of DBR and FOSS illustrated here are not without
their limitations. DBR’s iterative nature requires a relatively long time commitment in order to reap longitudinal benefits. This often means a dedicated research and development team is needed. And for all of its benefits, customization of source code with FOSS requires dedicated personnel with expertise. Finding and building that expertise involves time and financial resources, which can be a factor that limits the ability for a team to address needs locally. In addition, while the contributions from the broader community can be of great benefit, in order to reap those benefits, knowledgeable personnel with requisite skills are essential. Indeed, some situations seem more amenable to combining DBR and FOSS than others. Some examples of these situations include 1) when researchers are presented with a novel context for learning and experience in the field is limited, 2) when a diverse, vibrant and helpful development community exists, 3) when the expectation or opportunity for multiple iterations of designs and developed innovations is present, 4) when innovation is both expected and required and 5) when the organization has the capacity for participating in the FOSS community.

The cases provided in this paper illustrate some of the situations in which FOSS and DBR can be used in a complimentary way. The examples from our project demonstrate how outcomes of these processes impacted and forwarded design principles for individuals with ASD learning in a 3D VLE. First, we were able to incorporate activity monitoring into our 3D VLE as a way to expand the system as well as provide us more data on how participants were using the system. These data required significantly less human input to process and analyze, which corresponded with us being able to quickly generate recommendations for improvement. By modifying the virtual worlds
toolkit, we were better suited to inform our design process. The changes we incorporated made it possible to quickly and accurately gather and represent data on how individuals with ASD are using the system, thus reducing the need for labor-intensive human coding. The inferences we draw from these data can inform our design principles and provide an avenue for enhancing social interaction in the medium.

Second, we derived from our DBR process that the virtual world needed extensive improvements. Thanks to Open Wonderland's use of open standards and open file formats, as well as not having any explicit or required software for asset creation, we were able to flexibly and easily make significant and extensive changes to the virtual world. This provided an improved space which was more suitable for learning and instruction using the 3D VLE medium and better supported social interaction.

Third, we were disappointed when we found that the restaurant-building learning activity was not promoting interaction between participants to the degree we had hoped. While we could have made tweaks to the existing activity in an effort to better promote interaction, such changes would not have entirely incorporated the design principles that our finding had led us to develop. However, because we were using FOSS, we were highly confident that we could make significant and extensive changes to the design of the restaurant-building activity. This is not only because we were able to modify the source code, but also because we knew we could ask the Open Wonderland community for support if necessary. Changing this activity provided a more engaging and motivating context for individuals with ASD to practice turn-taking in basic conversation, and therefore better promoted social interaction within the medium.

Fourth and finally, we learned that participants needed supports for staying with
the group and maintaining appropriate proximity to others and were able to develop these supports. This example serves as particularly strong evidence for the benefits of combining DBR and FOSS. It illustrates how this coupling can be used for researching solutions to educational problems in naturalistic contexts and demonstrates longitudinally the evolution of design, development and theory afforded by using FOSS and DBR in conjunction. Endemic to the process was the discovery of unknown contextual variables and the development of design principles, facilitating the iteration of our design and consequently informing our design, development and ultimately our theory of learning and instruction in a 3D VLE. In addition, it illustrates how we were able to incorporate software supports to invite appropriate behavior and constrain inappropriate behavior. These scaffolds are particularly important for individuals with ASD because of the difficulties they have with social interactions, providing explicit support for appropriate social interaction within the 3D VLE medium.

DBR and FOSS combine to support systems improvement through iterative development and development of design principles. Given the multifaceted and complex challenges of teaching and learning in a 3D VLE, particularly for individuals with special needs, flexible methods to create and support this medium of instruction and learning are needed. The processes and cases we have presented here illustrate how we have advanced our theory of supporting youth with ASD learning in 3D VLE and how we have advanced our the 3D VLE system so as to implement curriculum and support participants in their acquisition of social competence.

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