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Teachers, Students, and After-School Professionals as Designers of Digital Tools for Learning

Michelle Hoda Wilkerson

As this volume shows, researchers are increasingly involving learners, teachers, and other stakeholders in even the earliest stages of design (Bonsignore et al., 2013). However, different groups—teachers, students, administrators—within educational systems often have different goals (Konings, 2005). For example, administrators adjusting to shifts in educational policy may wish to promote inquiry-oriented activities, whereas students accustomed to simple performance measures and direct instruction may expect to memorize and recall facts. Furthermore, since design-based projects seek to promote novel forms of learning (Cobb et al., 2003), participants may not know or share researchers' educational goals and values (Fishman, 2014). Such tensions are especially salient when digital tools for learning are at the center of design, because they often require new skills, pedagogies and social configurations (Blumenfeld et al., 2000).

Communication and collaboration routines have been developed to address these tensions by, for example, facilitating perspective taking and negotiation among stakeholders (Penuel, et al. 2011) and between practitioners and researchers (Penuel et al., 2013; Voogt et al., 2015). There are models to identify potential synergies and points of tension among members of educational systems (Konings, et al. 2005) and to identify relevant social, cultural, and technical features of systems that may influence how designs are enacted (Bielaczyc, 2006). But even with these routines and models, researchers are still likely to receive varied or even contradictory feedback during the design process. Investigating how different perspectives are navigated and contribute to design decisions is rarely the focus of deliberate study (Konings, Seidel, & Merriënboer, 2014).

In this chapter, I present a retrospective case study focused on these decisions. SiMSAM (NSF IIS-1217100) is a project to develop tools, curricular materials, and theories of learning to introduce middle school students to computational modeling as a form of scientific inquiry. For three years, the SiMSAM research team has worked with youth, teachers, and informal educators across study contexts including laboratory-based workshops, classrooms, and after-school programs. Here I extend Sandoval's (2014) method of conjecture mapping to investigate the influence of these different participant groups and study contexts on our design.

The analysis revealed implicit systematic influences and decisions: we attended to youth perspectives on design of the tool's interface and functionality, teacher perspectives when developing and refining pedagogical theory, and our work in after school environments informed our design of supporting materials and hands-on curricular activities for use with the SiMSAM tool. In some cases, different participant groups' input were well aligned, but in other cases their input conflicted and required designers to make decisions about whose input to take into account, and in what ways. Making these aspects of the design process explicit can reveal which stakeholder voices are reflected in the products of design and uncover the commitments that guide designer decision making, and can help researchers purposefully plan future participant design involvement. These details are particularly important to document in the design of digital tools for learning: retrospectively to uncover the values, perspectives, and pedagogical contexts within which the tools were developed; and formatively to help designers identify which participant groups and settings may be most appropriate to leverage for a given feedback session.

The SiMSAM Project

The SiMSAM Project aims to introduce middle school science students to *computational modeling*: the practice of creating and using computer simulations to elaborate and test scientific theories. The project brings together two important advances in science education. First, it builds on work that emphasizes the importance of scientific modeling in K-12 (e.g. Schwarz et al., 2009; Spitulnik, Krajcik, & Soloway 1999; White & Frederiksen, 1998), by encouraging young learners to create, test, share, and revise their own explanations for surprising or unknown scientific events. Second, it builds on work that engages students in computational thinking and construction to explore and communicate about science (Jackson, et al, 1994; Papert, 1980; Wilensky & Reisman, 2006; diSessa, Sherin & Hammer, 1993).

Inspired by these two lines of work, we are developing an integrated animation, simulation, and data analysis toolkit (SiMSAM). Young learners create stop-action movies to present theories about how unseen experiential phenomena such as smell diffusion, sound propagation, or evaporation work. They can then crop images from their animations to create a simulation. Each cropped image can be programmed to move and interact with other objects through a combination of direct manipulation and a menu. Finally, measurement tools allow youth to explore the quantitative entailments of their theorized and simulated models. Our goal was to introduce simulation as expressive by tying it directly to stop-action moviemaking, a more familiar medium, and by asking learners to model everyday scientific phenomena. Screenshots of the current version of SiMSAM are featured in Figure 1. We have also developed curricular activities and introductory materials for educators to use with SiMSAM.

Figure 1. The current version of the SiMSAM toolkit. Students create stop-action movies of scientific phenomena in the animation module (left; condensation) by taking photos using drawings and craft materials. They can then crop images from any frame of their animations; each cropped image becomes programmable objects within the simulation module (right).

The SiMSAM research team has regularly engaged in co-design and collaborative inquiry activities with youth, teachers, informal educators, and design consultants. These have taken place in workshops, professional development sessions, classroom enactments, and after-school programs (Table 1). We observed and captured detailed data about learning, usability, and social interactions as participants interacted with existing software and our developing design. We also actively consulted with those participants for feedback on how to improve those designs. In this way, participants are best described as design *informants* (Druin, 2002): our expectation was that each participant group would contribute "privileged observations" (Scaife & Rogers, 1999) that reflected their different roles and knowledge of the pedagogical system. This approach is similar to the informant design framework proposed by Scaife and colleagues (1997) which purposefully engages particular groups of users during particular phases of design. Our current exploration extends this approach to investigate not only how contributors might inform design at particular stages, but also what specific material, technological, social, or cultural elements of a design and its corresponding theory are influenced as well.

In this chapter, I will review four phases of research, design, and revision. The first two were internal, led by project staff at our home institution. The second two were external, conducted at educational sites where our partner educators led activities with support from the research team. Table 1 summarizes the study context, participant group(s) involved, and data sources collected for each; I also describe each phase in more detail in the next section. For my analysis, I use these data sources to identify: (1) Major changes in our design or theory across phases of the project, and (2) The participants, contexts, and/or events that informed each change.

Table 1. Overview of the first 4 phases of project.

	Phase 1	**Phase 2**	**Phase 3**	**Phase 4**
Study Context	10-hour Workshop at University	15 hour Workshops at University	10 hour Classroom Enactments	10 hour After-School Outreach Club
Participant Group(s)	Youth (grade 6)	Pre-service Teachers	Classroom Teacher Students	Club Director Facilitators Youth
Data Sources	Video of Session Design Recommendations Designer Notes	Video of Session Written Work Design Recommendations	Video of Sessions Consultation with Teacher Researcher Notes	Video of Sessions Consultation with Facilitators

Analytic Framework

To understand how different participant groups and study contexts influenced the design of SiMSAM, I extend Sandoval's (2014) *conjecture mapping* technique. Conjecture mapping is intended to help researchers systematically describe the material and theoretical aspects of learning environment design—what Sandoval calls the *embodiment* of a design conjecture, and the *mediating processes* through which that design is expected to contribute to learning. Material aspects include the software, curricula, and social and discursive structures needed to enact a designed innovation. Theoretical aspects describe how specific experiences structured through that design are expected to lead to desired learning outcomes. The assumed links that connect specific elements of an embodiment to the certain mediating processes that are expected to foster learning are called *design conjectures*. The assumed links between mediating processes and outcomes are called *theoretical conjectures*.

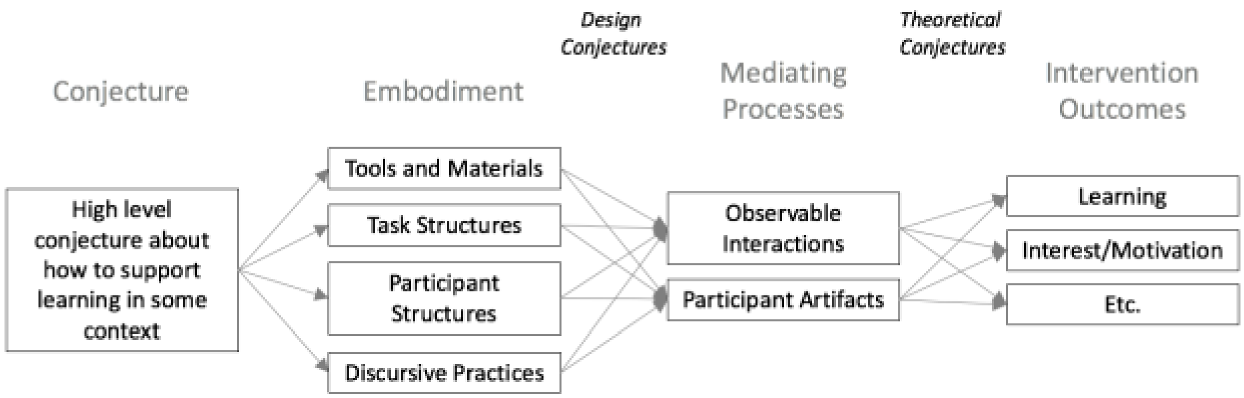

Figure 2. Overview of conjecture mapping method. Adapted from Sandoval (2014).

I choose conjecture mapping as an analytic approach for three reasons. First, it allows me to examine not only the influence of participant input on the material products of design, but also on its *theoretical* products and implications: a major goal of design-based work. Second, it offers a level of specificity that allows me to isolate and trace changes in both the specific elements of an embodied design, and the corresponding theories that I expect each design element to mobilize. Third, while conjecture mapping was not originally intended to trace trajectories of design across iterations, its simple, highly structured, visual format makes analysis across iterations tractable and available for study in ways that might be difficult with longer design narratives.

Sandoval notes that while "…conjecture mapping does not easily capture movement along a research trajectory, but there are a couple of ways they might be used to envision one" and "[a] longer [design] trajectory might be represented as a sequence of conjecture maps" (2014, p. 22-23). Here, I adapt conjecture mapping specifically to examine the iterative and participatory nature of design research. I focus on how the material and theoretical products of design are affected across time and participant group. I will focus on the dimension of time by presenting iterative versions of the conjecture map for each phase of research and development, highlighting changes in the elements and links from one conjecture map to the next. I will focus on the dimension of participant group using color to identify which participant group(s) informed each change.

Tracing the Design of SiMSAM

The SiMSAM project started with a set of design and theoretical conjectures articulated in the original project proposal. The high-level conjecture driving the SiMSAM project, as described in the original project grant proposal, is summarized as an effort "to bridge the gap between current theories of learning and available technologies for science education by merging an easy to use animation tool with domain-specific simulation and data analysis tools [for the purpose of]… Providing a technological continuum from students' ideas to simulations and analysis… Motivating the generative power of student-created models… [and] Introducing simulation as scientific discourse" (Wilkerson-Jerde & Gravel, 2011, p. 2-3). Figure 3 is a conjecture map I created from the initial intended design and conjectures described in that grant proposal. As I describe below, these conjectures and assumed pathways were quickly challenged and revised during each subsequent phase of the project.

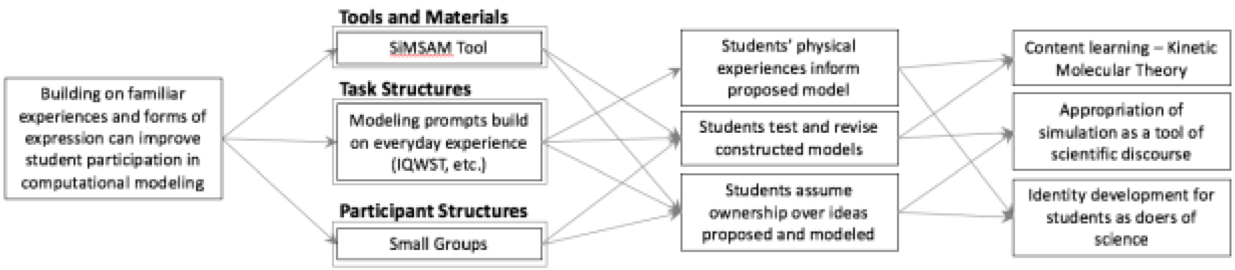

Figure 3. Conjecture map describing initial intended project design and goals.

Phase 1: Youth Design Workshops

In our first phase, we consulted with five sixth-grade girls during a multi day modeling activity using a number of existing software tools (SAM Animation, StageCast Creator, Scratch) that had inspired our own proposed design. We used a prompt from an established scientific modeling curriculum, "How can I smell from a distance?" (from IQWST, Shwartz, et al. 2008). We asked the girls to draw, animate, and then simulate their ideas for how this happened using the available tools, and analyzed their learning and discourse throughout the activity; a detailed report of our findings can be found in Wilkerson-Jerde, Gravel & Macrander (2015). We also directly consulted with the girls about how we could improve the existing tools so that would better support their activities.

Both our analysis of student learning and the girls' feedback about the tools they used suggested changes we needed to make to our design. The activity prompt we provided did encourage the girls to create models based on rich existing knowledge, one of our main design conjectures for this first round of work. However, they did not engage in as much testing and refinement of their models as we expected. Our prediction was that the ability to quickly change aspects of their models, run them, and create measurements to test how well the models reproduced reality would encourage the girls to recognize the limitations of their original models and work to improve them. Instead, they only revised their models when we directly challenged whether their model accurately reflected what they know should happen across time (smell should spread and "fade") or space (smell should be more intense at its source). We decided to add activity templates in the form of handouts that specifically focused students on how phenomena unfold across time and space.

The girls reported that they found some elements of the tools we used in the workshop frustrating to use. They confirmed that many of our intended design features, such as a drag-and-drop interface and the ability to import images directly from the animation, would improve their experience. They proposed a number of simulation functions they would like to have available in order to build the models they wanted, such as the ability to determine whether objects were overlapping one another. They also proposed interface features, such as the ability to save a simulation with a particular set up so that it could be re-set and re-run. We noted these suggestions and integrated many of them into our plans for the first version of the SiMSAM tool.

Figure 4 presents a revised conjecture map describing how the findings and feedback we obtained from this first phase of work informed our design revisions. Items that were added or revised are highlighted in red, to indicate that they are the result of feedback or findings from youth. Dotted lines indicate a link that we expected but that did not manifest in our data, and red solid lines to indicate new links we found during this phase.

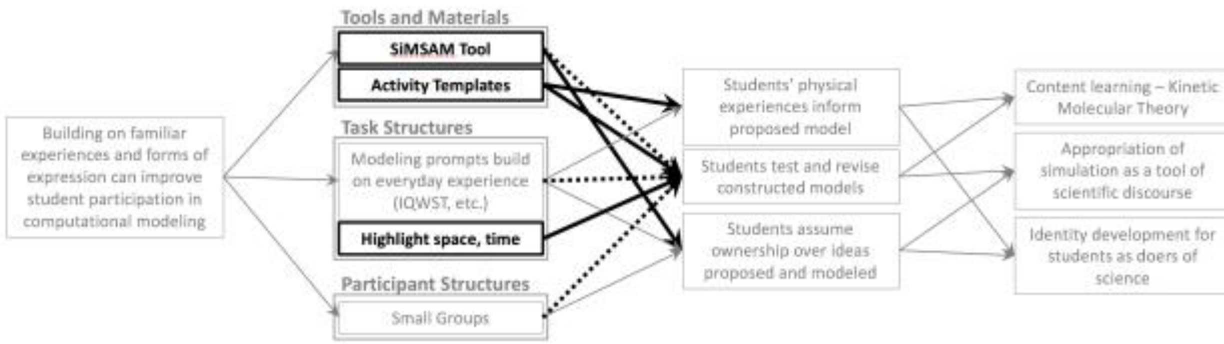

Figure 4. Revisions to conjecture map based on contributions by youth during Phase 1.

Phase 2: Consultation with Pre-Service Teachers

Next, we created a prototype of the integrated SiMSAM tool. We presented this prototype and draft curricular materials to pre-service teachers enrolled in a STEM-focused elementary certification program. Over the course of three days, we asked participants in the program to complete an activity as if they were students. Next, we asked them to watch video from our Phase 1 workshop for additional data about how students may experience the activity. We asked the teachers to provide us with feedback about the activities themselves, including what they believed would be the most accessible, difficult, and valuable parts of the activity. We also sought feedback about the design of the tools and materials, and about what supports they would need to feel comfortable enacting such activities in their own classrooms.

The pre-service teachers asserted that for the SiMSAM activities and tool to work in classrooms, students should be comfortable sharing, critiquing, and making sense of one another's work. They mentioned ways we could foster such an environment by leveraging already-existing classroom routines. For example, *gallery walks* are a common classroom activity. Students walk through the classroom, working to understand and provide feedback on one anothers' produced artifacts. Incorporating these pre-existing routines could make SiMSAM activities more familiar and comfortable for both students and teachers, and foster the classroom cultures needed for those activities to be productive and engaging.

The teachers were uncertain, however, about their comfort level with the simulation tool and were unsure whether they would be able to support students during the activities. These difficulties with the tool's interface were in conflict with feedback from youth users, who had specifically requested many of its features and found the interface accessible during user tests. These concerns also led the teachers to question the value of computational modeling for thinking about science, given the apparent learning curve. Some teachers believed that the difficulties of the tool would prevent students from comfortably and fluently sharing their ideas. Others suggested the constraints of the tool encouraged users to focus on precise, mechanistic descriptions of the phenomenon that could be tested in ways verbal descriptions or drawings could not—indeed, one of our major goals for the project.

We addressed these tensions in two ways. Rather than edit the interface, we introduced a one page "Tips and Tricks" document that helped teachers feel comfortable advising students on how to use the software environment. We also decided to focus more explicitly, both in our design embodiment and our theoretical considerations, on the unique benefits and limitations of computational modeling in comparison to other common science activities.

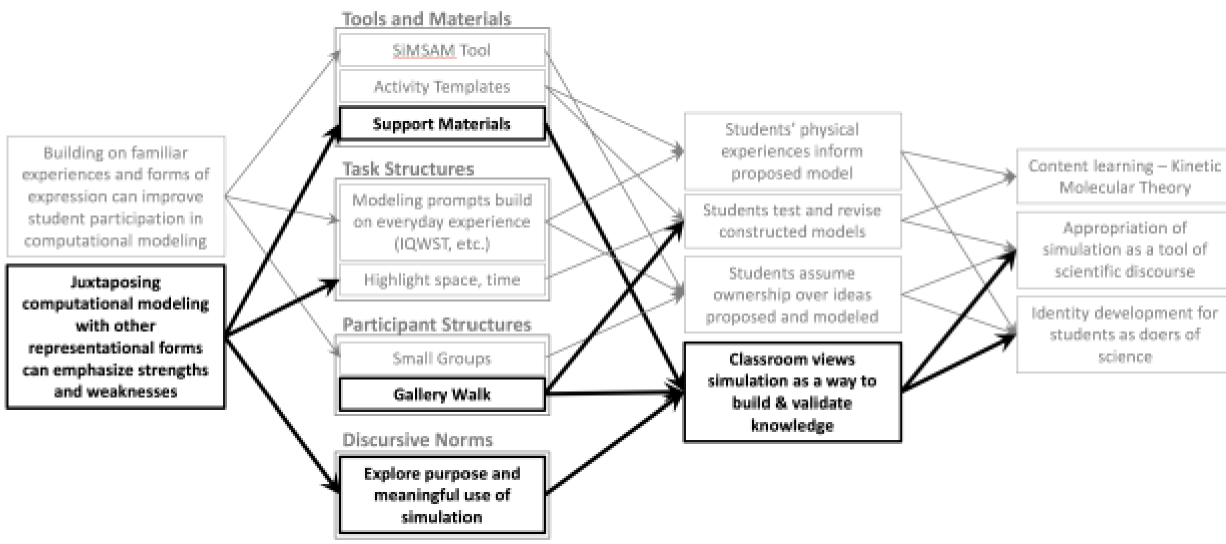

Figure 5. Contributions by pre-service teachers at design/professional development workshop.

Phase 3: Fifth Grade Classroom Enactment

After continued refinement of the SiMSAM tool and activities, we worked with a teacher who participated in Phase 2 to enact two-week long lessons using SiMSAM in two of his fifth grade science classrooms. The students created and refined models to address the questions: "When I am thirsty in the summer, I pull a cold drink out of the refrigerator and leave it on the counter. Before long, beads of water appear on the outside of the drink. How did the water get there?" And, "After a rainy day, sometimes you can see puddles on the ground. Later in the day, the puddles are gone. What happened to them?". We analyzed student discourse, the artifacts they produced, their interactions with facilitators, and we directly consulted students during class discussions about what types of things they wished they could do with the software but were unable to.

During these sessions, we found that the activity templates we introduced after our first phase led to some unexpected benefits. Because students created animations and computational rule sets based on the same template images, their rules could be combined or compared against one another to build or motivate classroom-level knowledge building. This led to especially productive classroom-level discussions and encouraged students to work toward group-wide consensus about what model best explained evaporation and condensation. This pushed our thinking about what mediating processes within the SiMSAM environment could lead to productive learning. Because this finding was due to feedback and findings from both the teacher/facilitators (blue), and students (red), we show it here in purple. Students also offered that while the interface was straightforward, they could not enact particular rules they thought would be important: for example, they wanted objects to spawn other objects (such as puddles creating water droplets), and they wanted to be able to change the color of objects.

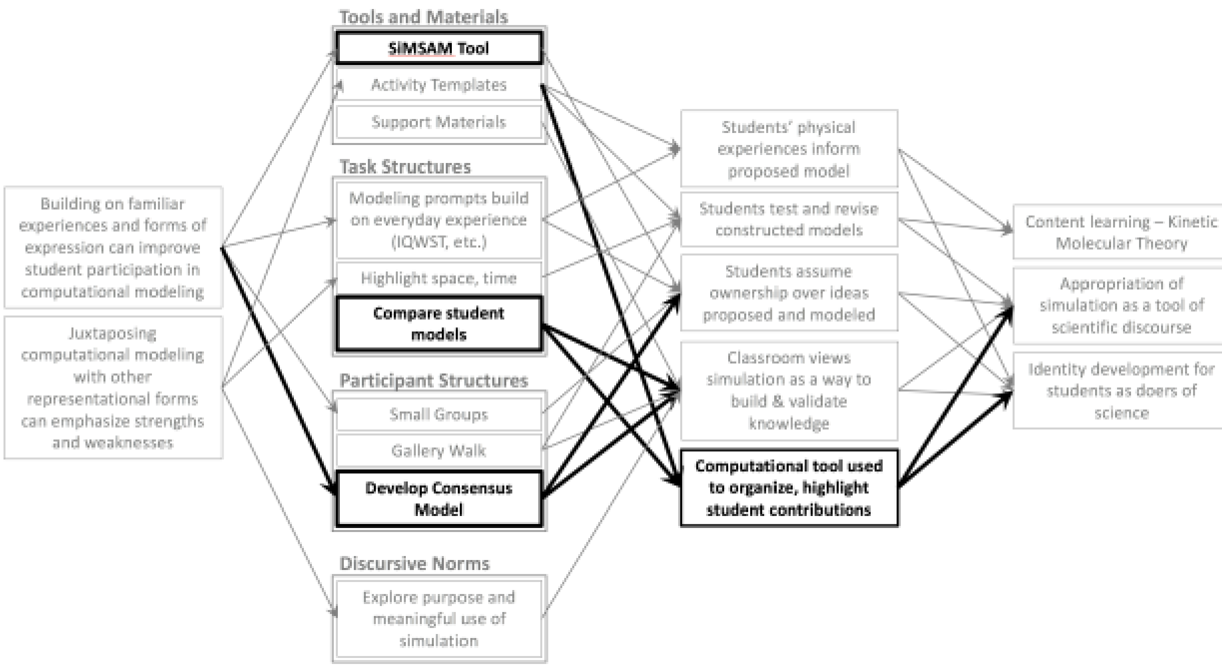

Figure 6. Contributions by youth and teacher during classroom activities.

Phase 4 : After School Workshops

In Phase 4, we partnered with an after-school science outreach program to conduct SiMSAM activity units at four sites. Each site met once per week, and each enactment lasted four weeks. Participating youth modeled molecular phenomena including evaporation, melting, and heat diffusion (different topics were taken up at different sites) using the latest version of SiMSAM and activity materials. The science club included educational directors and mentors—often college students—at each site, and junior mentors in their mid teens who facilitated each activity.

This new context introduced a number of new challenges. Given the information nature of the club, it was not atypical for students to "drop in" or "drop out" during activities, and many did not attend regularly. We had to develop methods to sustain youth's participation in the same, extended modeling activity across multiple weeks, offering ways for students who did not attend regularly to engage or re-engage with the scientific content without disrupting ongoing activities. At the same time, we had more flexibility and time to create hands-on supplements to the modeling activities. This led to the development of a number of new materials and social structures designed to foster and sustain inquiry across longer periods of time, and for groups that may change members over the course of the activity. We incorporated the two most successful approaches to addressing these issues into our final set of materials. First, we found it useful to have a continually present physical set up that illustrated the phenomenon at hand: a water still, tuning forks, heaters, or other materials that students could use to empirically investigate and demonstrate to one another the phenomena under exploration. Second, we found it useful to have a laptop available to show a selective number of videos—both describing the phenomenon (such as time-lapse videos of a puddle drying or ice melting)—and of students' prior animations and simulations—for youth to consult as needed.

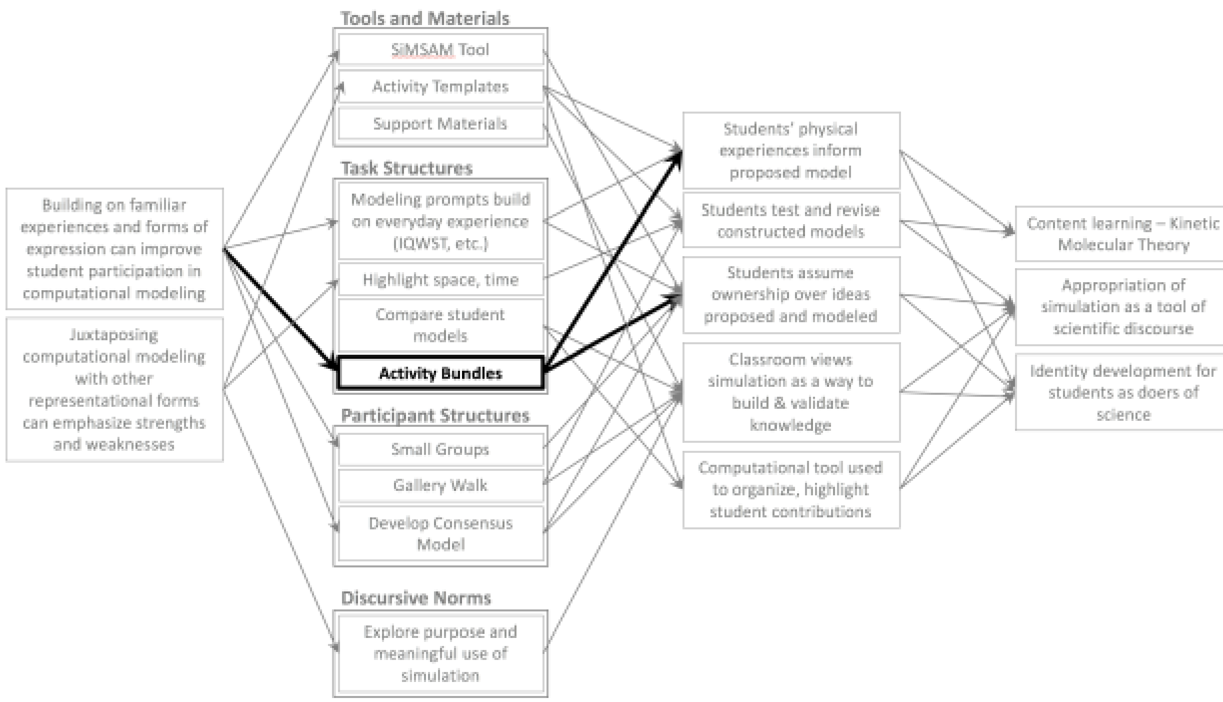

Figure 7. Contributions by informal educators and mentors during after-school activities.

The outreach program we worked with was also interested in working with us to develop infrastructures and pedagogical approaches that would allow them to continue using the SiMSAM activities after our research team was no longer able to support them. We created "bundles" of resources (templates, physical set ups, videos, questions and prompts), rather than the specific content-related sequences we used in classrooms, so that activities were flexible. We also created a document geared toward practitioners that briefly described model-based pedagogy and the importance of encouraging a focus on theory building and scientific mechanism during SiMSAM activities.

Discussion

Overlaying the four maps that result from each iteration of design reveals systematicities in which participant groups influenced aspects of our material design and theories of learning. Specifically, findings from working directly with youth contributed most to our design of the toolkit, and some of the task structures introduced over the course of the project. Working with pre-service and in-service teachers informed our design of participant structures and some support materials. And, working with after school groups helped us think about how to make the design of our activities more sustainable and engaging, and to develop flexible ways to disseminate the design and related pedagogical strategies.

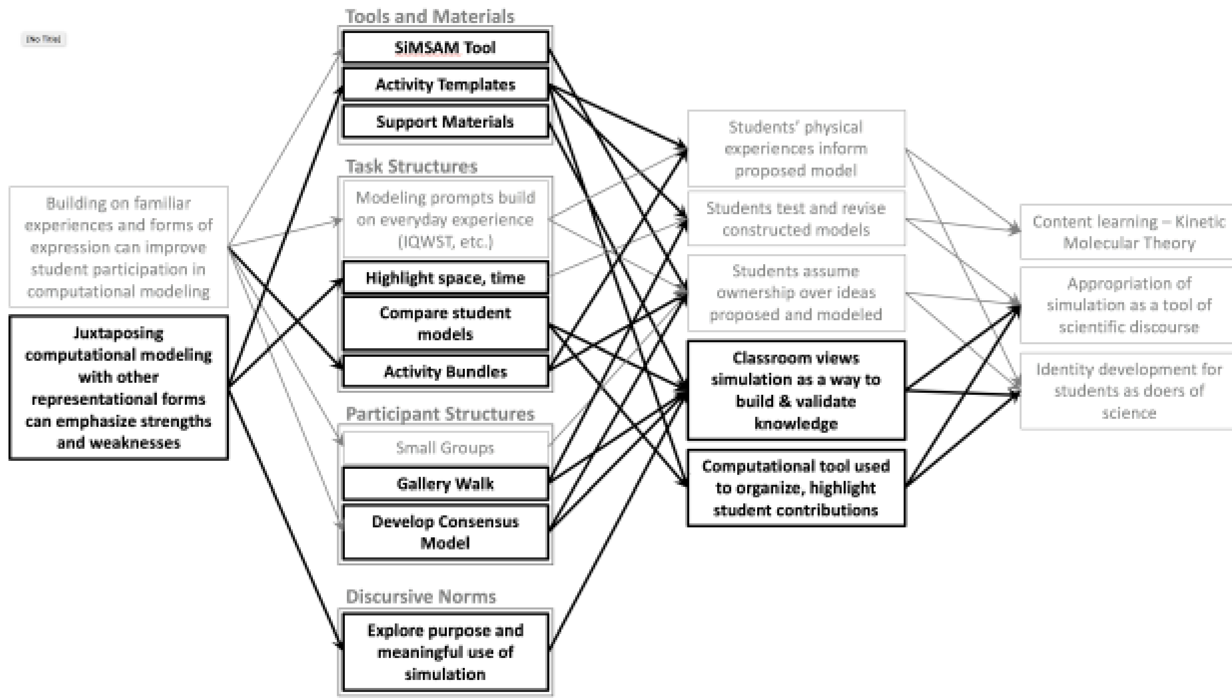

Figure 8. Contributions by all participants during after-school activities.

Analyzing our design process through conjecture mapping also revealed other patterns that can be useful for thinking about and reporting design research. For example, pre-service teachers during Phase 2 suggested building on existing classroom routines to encourage students to share and critique one anothers' work. In our conjecture map, we identified the design product resulting from this feedback to be a "Gallery Walk" participant structure. However, the suggestion from teachers was not for a particular structure, but for the design to leverage pre-existing practices *in particular classrooms*. For some students, this might be presenting animations and simulations as parts of sharing circles; for others it might be critiquing one anothers' work using familiar discursive routines such as accountable talk. Similarly, while more specified, template- and activity prompt-based activities worked well in time-strapped classrooms, after-school environments benefitted from empirical set ups that allowed learners to remember and re-visit their explorations over extended periods of time. Explicitly allowing for such flexibility in design can likely facilitate the integration and productive use of digital tools for learning, especially for use at scale and across settings.

Conclusion

Applying conjecture mapping across participant groups and contexts helped us to see two more general patterns in our design approach. First, it made more evident the implicit commitments we were enacting in our design choices. For example, when testing our first iteration of SiMSAM's programming interface, we received dramatically different feedback from middle school students (who found the interface easy to use) and teachers (who found it very difficult). The interface employs interface paradigms that were familiar for our youth participants, but not for many of the teachers we worked with. Since our goal is to support youth's facility in exploring scientific ideas through computational means, we chose to prioritize their access to programming and maintained the programming-by-demonstration paradigm. This, in turn, is leading us to explore other ways to allay teachers' concerns, for example through the development of additional support materials and social structures that allow students to demonstrate their competencies with the environment to teachers.

Second, it illustrates how important it is to involve multiple participant groups and contexts in the ongoing process of design. This retrospective clearly illustrates how we would not have been able to receive feedback about certain aspects of embodiment—notably participant structures and discursive norms—without the involvement of teachers and facilitators in our work. Similarly, we may not have created a tool that is engaging and accessible for youth had we only consulted with teachers. These emphases also provide information about which groups we may wish to consult in the future as we continue to refine particular aspects of our tool. Indeed, in a recent special issue dedicated to participatory design, it was noted that there is "...a need for more evidence on how to best involve different stakeholders [in design initiatives]" (p. 3; Könings et al, 2014). As more projects utilize conjecture mapping to explore the influence of participant groups on design, we as a community can develop better approaches to co-design for digital tools for learning in complex educational settings.

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