At-Risk Voices Speak, Theory is All Ears: Toward an Empirically-Based Model of Agency for STEM Learning

Background and Objectives

It is every educator's aspiration that students become powerful agents in their own learning by adapting, transforming, and applying knowledge in the pursuit of change they want to see within themselves and the world. Herein we report on a design-based research study that investigated the nature and conditions for the development of mathematical and computational agency. Our proposed paper has two parts. Part one is a narrative-based lens on one participant's experience in a month-long implementation of a design for fostering student agency—an implementation that took place at an alternative high-school for expelled, at-risk students. Part two uses results from part one to describe the evolution of our theoretical model of agency.

A potential contribution of this paper is in highlighting emergent reciprocities between methodology and theory in design-based projects. Namely, we have come to reinterpret aspects of the facilitation, which we had regarded as logistical, as bearing directly on the complexity of constructs under inquiry.

Pedagogical and Theoretical Commitments

We assert that fostering student agency necessarily involves attention to a complex set of cognitive, affective, technical, and social contextual factors. With the goal of developing and implementing sustainable best practices to foster agency development and deep STEM learning in marginalized communities, our design was informed by theory on critical pedagogy and critical literacy (Freire, 1973; Street, 1993), computational literacy (diSessa, 2000), constructionism (Papert, 2000), and a cognitive-sciences view of cognition as embodied, distributed, and situated (Barsalou, 2008).

Author1 (2007) proposed and studied a model of mathematical agency that is comprised of the following six interacting factors characterizing aspects of individual students' knowledge, skills, and psychological and social inclinations:

a. Availability of mathematical concepts, such as definitions and formulae, in the personal knowledge-base repertory;
b. Ability to select and apply appropriate mathematical procedures during inquiry, proof, and problem solving (Collins & Ferguson, 1993; Schoenfeld, 1985);
c. Personal positioning with respect to the practice of mathematical reasoning, both in terms of identification as a mathematics learner and doer (Cobb & Hodge, 2002; Nasir, 2002; Lee, 2003) and within the socio-cultural context of mathematical practice, such as a one-to-one tutoring session, whole class discussion, or small group project (Lave & Wenger, 1991; Yackel & Cobb, 1996);
d. Affective disposition toward mathematics content and mathematical practices, e.g., toward explorative modeling-based mathematical problem solving;
e. Fluency in mathematical literacy, broadly perceived, and knowledge of privileged mathematical discourse norms, e.g. ability to articulate one's reasoning using a mathematics 'register,' generating normative mathematical

inscriptions and artifacts in so doing (Balacheff, 1999; diSessa, 2000; Ernest, 1998; Mahiri, 2004);

f. Facility (cognitive, affective) in appropriating personally new semiotic means, e.g., diagrams or innovative computer-based tools, (Vygotsky, 1978/1930).

Stemming from a framework in which critical pedagogy and constructionism are jointly applied to STEM content, the following pedagogical commitments informed the design of an instructional intervention to foster mathematical agency: (1) engage generative themes; (2) develop computational literacy; (3) foster imagination play; and (4) focus on constructionist activity.

Central to our approach is the Frerean concept of dialogic education, by which teacher and student share ideas "horizontally" (not hierarchically) with mutual trust, and knowledge and understanding are seen as emergent and transformational (as opposed to static and conventional). Accordingly, we worked with students to identify generative themes—central productions of dialogic education consisting of aspirations, motives, and objectives, rooted in temporal-spatial conditions of the students (Freire, 1973), albeit with the understanding that such themes are dynamic. Through constructionist activities, we aimed to create opportunities for students to develop mathematical reasoning skills and computational literacy as they engage the generative themes.

Data Sources

This being a design-based research study, our data sources are comprised of a rich documentation of the implementation of an experimental instructional intervention. Following, we overview this implementation and then focus on our case study.

Materials: Virtual Location and Journals. We used networked computers with access to Teen Second Life (TSL) or Second Life (SL). SL/TSL is a cutting edge multi-user domain (MUD). TSL provides a safe environment for minors in a virtual world as well as infrastructural C style programming support that utilizes the Linden Scripting Language (LSL). "Fractal Village," our virtual-world activity, takes place on a 16-acre island in TSL. Each student maintains a journal in which they regularly respond to questions the research team poses. These questions are intended to elicit students' experiences with technology and their dispositions toward media and content as well as to collect feedback on their experience with the designed activity and environment on an on-going basis.

Participant. Be'zhawn is categorized as a Special Education student with an Individual Education Plan (IEP), by which teachers must not expect him to engage in activities longer than 20 minutes. All students at the urban California school for evicted youth qualify for the free lunch program and, similar to 95% of the students, Be'Zhawn is African-American. Other similarities between Be'zhawn and most of his schoolmates are: living in unstable home environments, experiencing negative forces, having few role models, and working to support the household. Be'zhawn takes great pride in his work as a part-time humane animal trapper, regularly working until midnight 3 nights a week to supplement his mother's retirement income. He is 1 of 7 students who participated in the study (Authors, 2008). None of the participants had previously been exposed to virtual worlds or had any programming experience. Despite his IEP, Be'zhawn's engaged diligently in 110-minute sessions in our project, wherein he immersed himself in 3D mathematical reasoning and computational thinking. He constructed complex artifacts in Second Life and showcased these on a personalized homepage that he coded. Students in the class presented their work to programmers and management at Linden Laboratories corporate headquarters, makers of Second Life. Students also demonstrated their projects to faculty and graduate students at the authors' university. Be'zhawn was open and forthright in interviews, making him a prime candidate for the case study.

Procedure. In this study, researchers were not perceived as peripheral objective observers. On the contrary, the potential success of the study depended largely on just the opposite, i.e., researchers being subjective emic actors within a complex social network.

Extending an invitation. In the spirit of critical pedagogy and based on discussions with the teachers and principal regarding the ethos of our target classroom, we decided to engage the students in a democratic decision-making process for their participation in the project.

Logins and avatars. The intervention began with students creating logins and avatars. In choosing login-names, each participant is asked to compose any first name yet choose a last name from a pre-compiled list. In choosing a visual representation for themselves, however, users are limited to a dozen basic images (see Figure 1) upon which they can subsequently elaborate through dedicated interface features with which they can alter their skin color, including adding tattoos, changing their facial features and hair, putting on makeup and accessories, etc.

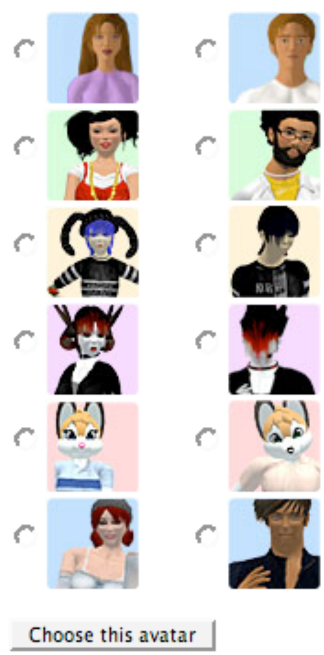

Figure 1. Generic set of avatars user can choose among. These can be modified later.

Generative themes. The research team asked the students as a group to consider what they wanted to do with their island. We elicited students' interests both directly and through reading their journal entries that they shared with us daily.

Customizing the extension of mathematical and computational content. Once the study began, the research team had to creatively and dynamically match content to student interests. To do this effectively the research team did two things: (1) take detailed field notes on students' interests and challenges and upload them daily to a wiki that was reviewed by the entire research team; and (2) discuss each individual student's interests, growth, and challenges in the weekly meeting.

Collected data. Our raw data consist of: digital movies of collaborative work, screen-capture movies that archive every keystroke and mouse click made by each student, journal logs the students kept throughout the study, movies of day-by-day individual semi-clinical interviews with a set of focal students selected on the basis of real time events occurring in the classroom, rich field notes we amassed and co-edited on our laboratory Wiki, videotaped design-team debrief/plan sessions, and participant-generated mixed-media artifacts, i.e., worksheets, modeling constructions, and computer screenshots (see Figure 2, below).

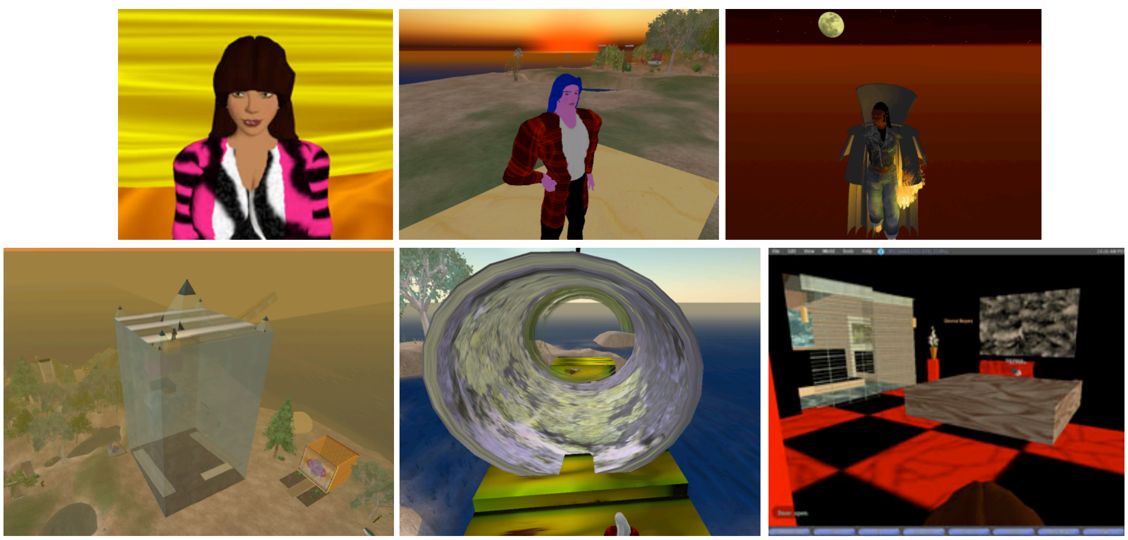

Figure 2, Student-constructed avatars and objects (tunnel, building, bridge, home).

Methods of Analysis

Using grounded theory techniques (Glaser & Strauss, 1967) and micro-genetic analysis (Schoenfeld, Smith, & Arcavi, 1991), we developed the key constructs discussed herein, and specifically we examined the adequacy of the initially proposed model of mathematical agency to capture the collected data. The Results section summarizes consistent patterns in the data as well as our interpretations of these patterns vis-à-vis our emerging model.

Results

We have found that key to students' development of agency was the research team's coordinated efforts to customize technical, cognitive, and affective scaffolds. We now briefly describe two data segments so as to exemplify the nature of the analyses we have been conducting.

In the first data episode, Be'zhawn is working one-to-one with the first author to comprehend and use the computer science concepts of compiling code, setting variables, and implementing events. Specifically, Be'zhawn wishes to program an interactive smart door that opens upon being touched by an avatar and closes automatically after 3 seconds. The nature of this activity reflects all four of our pedagogical commitments, and yet, as the analysis reveals, the student needed additional technical, cognitive, and affective supports. Using his imagination to experiment in the virtual space, Be'zhawn generated the idea of building a fortress–home surrounded by a dense forest and a mote as well as a small cave in the backyard. In the midst of engaging in this complex construction, Be'zhawn became self-motivated to learn to program, because he wanted to build a door for his fortress. However, he needed technical and cognitive assistance, because he lacked the appropriate knowledge to conceive of this task.

The second episode involves Be'zhawn's is an interview the first author conducted with Be'zhawn shortly after this class session. In this interview Be'zhawn realizes it is possible for him to be an engineer. He states, "No one has ever told me that was a possibility before" and asks the first author if she thinks he is capable of becoming an engineer. Attending carefully to Be'zhawn's affect towards STEM practices and content and his self-image as a STEM practitioner are key in continuing to support Be'zhawn's agency development.

Educational and Scientific Importance of Study

The students in this study are those that have been thrown away by the mainstream school system and explicitly told not to return. They are marginalized and disenfranchised, and the alternative school represents a last chance for most of them. While the resources necessary to support their development of agency in learning, as Be'zhawn's did, are enormous, this study acts as an existence proof that we can learn from, and build upon. The consequences of not paying attention to research that yields demonstrable positive results is devastating, both for students—the "end client" of the entire educational research endeavor—and for design-based researchers who are liable to continue wondering why their instructional materials fail to "work" for all students.

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