Journal of
Virtual Worlds Research
jvwresearch.org ISSN: 1941-8477

The Metaverse Assembled

Volume 2, Number 5

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The Metaverse Assembled
April 2010

The Journal of Virtual Worlds Research
is owned and published by the
Virtual Worlds Institute, Inc.
Austin, Texas, USA

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Second Life Unplugged: A Design for Fostering At-risk Students' STEM Agency

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Abstract

At an alternative high school serving predominantly at-risk underrepresented students evicted from mainstream education, we designed and implemented Fractal Village, a critical-constructionist computational and mathematical pedagogy learning environment. Fractal Village, instantiated in the virtual world "Second Life," constituted an empirical environment to research our emergent model of mathematical/computational agency (m/c) as well as an intervention aiming to foster such agency. Key research objectives were to: (1) study relations amongst cognitive, affective, material, technological, and social factors that would contribute to individual development of m/c agency; and (2) delineate design principles for fostering m/c agency. The student cohort engaged collaboratively in virtual world imaginative construction activities each manifesting generative themes (Freire, 1968), to which the designers-as-teachers tailored mathematical and computer-science concepts, such that students appropriated the STEM content apropos of tackling their own emergent construction problems. We argue that to build agency, students must develop both skills and dispositions—a spiraling inter-constructive growth—and articulate a developing methodology for fostering agency development. We conclude that we can, and must, engage at-risk youth by helping them to build STEM-oriented identities, engaging their a priori m/c agency, and customizing skills and dispositions-related classroom discursive supports.

Keywords: youth; virtual worlds; pedagogy; STEM

Fractal Village Unplugged: Design-Based Research On Computing with Marginalized Youth

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Overview and Theoretical Background

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 (m/c) agency. Veeragoudar Harrell (2007) proposed and studied a model of m/c 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).

We will use a series of diagrams of increasing complexity to illustrate the study's progress from the development of the above hypothetical model of m/c agency through empirical evaluation of that model in a real-world setting (see Figure 1, below).

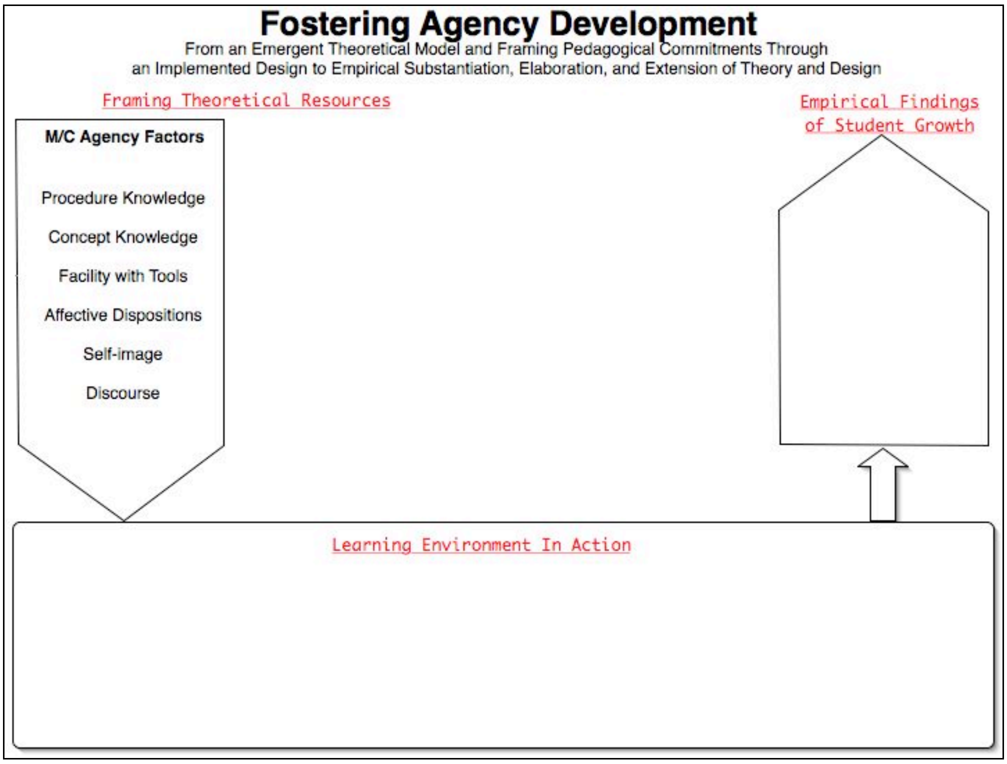

Figure 1. Agency Development Model: M/C agency factors as theoretical design resource.

Our two research questions straddle theory and practice. The theory-oriented research question is: What are the relations amongst cognitive, affective, material, technological, and social factors apparently contributing to m/c agency? The practice-oriented research question is: What are the design principles that help foster m/c agency development?

In order to create an empirical setting for investigation of these research questions, we searched for a medium that would provide space sequestered from real-world contexts, including any personal inhibitions students might have—a space that would provide opportunity for powerful identity transformations and potentially develop students' mathematical and computational literacy. We chose a digital environment called Teen Second Life (TSL), a proprietary virtual 3D world owned by Linden Laboratories (Linden_Research, 2007). Within TSL, we designed and implemented *Fractal Village* (Veeragoudar Harrell & Abrahamson, 2007), a 3D virtual island in which students could construct personae of their own making and build imaginative artifacts through a programming interface.

The construction and facilitation of Fractal Village was inspired by the proposed slogan *Critical-Constructionist-Computational literacy,* a blend of the critical-pedagogy vision of Paulo Freire (1973), the constructionist pedagogical philosophy of Seymour Papert (1980, 1991), and the vision that computational literacy will one day be as widespread and important as textual literacy (diSessa, 2000).

Central to our approach is the Freirean 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.

Veeragoudar Harrell’s (2007) emergent view of STEM agency should be viewed as operationalizing the application of *critical-constructionist pedagogy* to students’ STEM learning. This m/c agency model spells out the six factors discussed above that are pertinent to individual students’ agency in a situated mathematics-problem-solving context. In turn, this model informs design decisions on the iterative development of Fractal Village.

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 and computational agency: (1) engage generative themes (Freire, 1973); (2) develop computational literacy (diSessa, 2000); (3) foster imagination play (Gee, 2003; Clinton, 2006; Hayles, 1999); and (4) focus on constructionist activity (Papert, 1980, 1991). These pedagogical commitments (see Figure 2, below) reflect the intellectual commitments of the study and, specifically, the design that was created to provide the empirical setting of the central study.

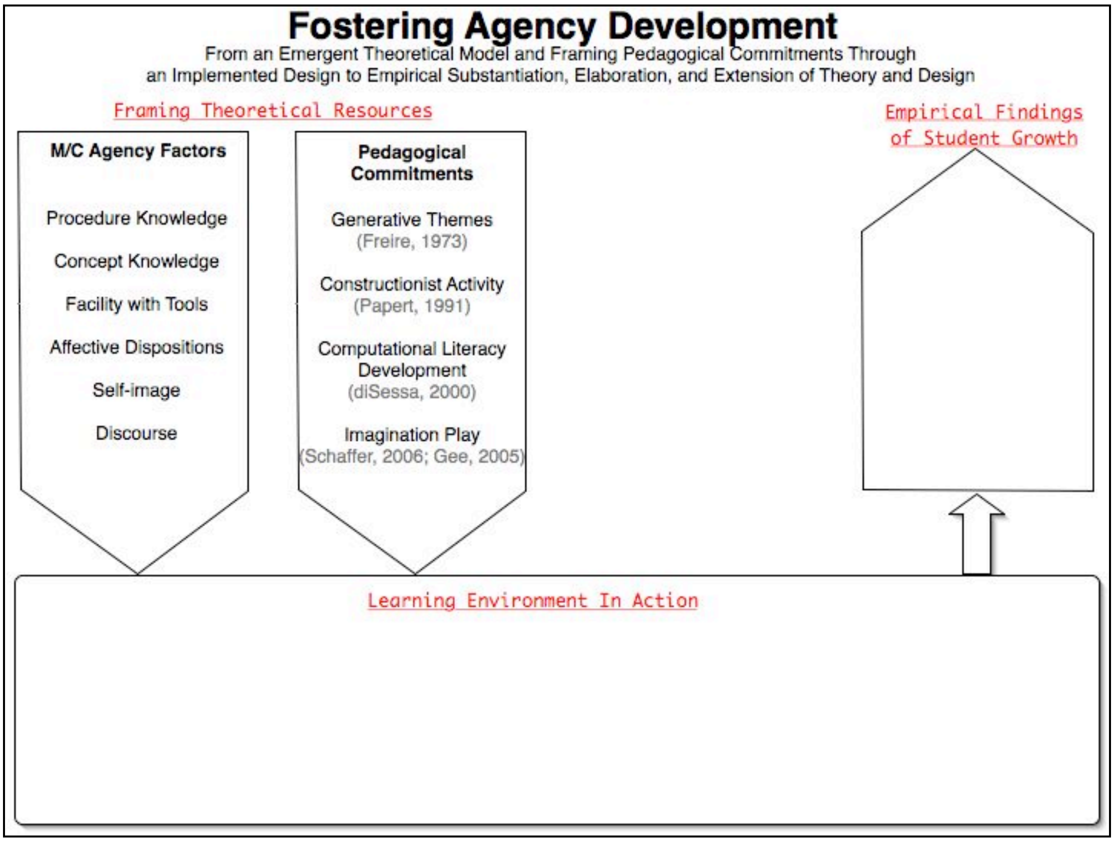

Figure 2: Agency Development Model: Pedagogical commitments as theoretical design resource

The m/c agency model and pedagogical commitments informed the instructional design elements, comprised of materials, activities, and facilitation (Abrahamson & Wilensky, 2007). Thus, the materials selected/built for this study served dual purposes: (1) to create context for activities eliciting students’ *generative themes* (Freire, 1973) that the designers-as-teachers could then reflexively and strategically match with target mathematical concepts (e.g., variables and functions) and computer-science concepts (e.g., recursion, looping), so that students appropriate the STEM content in the process of tackling emergent construction problems they have identified and articulated; and (2) to elicit students’ discourse surrounding mathematical activity and, hence, provide a lens on their evolving self-image as mathematical practitioners (see details in Figure 3, below).

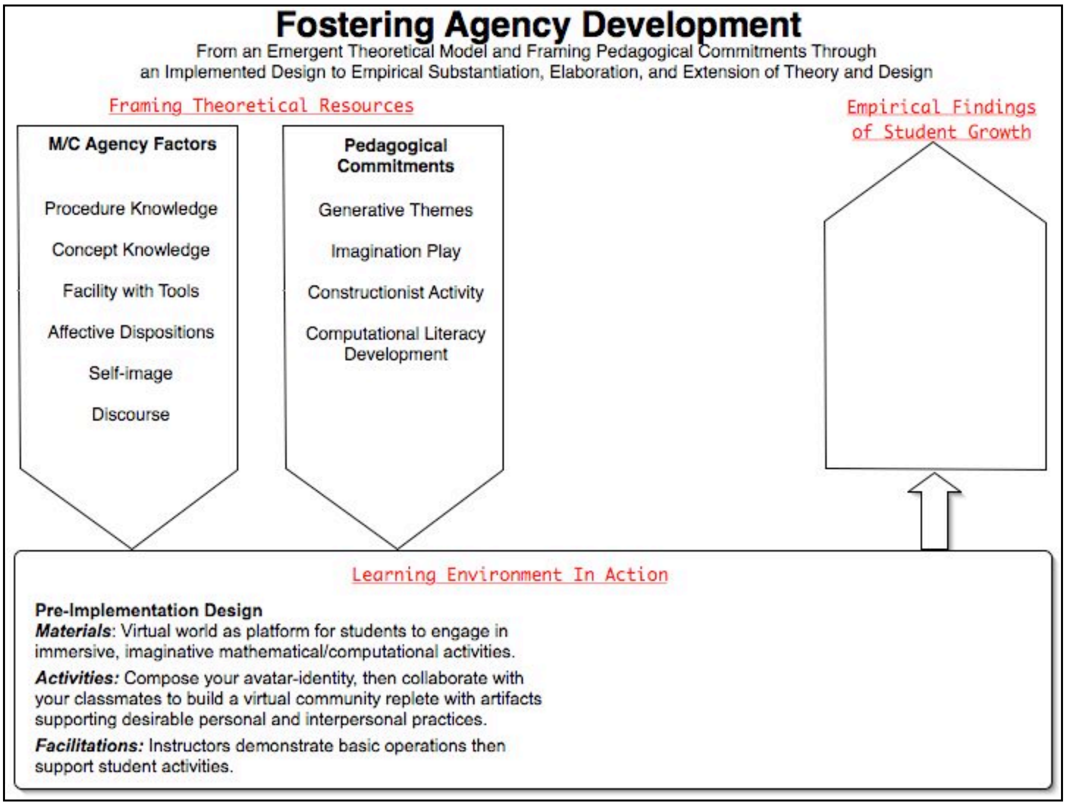

Figure 3: Agency Development Model: Materials, activities, and facilitations

Methods

Participants

Fractal Village was implemented with a class of thirteen 15 – 19 year old students from an urban California alternative high school. All students at this school enroll because they have been expelled from the local mainstream schools. The students are mostly of African–American and Latino–American descent, and all qualify for federal free lunch programs. Over half of the student participants have been categorized as Special Education students and have Individual Education Plans (IEP).

Procedure

We worked with the class for fourteen 110-minute sessions. After creating a virtual identity (starting with the generic avatar options shown below in Figure D), the students then spent the first 10 sessions constructing Fractal Village, a community in the TSL virtual world, learning programming skills in the process. The last four sessions were spent with students learning Hypertext Markup Language (html) in order to build customized web pages that presented the work they had accomplished in the intervention. Additionally, the students took a field trip to the Linden Research Laboratory and made a final presentation to a research group at our university.

Data Collection

The raw data collected in this study consist of: digital movies of collaborative work, screen-capture movies that archive every keystroke/mouse-click produced by each student, students' journal logs, digital movies of day-by-day individual interviews with a set of focal students, rich field notes, and participant-generated mixed-media artifacts, e.g., worksheets, modeling constructions, and computer screenshots. In addition, we videotaped the design-team's debrief/plan sessions.

Data Analysis

Using techniques adapted from grounded theory (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 m/c 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.

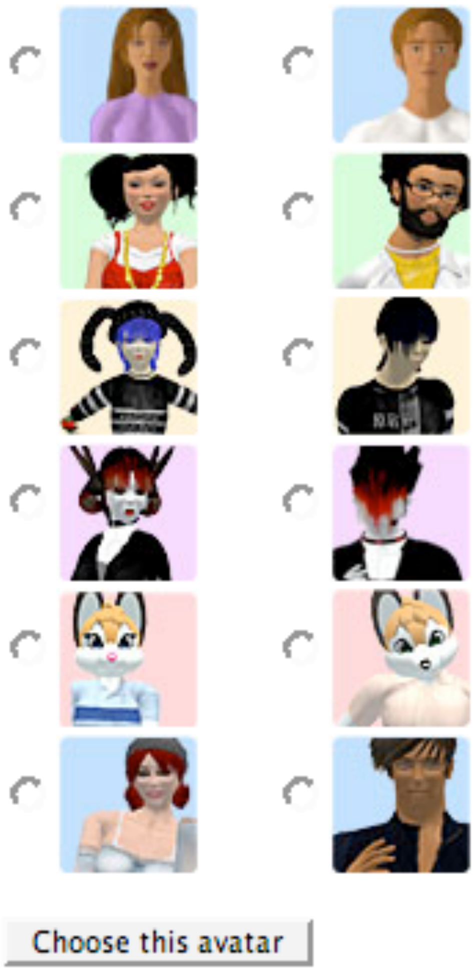

Figure 4: Generic set of avatars user can choose among. These can be modified later.

Results

We identified two discursive supports as necessary for student success that had not been specified prior to the implementation. The discursive supports (see Figure 4, above) – skills- and dispositions-related—reflect aspects of teacher–student interactions. These supports were not part of the initial design, but to maximize student success we augmented the model

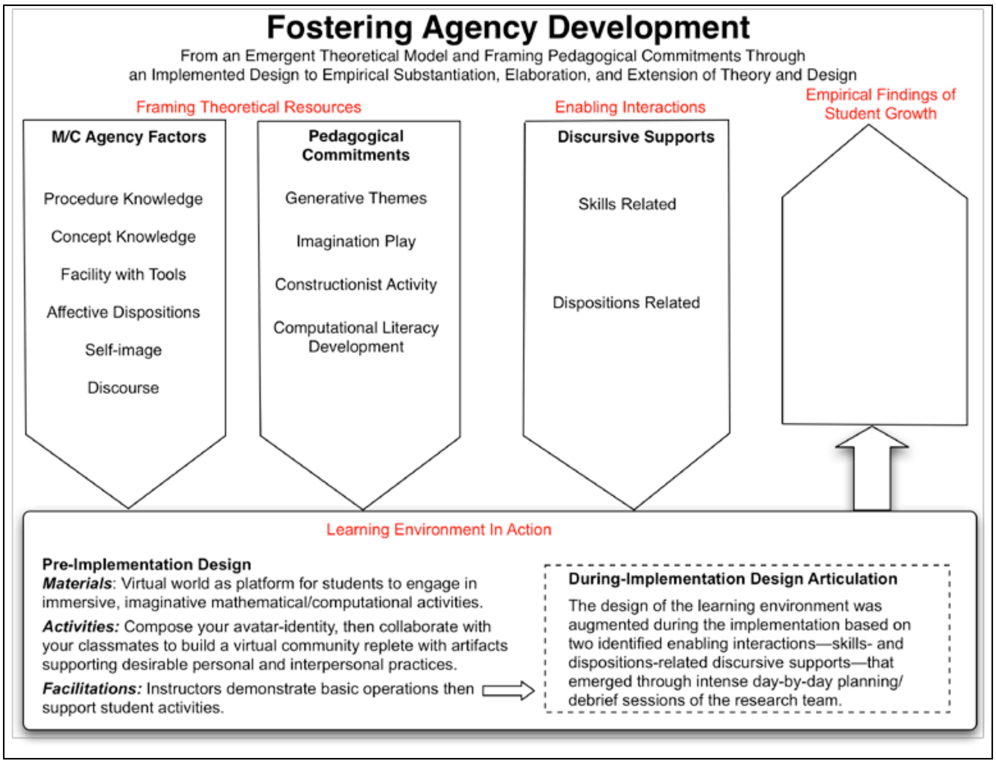

Figure 5. Agency Development Model: The design of the learning environment was augmented during the implementation based on two identified enabling interactions—skills- and dispositions-related discursive supports—that emerged through intense day-by-day planning/debrief sessions of the research team.

<u>Skills and Dispositions</u>

Through data analysis, we came to appreciate that it would be methodologically beneficial to cluster several of the original six m/c agency factors into two groups: skills (to include procedural and conceptual knowledge and facility with tools) and dispositions (to include affective disposition and self-image/personal positioning). As we attempted to code data[1], we found that the same data segments could be assigned to two or three different factors. Thus, creating the six factors into two clusters availed us of richer data segments. A brief description of each of the two clusters is furnished below.

Skills. Students developed two types of skills; *interface deftness* and *computational literacy*. By "interface deftness" we refer to students' ability to efficiently navigate the graphical user interface to accomplish a problem-solving task. "Computational literacy" is based on diSessa's (2000) work in new literacies and is defined as effective deployment of material intelligence in the context of computational problem solving to achieve valued intellectual ends (a slight adaptation of diSessa's definition of literacy, p. 19). The original scope of computational literacy has been narrowed for purposes of skill analysis in this study.

Dispositions. Mathematics-education research into affect has risen dramatically over the past two decades and was prominently positioned by both the National Council of Teachers of Mathematics and the National Research Council in 1989, in their recommendation that researchers attend to affective, as well as cognitive, factors related to mathematics teaching and learning (NCTM, 1989; NRC, 1989). Much of early mathematics-education research into affect utilized McLeod's (1994) classification scheme for concepts in the affective domain. The scheme included three concepts: *emotions*, *attitude*, and *beliefs*,

[1] The coding scheme we used is detailed in Veeragoudar Harrell, 2009 (Dissertation, U.C.Berkeley).

ranging from 'more affective/less stable' to 'more cognitive/more stable' (see Figure 6, below).

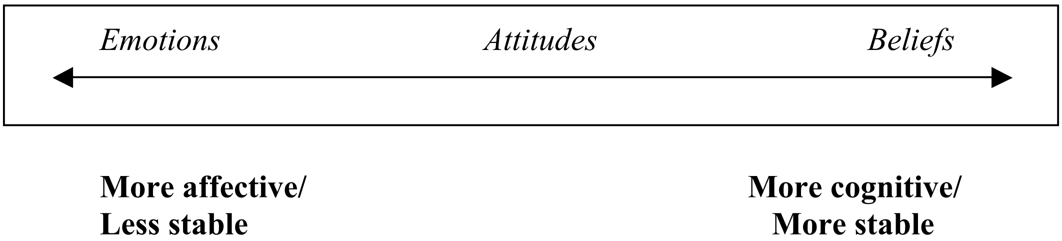

Figure 6: Uni-dimensional view of concepts in affective domain (McLeod, 1994).

McLeod's influential classification scheme was an important beginning that has since been elaborated to include the concept of *values* as well as interaction amongst the concepts (DeBellis & Goldin, 1997). The resulting model can be illustrated as a tetrahedron diagram (see Figure 7, below).

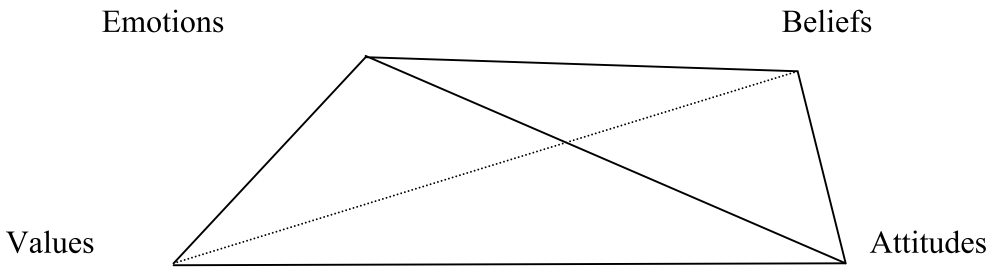

Figure 7: Tetrahedron model of affect in mathematics learning (DeBellis & Goldin, 1997).

Yet the tetrahedron model of affect, too is incomplete: it does not account for a variety of emotional phenomena such as motivation, mood, interest, anxiety, and self-conception that need to be, and are currently being, investigated by numerous researchers across disciplines. Predominantly, mathematics-education researchers have focused their attention on attitude. A newer wave of researchers has been oriented toward coupling, "what one knows" with "how one learned it" (Gresalfi & Ingram-Goble, 2008). Our research is aligned with this last view, which couples knowledge with the process of obtaining that knowledge. We utilize the disposition construct defined by Gresalfi and Cobb (2006) as "ways of being in the world that involve ideas about, perspectives on, and engagement with information which can be seen both in moments of interaction and in more enduring patterns over time." In this way the term "dispositions" is intended to capture affect towards mathematics/computer-science problem solving ("looking out") as well as towards one's self as a mathematics/computer science learner and practitioner ("looking in").

After collapsing the six factors into skills and dispositions[2], we came to realize that these were aligned with the enabling interactions we had earlier identified. These relations are color coded in Figure 8, below. M/C agency factors and discursive supports related to skills are written in blue text and those related to dispositions are in written in green text.

[2] The factor relating to discourse practices will not be discussed in this paper.

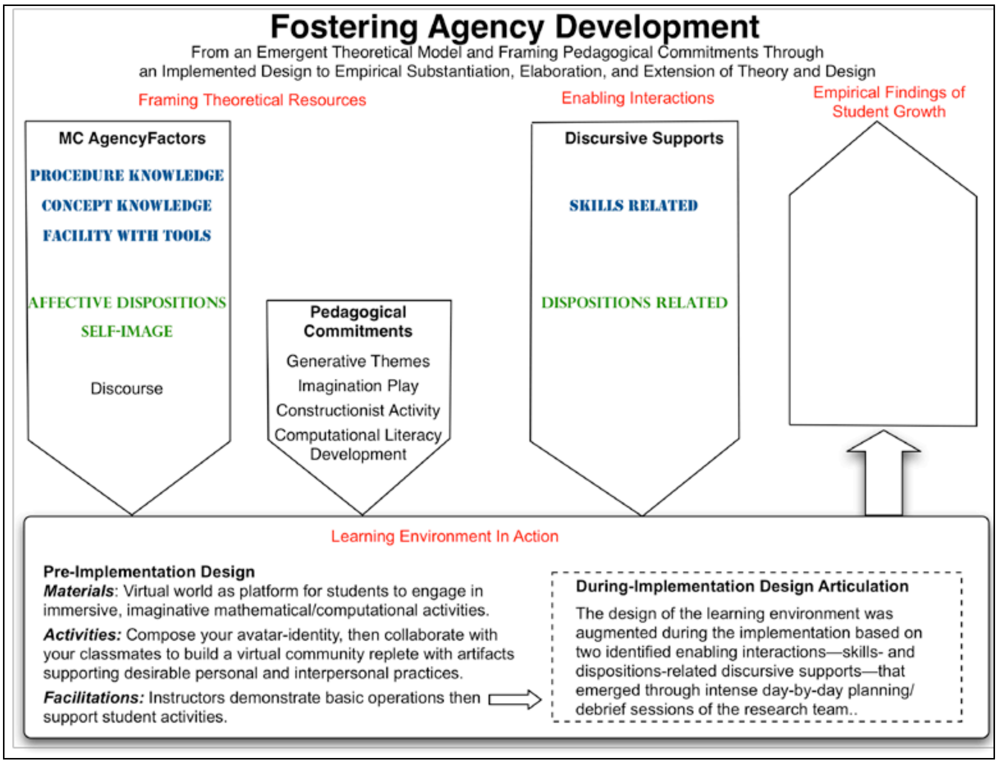

Figure 8: Agency Development Model: We collapsed M/C agency factors into skills- and dispositions-related factors. We realized after the study that there was a correspondence of the newly collapsed m/c agency factors with the discursive supports we had identified during the study.

Thus far, we have discussed all that was invested *into* the learning environment. Next, we will look at what came *out* of the learning environment. Specifically, we will look at students' m/c agency development over the course of the project, which temporally stretches from left to right in the figures.

Students' m/c agency development. We found that students developed m/c agency. This claim is substantiated by measurable skills and dispositions found in data collected during the study (see Figure 9, below).

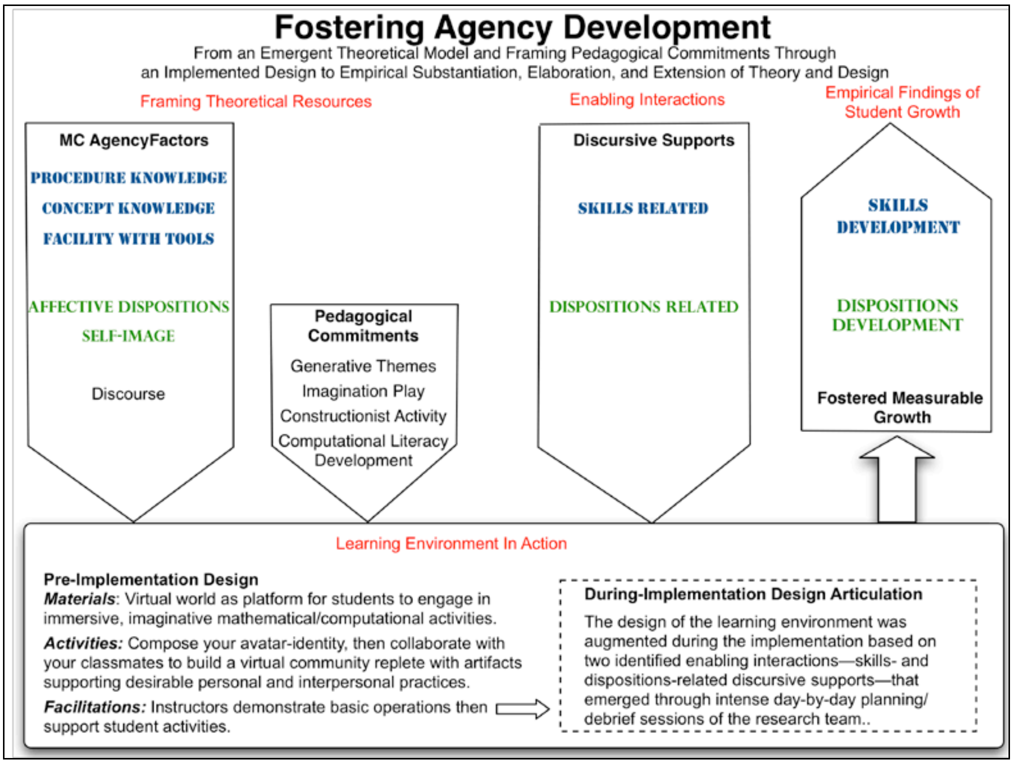

Figure 9. Agency Development Model: The learning environment in action fostered measurable growth in students, specifically skills- and dispositions development.

Recall that the project aimed to foster agency, thus straddling theory development as well as best practices development. With respect to the theory-oriented goal, we found that cognitive and affective factors are co-dependent variables, reciprocally related, in contributing to m/c agency development (see Figure 10 below, noting the feedback loop between skills and dispositions).

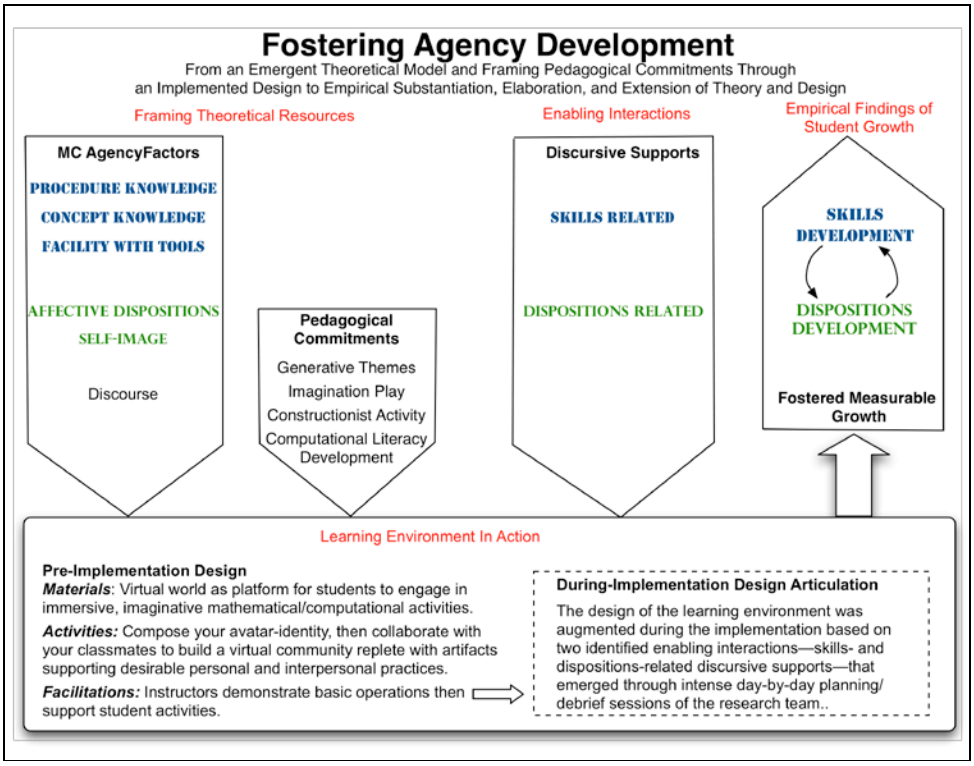

Figure 10: Agency Development Model. Students' skills- and dispositions development was reciprocal, gaining skills fostered positive disposition development and vice-versa.

With respect to the practice-oriented goal (delineating design principles), the emerging claim is that m/c agency development can be fostered through implementing a convergence of two sets of interventional components, namely *pedagogical commitments* and *discursive supports* (see Figure 10, above).

Grounding Theory in Data: A Case Study

The paper thus far has been a primarily theoretical treatment of the increasingly complex model of agency development. In this section we ground this evolution in data through the lens of one case study (for a greater elaboration, see Veeragoudar Harrell, 2009, for three case study reports). We report a snapshot of Shahzor, the case study participant, at the beginning and end of the project so as to illuminate the change he underwent. We then provide an overview of his activities in the project and then attend in detail to his inter-constructive skill and disposition development.

Snapshots: beginning and end. Shahzor, a participant in the study, is also a self-professed gang member, drug user, and he admits to engaging in criminal activity. He is in his 4th high school placement. At the beginning of the project he had the following exchange with the PI.

PI: Where do you see yourself in 5 years?
SQ[3]: [shakes his head side to side, indicating he does not know]
PI: [pause, giving him time to think] Where would you *like* to be in 5 years?
SQ: [laughs and shakes his head again indicating he does not know]
…
PI: What are you most proud of yourself for?

[3] We will abbreviate the pseudonym Shahzor when quoting him by using his initials, SQ.

SQ: Nothing. Ain't proud of myself, I'm ashamed of myself…I'm ashamed of myself.

Shahzor was unable to explain where he saw himself in 5 years. He had never experienced a virtual world environment and had never programmed. He claimed not to like mathematics. He could not identify accomplishments in his life that he was proud of.

By the end of the project Shahzor had the following exchange with the PI:

PI: Where do you see yourself in 5 years?

SQ: I want to be an architect.

…

[After presenting his project to a group of scholars at the University of California, Berkeley]

PI: What was your favorite part and what was the hardest part?

SQ: It was just hella fun cause these people they never saw anything like that so every time you show them they see they was like WOAH! It makes you really feel appreciated, they really like my work you know, give you a little confidence….Nothing was hard.

What fostered these changes in Shahzor over the course of the 4-week project? In this section, we will argue that the humanistic design principles at the heart of the study promoted Shahzor's agency growth. Namely, the design intervention enabled students' skill and disposition building within a safe, collaborative environment; this environment facilitated imaginative play, and students' development of m/c literacy skills was an authentic product of their immersive, supported engagement in the virtual world project.

Overview. Shahzor did not begin the project with great content knowledge, nor did he identify with mathematics as a discipline nor see himself as a mathematics learner or practitioner. Yet he leverages his comfort with construction tools. Experimenting with these tools, Shahzor engages mathematical/computer science concepts and procedures apropos of building artifacts, and he draws on the one-to-one support to accomplish his goals within the virtual world.

Shahzor had no programming or other computer-science knowledge at the beginning of the study, but did have experience with 3D object manipulation through playing computer games (e.g., Sims[4]), which may have served him as an entry point into the activities. For example, Shahzor wanted to build a skyscraper with multiple floors (Figure 11, below). To accomplish this task, he had to weigh the pros and cons of using the graphical interface to manually build stairs versus programming a set of stairs that could be generated automatically (see Figure 12, below). Should he decide to program the stairs, he would need to determine whether he should hardcode a set height for the stairs or base the construction on user input. Note that there are tradeoffs regarding the workload, knowledge, complexity, and usability of each decision.

[4] http://thesims.ea.com/us/

Figure 11, Shahzor's final skyscraper, comprised of glass walls, an interactive door, a wood floor, staircases, and a striped rooftop with pyramid décor.

Figure 12. Shahzor builds a series of staircases as we discuss various construction options.

Initially, Shahzor harbors negative feelings toward mathematics, yet he nevertheless consistently engages mathematical activity throughout the project. For example, Shahzor expresses interest in architecture, yet feels he cannot study this field because of the demanding amount of mathematics he would need to know. However, he experiments with mathematical thinking when utilizing tools embedded within the 3D environment to manipulate his artifacts.

Shahzor readily engages in mathematical thinking just as long as he does not perceive the activity as constituting traditional classroom mathematical problem solving. For example, he began experimenting with building and manipulating objects in the virtual world on the very first day of the intervention, without any suggestion to do so by the researchers. This behavior is in contrast to his behavior in his mathematics classroom where he needs to be repeatedly told to do his work before he will finally do it.

Reviewing Shahzor's computational-, mathematics-, and school-related comments reveals that the process of building mathematical or computational identity or gaining discipline-affirming dispositions is certainly not straightforward. In summary: (1) In relation to Shahzor's computation-related dispositions, we found a distinction between his use of the computer as a medium for interacting with software programs and his use of the computer as a programmable tool, a distinction reminiscent of diSessa's (2000) articulation of computer literacy vs. computational literacy. (2) In relation to Shahzor's mathematics-related dispositions, we found that he had inconsistent dispositions towards mathematics based on whether he feels he comprehends the material. Furthermore, it could fruitful to explore if his self-image varied based on his contextual framing of any mathematical content as 'school-' or in the 'real-world.' (3) In relation to Shahzor's school-related dispositions we found that he feels disengaged by lecture-style instruction. However, despite a general sense of disenfranchisement from the educational enterprise, he nevertheless appraised that school would be instrumental for his future prospects and thus tries to do his best.

Inter-constructive skill- and disposition- development. Below, we provide evidence to support our assertion that Shahzor's agency development were a dynamic and reciprocal co-construction of skills and dispositions. We begin with a visualization of Shahzor's skill and disposition growth over time (see mapping on Cartesian plane in Figure 13, below). The coding scheme we utilized to plot the points in Figure 13 is based on student behaviors, statements, and activities contributing towards skill- or disposition- building.

When we had coded all the chunks, we plotted them on a Cartesian plane as ordered pairs of cumulative disposition and skill (disposition, skill).[5]

---

[5] Most days are single data points, but on Day 17 there was both a class session in the morning and an afternoon presentation to a group of scholars at U. C. Berkeley, and therefore Day 17 is broken into 17am and 17pm. Most days are represented by a dot, but Days 6 and 15 are represented by horizontal lines. On these days, Shahzor conveyed a wide array of dispositions (see below for further details).

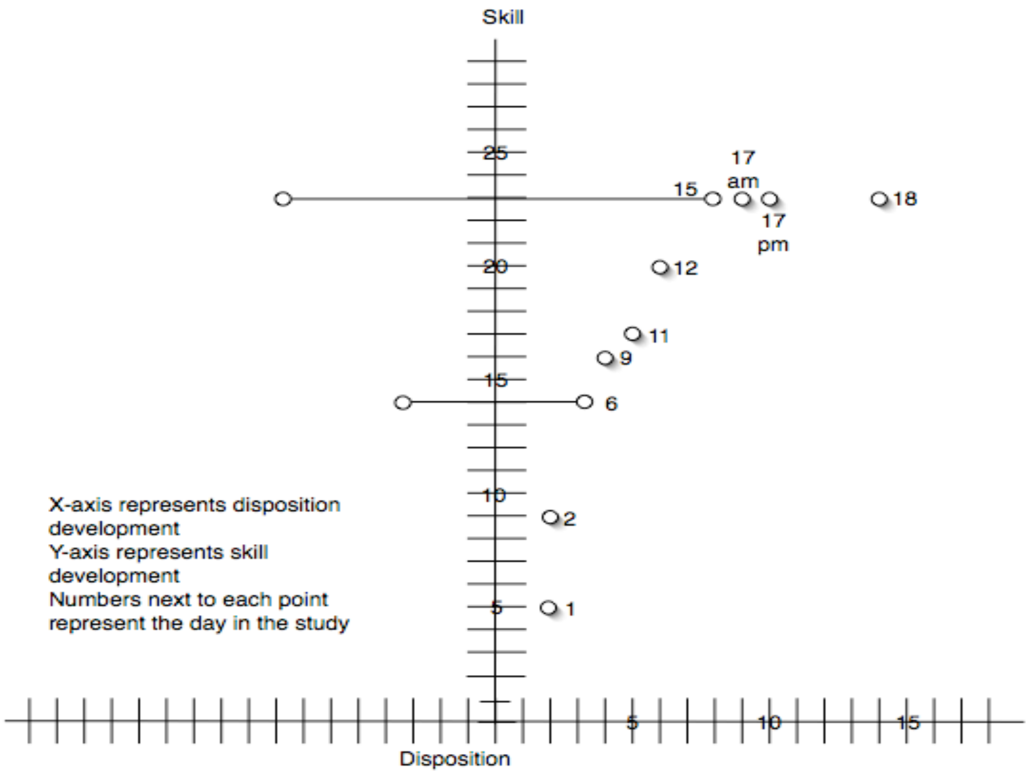

Figure 13. Shahzor's skill and disposition development synthesized.

The above grid shows both skills and dispositions developing over time. This plot demonstrates a monotonic increase in both skills and dispositions. However, at this point one need not read this plot as necessarily expressing a *relation* between the two dependent variables (skill, disposition). Following, we will narrate Shahzor's experience in the intervention. The analysis captures observed connections amongst skill-related and disposition-related data segments. Emerging from this analysis is an assertion that skills development and dispositions development are reciprocal and co-dependent. That is, student development along each of these two dimensions enhanced development along the other dimension, and vice versa, in a dynamical "zigzag" reciprocity (see Figure 14, below—several of these episodes, which are captured by titles in boxes, are then elaborated in the subsection). Further analysis can reveal more of the details of a general connection between perceived incrementally competence and an improved disposition.

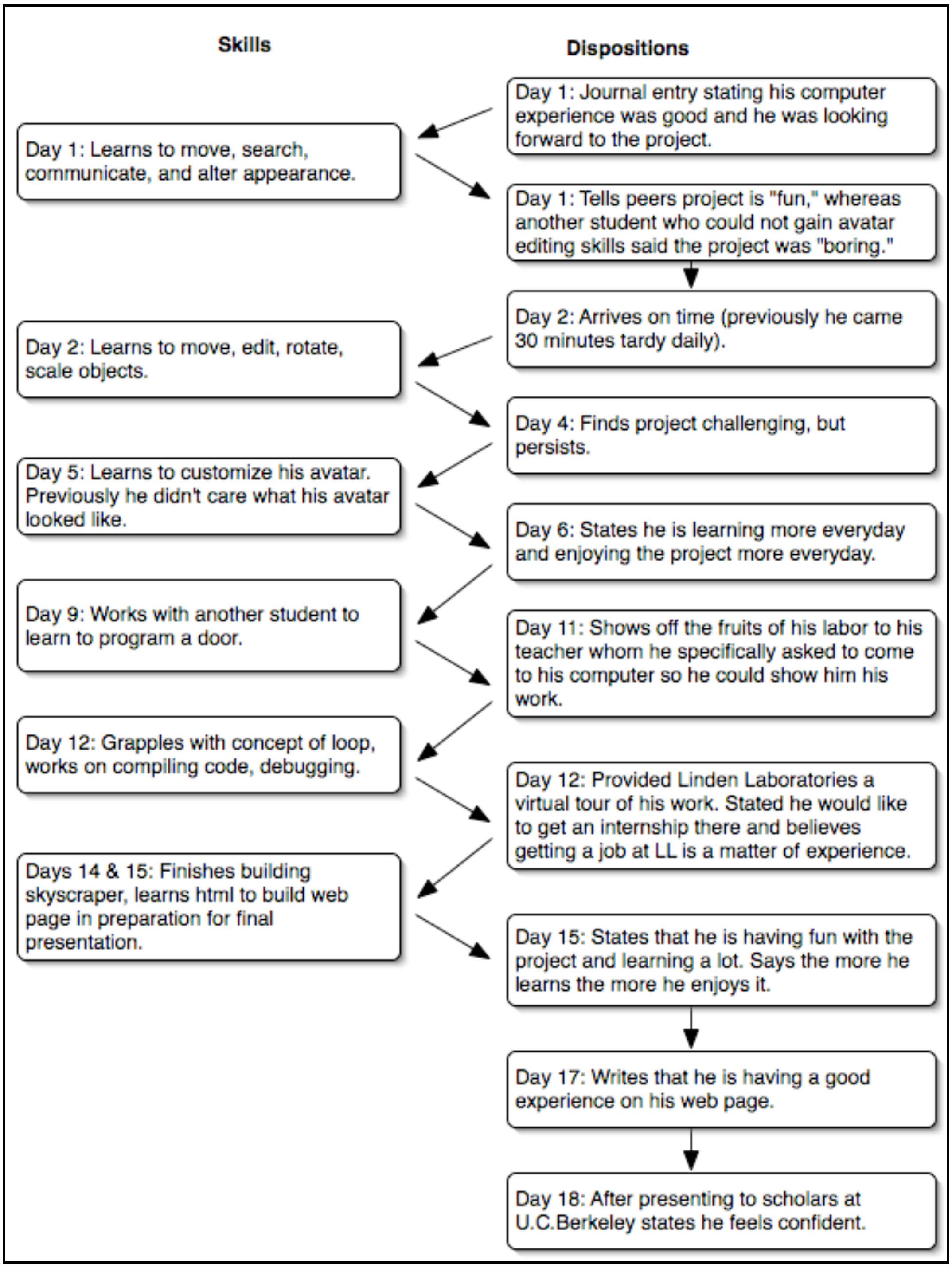

Figure 14. Snapshot of Shahzor's construction of skills and dispositions over the course of the project, with arrows that demonstrate the reciprocity of these two types of increments.

In order to support our emergent conjecture regarding the reciprocity of student development along the two core trajectories, skill and disposition, we now report on results of inspecting the relationship between skills development and dispositions development. To do so, we shall inspect a small selection of data episodes from the above diagram.

Day 1: positive mental attitude. After having spent most of the class guiding students in creating accounts and begin exploring the environment, we gathered all the participants for a brief discussion so everyone could share their initial experiences. As compared to his classmates, Shahzor had been making significant headway in terms of exploring and learning in the environment. One classmate who had had a particularly negative experience trying to edit his own avatar proclaimed, "This stuff is boring." Shahzor responded, "Naw you're trippin' man, this stuff is fun." The classmate who thought the project was boring had not been able to obtain the skills he desired. In contrast, Shahzor, who had had a positive experience gaining the requisite skills reacted with positive sentiment towards the project.

Day 2: In class, and on time. On Day 2, and all days thereafter in the project, Shahzor arrived to class on time, whereas previously in the semester he regularly arrived 30 minutes tardy. His interest in the project thus increased his time-on-project, in turn increasing his opportunities to develop further skills.

Day 11: Taking pride in his work. Shahzor made it a point to ask his teacher to come visit his work area so he could show him the skyscraper he was building. In this gesture, Shahzor demonstrated pride in the work he has accomplished with his new skill-set.

Day 12: It's a matter of experience. Shahzor gave a virtual tour of his work to Linden Laboratories employees while on a field trip to the company's headquarters in San Francisco, California. After the visit, the PI conducted a brief interview with him. Shahzor stated, "It's like cool working there…I'd work there if I could. I think you just gotta be experienced." Shahzor's statement suggests he believes gaining employment at Linden Laboratories is an actual viable prospect for his future employment, contingent only upon gaining further experience and skills. He thus construes achievement as the product of learning and views such achievement as well within his personal horizon of possibilities.

Day 15: Wants to take it home. On Day 15 Shahzor states, "I was thinking I might, I might just put that [SL] on my computer at like, home you know. Find out more about it. Work on it. The more I work on it the more I'm going to find out about it...I take it as fun so the more I'm gonna do it the more I'm going to be good at it." His statement indicates a reciprocal relation between being positive about a learning activity and gaining knowledge and skills.

With that, we conclude the survey of daily instances of skill- and disposition-related exchanges with Shahzor. The survey demonstrated an intermittent tie between these two aspects of Shahzor's agency growth. As design-based researchers interested in students' development of skills as well as positive mathematics- and computer-science dispositions, the interesting question becomes, "How do we design so as to foster both skills and dispositions?" In particular, looking at our data, a more specific question has been, "Which, if any, aspect(s) of the design and facilitation of the learning environment fostered the skill-based and dispositional aspects of Shahzor's agency development?"

In order to begin addressing this practical question, let us recall that the framing theoretical and practical resources that input into the design of the empirical environment included four *pedagogical commitments* and the facilitation involved two *discursive supports*. This case study analyzed empirical data from a single student's experience in our intervention. The study's objectives were two-fold—theory-oriented and practice-oriented. Toward the theory-oriented goal, we presented evidence of this student developing along lines of both skill and disposition and argued for the "zigzag" inter-constructive relation between growth in skill and disposition. Toward the practice-oriented goal, we traced these effects to the design's original pedagogical commitments and to the discursive supports proffered by the researchers.

Educational and Scientific Importance of Study

The implications of these findings are important for Shahzor and students like him, who have been failed by our public school system. Shahzor has spent nearly thirteen years in a school system that he felt he did not belong in. Over those years, he has bounced around schools and finally was (r)ejected by the mainstream high school. In his alternative school and adult school, he often wants to walk away, and some days *does* walk away. Through his own admission, Shahzor is engaged in gang and criminal activity. The bleak prospects, which unfortunately are statistically viable, are that Shahzor could end up in prison. Yet, at the same time, and just as real, Shahzor still maintains buried, dormant yet intact dreams of becoming an architect and a desire to make his family proud.

This case study serves as an existence proof and wake-up call to the effect that Shahzor, and students like him, can: (1) be critically engaged, highly motivated, and maintain disciplined focus in learning mathematical and computational content; and (2) develop positive mathematical/computational self-images. *For these students, who have few if any attentive academically-oriented adult models in their lives, teachers' dedicated provision of skills-related instruction, though paramount, is not sufficient.* Dispositions-related supports are also required. Making a deep impact in students' self-image and affective disposition toward the very knowledge and skills that may enable them to soar above their statistical rubric requires forming a human-to-human connection, even before or even as forming a teacher-to-student relationship. Attending to Shahzor's development of positive affective dispositions (towards mathematics, computing, and schooling) and positive self-image was a pedagogical requisite that operated hand-in-hand with his development of conceptual and procedural knowledge and facility with the tools associated with STEM disciplines. With these supports ready and able, the learning environment—which drew upon our theory of m/c agency factors, pedagogical commitments, and discursive supports—fostered Shahzor's mathematical- and computational-agency development.

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 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 are devastating, both for students—the "end clients" 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.

Acknowledgements

We acknowledge with gratitude the comments of members of the Embodied Design Research Laboratory (Abrahamson, Director) at the University of California, Berkeley and in particular members of the Fractal Village Crew: Kelly Buchanan, Daniel Fragiadakis, José Francisco Gutiérrez, and Dragan Trninic.

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