Mediated Education in a Creative Arts Context: Research and Practice at Whittier Elementary School

Aaron Cuthbertson, Sarah Hatton, Gary Minyard, Harper Piver, Christopher Todd, David Birchfield

Arts, Media and Engineering
Arizona State University
PO Box 878709, Tempe, AZ 85287-8709 USA
+1 480 965 9438
{aaron.cuthbertson, sarah.hatton, gary.minyard, harper.piver, christopher.g.todd, dbirchfield}@asu.edu

ABSTRACT

Many students’ learning styles are not well served by traditional classroom educational approaches. While interactive media tools can be effective in addressing shortcomings in traditional approaches, few projects provide practical solutions that support collaborative, discovery-based educational models while simultaneously addressing different student learning styles. In this paper, we describe the realization and outcomes of a recent 15-week after-school mediated education program undertaken with elementary school students in our region. We present our integrated approach to research and practice in the design of new tools, curricula, and assessment strategies for K-12 education that employ emerging interactive media technologies in the classroom. We focus on our efforts to support learners through discovery-based activities, cooperative and collaborative learning strategies, and the realization of new expressive forms that arise from the intersection of arts education and technology.

Keywords
K-12 Education, mediated education, multimodal interaction, arts, discovery learning

INTRODUCTION

For K-12 education to keep pace with the rapid technological advances in other sectors of our society, we must develop new approaches to education that harness emerging technologies, enable collaborative learning, bridge the physical/digital realms, and prepare all students for the dynamic world they are entering. We must devise innovative strategies that engage the creativity and innate curiosity of our students, and we must design educational activities that engage minority and underserved students and those with diverse learning styles.

For our students and communities to have a voice and stake in these innovations, we must work closely with them to collaborate in the design of new educational tools and pedagogies. We must design adaptive learning frameworks that empower students and support complex and even emergent learning strategies. Furthermore, we must develop instructional approaches and innovative curricula that encourage discovery learning that is motivated by the needs of today’s youth. When designing new mediated platforms for learning, we must devise technologies that address the practicalities of today’s classrooms and informal learning environments (eg: space, infrastructure, financial resources) while embracing the innovative forms of interactivity that are emerging from our media research communities (eg: multimodal sensing, real time interactive media, context aware computing).

In this paper we describe our work at the nexus of research and practice that encompasses the design of new tools for mediated education, innovative curriculum design, and empirical research with students and teachers in our community. We illustrate our approach through a case study of our experiences in a recent program at Whittier Elementary School in downtown Phoenix. For 15-weeks, our team of hybrid artist/educators/media designers deployed interactive technologies in a classroom setting with a group of 15 – 30 fourth and fifth grade students.

Figure 1. Mediated education in SMALLab

We built upon our prior work in the design of a new platform for mediated education, SMALLab and developed a new suite of tools and approaches onsite with a reduced
Hardware infrastructure, SMALLab Lite. We describe prior related work and discuss the structure of the case study project. We then provide details of our educational technology infrastructure. We detail the strategies and outcomes in three focus areas including: (1) discovery learning through multimodal interaction, (2) supporting cooperative and collaborative learning, and (3) supporting new expressive forms. Finally, we summarize the results of the case study and address future directions for our work.

PRIOR RELATED WORK

Our approach to education is informed by related research in open-ended educational philosophies that support exploratory and active learning approaches. Constructivism proposes that learners construct much of what they learn [1], and emphasizes the necessity of play and exploration in self-guided learning, particularly in mediated environments [2]. Instructional teaching can play a complementary role in these learning environments where advanced students and teachers create a “zone of proximal development” that speeds learning [3]. Howard Gardner’s thesis in the Theory of Multiple Intelligences [4] posits that there are multiple forms of knowledge, including musical and kinesthetic, that support and reinforce one another. This research supports evidence that students have diverse learning styles that are influenced by their life experiences, cultural background, and genetic predisposition. Active and visual learners are examples of students who thrive in environments that differ from those provided by conventional book and lecture teaching methods.

One of the most exciting strategies for engaging learners that has emerged in recent years is the development of technology-based learning systems that are highly inquiry-based. The most effective such learning systems are those that are learner-centered, knowledge-centered, and assessment centered [5]. Mediated education systems SMALLab and SMALLab Lite, developed by our research team, represents a new breed of student centered learning environment (SCLE) that incorporates multimodal sensing, modeling and feedback while addressing the constraints of real world classrooms.

By extension, our work is influenced by prior research in the design of Smart Environments and Perceptive Spaces. For example, in Combining Audio and Video in Perceptive Spaces, Wren, Basu, et al. [6] describe their work in the development of environments utilizing unencumbered sensing technologies in situated environments. The authors present a variety of applications of this technology that span data visualization, interactive performance, and gaming. These technologies suggest powerful opportunities for the design of learning scenarios, but they have not been leveraged for this purpose.

There has been related prior work in the use of Virtual Reality environments for learning such as the NICE project [7, 8]. While this research points to interesting approaches that can be of great value to active and visual learners, in our work we are focused on the use of unencumbered sensing and feedback approaches. In particular, the use of head mounted displays and fully immersive visual display environments can deemphasize direct student-to-student interaction during learning. In addition, the use of such specialized hardware makes deployment in most school environments impractical.

KidPad [9] is an example of a collaborative project involving an iterative design process between children and designers. Used as a tool to engage young children in drawing and storytelling through multimedia technologies, KidPad aimed to promote visual and verbal literacy in a fun, integrated learning environment. The developers of KidPad made a sincere effort in evaluating their primary users, the children, so to understand best how to design the interface of their tools. One of their challenges was overcoming the learning curve associated in using their software and the communication involved in this obstacle.

Related work in arts and technology has influenced our approach to the design of mediated learning scenarios. Our work draws from extensive research in the creation of interactive sound environments [10-12]. While much of this work is focused on applications in interactive computer music performance, the core innovations for interactive sound can be directly applied in our work with young students. In addition, we are drawing from the 3D visualization community [13] in considering how to effectively display visual content in this situated environment.

When designing multimodal learning environments for children, we are mindful of obstacles such as access to emerging technologies that would otherwise be unavailable to them. We have drawn inspiration from projects like Storytelling Alice [14] that involve the development of specialized software to encourage underserved groups of students to engage with technology. Storytelling Alice enables girls to collaborate with one another to create stories and develop a sense of ownership over their media creations. However, screen-based technologies like KidPad and Storytelling Alice, do not afford interaction between large groups of students. Additionally, traditional mouse and keyboard environments do not encourage full-bodied interaction, thus, they cannot engage kinesthetic learners to their full potential.

STRUCTURE OF THE CASE STUDY PROJECT

The focus of our discussion is the execution of a 15-week onsite Art Education program that integrated the efforts of our own education and media research team, community arts organizations, and elementary school students from Whittier Elementary School in downtown Phoenix, Arizona. Whittier Elementary is an inner city public elementary school with a primarily underserved student population.

During the 2006 fall semester, our team of media teaching artists and researchers traveled to Whittier Elementary twice a week for fifteen consecutive weeks to lead after-school sessions lasting one and a half hours each. The
students were able to make one field trip to our lab space on the campus of Arizona State University at the mid-point of the semester. Joined by an audience of their families and friends, the students made a second trip to our campus facility for a final sharing event at the end of the term.

With hybrid skills as educators, artists, and media designers, our five-member team jointly led the sessions at the school, designed the curriculum, served as interaction designers and programmers, and collaborated with the students to shape the overall aesthetic of the final event.

The common element to our educational program is the exploration of Sergei Prokofiev’s well known musical story of Peter and the Wolf [15, 16]. The story follows the young protagonist’s successful planning and capture of a prowling wolf that is eventually taken to the zoo. We designed a sequence of activities and exercises, drawing from a variety of creative disciplines and employing a multitude of technologies that allowed students to learn through creative exploration of this story.

LEARNING PLATFORMS AND MATERIALS
Our team of media researchers and educators has collaborated to develop a set of tools for mediated education that were utilized in the case study project. Here we describe these technologies and discuss the use of supporting pedagogical approaches.

SMALLab
The Situated Multimedia Arts Learning Lab, SMALLab, is a 15 foot X 15 foot portable, freestanding media environment [17]. It can be readily transported and installed in classrooms or community centers. A rectangular trussing structure frames an open physical architecture and supports the following sensing and feedback equipment: a 5-element array of cameras for vision-based tracking, a top-mounted video projector providing real time visual feedback, four audio speakers for surround sound feedback, and an array of tracked physical objects. A networked computing cluster with custom software drives the interactive system.

Figure 2. SMALLab, Situated Multimedia Arts Learning Lab
Groups of students and educators interact in SMALLab together. The vision-based tracking system senses the 3D position of a set of illuminated objects at a rate of 30 fps. This sensed data is routed to custom software that generates real time interactive sound and visual manipulations in the space. We have developed an extensible suite of interactive learning scenarios and curricula that integrate the arts, sciences and engineering education.

We have continued to refine the design of SMALLab over the past two years, incorporating current research in mediated education with direct feedback from students and educators. The physical architecture of the space is designed to encourage human-to-human interaction, collaboration and active learning within a computational framework. It can be housed in a large general purpose classroom without the need for additional specialized equipment or installation procedures. The use of simple, unencumbered sensing technologies ensures that there is a minimal learning curve for interaction, yet it has been utilized in diverse educational contexts spanning from physics to dance education.

Figure 3. A combination of traditional arts and technology
The SMALLab hardware can be easily transported, but it does require one full day to move and set up in a new location. Consequently, given the time constraints of this after-school program it was not feasible to use SMALLab onsite on a daily basis. Thus, we have developed a highly deployable subset of the SMALLab system that supports the same fundamental learning approaches with a reduced set of equipment.

SMALLab Lite
SMALLab Lite consists of a laptop computer, 2-channels of audio, a microphone, a video projector, a firewire webcam, a Wacom drawing tablet, and a conventional joystick. Although this system uses a different and more rudimentary set of input devices than SMALLab, it employs the same feedback and interaction software. With the combination of 2D position and pressure data, the pen of the Wacom drawing tablet is used to simulate the 3D position of a tracked object in the full SMALLab system. Employing a single webcam, we have developed a set of vision-based activity sensing routines using frame differencing techniques [18] that provide a coarse representation of student movements in the active space. Similar to the full SMALLab system, these sensing interfaces allow students to engage in full body, collaborative interactions that drive visual and sonic media in the classroom.

Non-Digital Materials and Activities
SMALLab and SMALLab Lite served as important tools for student learning in this project and will be a focus of this
paper. However, throughout the 15-week program we also utilized a wide variety of learning approaches and activities to support student learning. For example, various theatrical games and movement activities drawn from the Arts Education literature [19-22] were used to help students gain confidence with speaking and moving in front of their peers, to learn what it means to work as an “ensemble,” and to develop leadership skills. Journal writing exercises during each session provided a way for the teaching artists to document the work the students were doing in the classroom as well as assess their progress, comprehension, and desires to learn more. Reading and storytelling relating to the story of *Peter and the Wolf* helped students understand aspects of narrative such as mood and tone. Traditional drawing and sketching activities aided students’ exploration of characters, moods, settings, and ideas contained in the *Peter and the Wolf* story.

**INTERACTION DESIGN FOR CREATIVE LEARNING**

We now present three focus areas that illustrate our process of iterative design with students. In each case we provide a theoretical framework, describe the evolution of our approach, evaluate the results, and discuss opportunities for future work.

**Supporting Discovery Learning Through Multimodal Interaction**

Given the power and accessibility of today’s computing platforms, rich media elements such as digital sounds, videos, and images can be easily transformed and manipulated in real time. Constructivism learning theory posits that students construct much of what they learn through interaction and manipulation of their environment. There is a long history in Arts Education of self-guided learning, motivated by the creative process. Indeed, Seymour Papert’s development of technology-based learning approaches are rooted in Constructivism, and were inspired by the sight of sculpture students learning through the process of creation and the manipulation of pliable physical materials [23].

While the malleable nature of digital sonic and visual media materials seemingly present similar opportunities for discovery learning, important challenges remain in putting this capability in the hands of our students. Commercially available software applications such as *Photoshop* and *Final Cut Pro* provide a powerful array of tools for manipulation that could be harnessed in an educational setting. However, given the complexity of their interfaces, they are difficult for young students to learn. Furthermore, these applications primarily rely on conventional mouse/keyboard interaction and do not allow students to explore using naturally expressive movements and sounds.

**Evolution of Tools and Approaches**

In our work at Whittier Elementary, we have created software tools that exploit the malleability of digital media, and allow students to explore relationships in sound, movement and visual media through media manipulation in a discovery framework. Extending our prior work in this area [24], we have focused on the exploration of sound and movement, and worked with the students in two phases.

**Phase I:** Using the Max/MSP audio programming environment we developed a live audio manipulation and capture interface. Working with a facilitator, students engaged in an iterative process of performing, recording, auditioning, evaluating, re-recording, and manipulating sound. For example, one group of students trying to craft the sound of a frightened duck first practiced vocalizing duck sounds, performed, recorded and listened to these sounds, then tried shifting the pitch of the sounds higher and lower until they settled on a set of parameters and performance techniques that was satisfactory to the group. This was recorded, and archived for use in later segments of the program. Students could also apply pitch-shifting transformations to their voices as they vocalized into the microphone in real time. At the beginning of this exercise, the facilitator led the exercise and guided the students in exploring the manipulation of sound parameters. The facilitator would alter the sound transformation features by moving a set of graphical sliders and buttons. We found that students immediately wanted direct control of the transformation features, and they soon began to take control of their own exploration by directing the facilitator in how to manipulate the sounds. As a result of this experience, we developed a second interface that was movement-based, and provided full control over different parameters of the sounds.

**Phase II:** We developed a second interface that integrated the vision-based movement sensing features of *SMALLab Lite* with the real time parametric control of live sounds from Phase I. Here, individual students can transform their vocalizations through fast/slow and high/low physical movements in the active space. For example, the jumping up and down caused the pitch of their vocalizations to rise and fall in real time.

![Figure 4. Student works to explore interactive sound](image_url)

**Evaluation**

These tools were developed to support a set of learning outcomes that were central to our curriculum design. One such learning outcome was that students should develop a deep understanding of the difference between high frequency and low frequency sounds. This was measured in terms of their ability to both reproduce and perceive such
Furthermore, the practice of collaboration helps students to improve their motivation, and improves self-esteem. Research has demonstrated that this skill facilitates competition as they learn. Cooperative and Collaborative Learning approaches differ from traditional methods in that mixed-skill students are encouraged to work together rather than compete as they learn. Research has demonstrated that this style facilitates a deeper understanding of content, improves students’ motivation, and improves self-esteem. Furthermore, the practice of collaboration helps students to develop necessary social and communication skills that will allow them to thrive outside the classroom.

As a practical consideration, with nearly thirty students in our case study project, collaboration was an essential component. Particularly given the fact that after-school student schedules can be inconsistent, we needed to develop collaborative structures that would allow groups of students to work together even if some students could not be present for every session.

There is a long tradition of collaboration in the fine arts. Examples from the performing arts including Theater, Music, and Dance rely on collaboration. We have borrowed heavily from these disciplines, and collaboration has been foundational in our curriculum design. Throughout the program, students worked together to produce drawings, movements, and sounds. Because of the success of these activities, we have sought to design new scenarios that foster collaboration within the computational frameworks of SMALLab and SMALLab Lite.

There has been extensive work in the area of social and collaborative computing frameworks that move beyond conventional mouse/keyboard/screen interfaces. Tangible and tabletop interfaces [27] offer compelling approaches, but do not allow for full body 3D movement that is critical to our instructional design. Motion capture systems offer a high resolution sensing apparatus for embodied interaction, but they are prohibitively expensive and complex for classroom use. Thus, we have been working to develop low-cost, portable technologies and scenarios that will support collaborative learning.

Future Work
Building from the success of our students’ exploration of movement and sound, we are developing a full suite of cross-modal interaction scenarios. These scenarios will first enrich the relationships between movement and sound to support additional learning outcomes. We will also extend our sensing and feedback capabilities to explore direct interactive relationships between students’ vocalizations, visual media, movement, and text.

In terms of our curriculum design, we are investigating the sequence of exercises that we employed in this project. Importantly, we will explore if the instructional methods of Phase I are required to prepare students for the discovery approach of Phase II.

Finally, we are working to develop a computational framework for assessment that would allow us to identify and encourage effective strategies that emerge from students’ self-guided learning.

Supporting Cooperative and Collaborative Learning
Cooperative and Collaborative Learning [25, 26] approaches differ from traditional methods in that mixed-skill students are encouraged to work together rather than compete as they learn. Research has demonstrated that this style facilitates a deeper understanding of content, improves students’ motivation, and improves self-esteem. Furthermore, the practice of collaboration helps students to develop necessary social and communication skills that will allow them to thrive outside the classroom.

As a practical consideration, with nearly thirty students in our case study project, collaboration was an essential component. Particularly given the fact that after-school student schedules can be inconsistent, we needed to develop collaborative structures that would allow groups of students to work together even if some students could not be present for every session.

There is a long tradition of collaboration in the fine arts. Examples from the performing arts including Theater, Music, and Dance rely on collaboration. We have borrowed heavily from these disciplines, and collaboration has been foundational in our curriculum design. Throughout the program, students worked together to produce drawings, movements, and sounds. Because of the success of these activities, we have sought to design new scenarios that foster collaboration within the computational frameworks of SMALLab and SMALLab Lite.

There has been extensive work in the area of social and collaborative computing frameworks that move beyond conventional mouse/keyboard/screen interfaces. Tangible and tabletop interfaces [27] offer compelling approaches, but do not allow for full body 3D movement that is critical to our instructional design. Motion capture systems offer a high resolution sensing apparatus for embodied interaction, but they are prohibitively expensive and complex for classroom use. Thus, we have been working to develop low-cost, portable technologies and scenarios that will support collaborative learning.

Figure 5. Students collaborating with interactive movement

Evolution of Tools and Approaches
As described above, with its large physical dimension and support for multiple object and people tracking, SMALLab is optimized for collaboration. In prior work, we have designed a number of learning scenarios that require cooperation and collaboration among learners [17, 24]. We have been pleased with the success of these prior approaches, but needed to devise new scenarios within SMALLab Lite that address the objectives of this initiative.

Previously we described the development of a vision-based activity-sensing module in SMALLab Lite. Building from the successful use of this sensing apparatus in the
exploration of movement and sound relationships, we constructed a series of related interactions that demanded the cooperation of groups of students. We calibrated a twenty-foot sensing area, divided into two zones. Several interactive mappings were explored, whereby activity generated in either zone would cause different sonic outcomes. For example, activity in Zone I would increase the amplitude of a looping sound file. Activity in Zone II would increase the amplitude of a second sound. Importantly, we calibrated an activity threshold for each zone that required extreme variations in movement in order to drive a change in the sound outcome. Thus, students were required to collaborate in the execution of movement sequences. In further exercises, we challenged the students to create diverse sound compositions with this interface, which required them to plan, practice, and execute a multitude of cooperative strategies for interaction. This approach resulted in a thorough exploration of the attributes of movement and sound that was self-directed by the collaborative teams.

Figure 6. SMALLab Lite activity sensing software

Evaluation
At the end of the Whittier program, we held an informal debriefing and feedback session with the participating students. During this session, students reported that working and interacting with their peers was a highlight of the program. We observed that collaboration was a strong motivational force throughout the semester, and found that this group of students developed a strong sense of group ethic that facilitated their learning. As a direct result of the interactive scenarios as described above, students were able to develop relationships and teams that remained in tact for the duration of the term. In particular, we found that their positive collaborative experiences carried over as a contributing factor in the success of the final sharing event that will be described in the next section

Future work
Collaborative and cooperative educational scenarios will continue to be a central component of our research. While we have implemented several such learning scenarios, there is substantial work to be done regarding the realization of high resolution computing interfaces that support collaboration, the design of feedback scenarios that reward cooperation, and the implementation of appropriate metrics of assessment to identify successful cooperative learning strategies and more accurately address current ambiguities in the evaluation of group learning.

Supporting New Expressive Forms
Just as technology is transforming most aspects of our daily lives, the advent of inexpensive and readily available technologies continues to transform the fine arts. Numerous forums (eg. New Interfaces for Musical Expression, International Dance and Technology) have emerged that are defining new domains of integrated arts and technology research and practice. There is currently an increasing trend toward convergence across the arts, and new forms of expression are arising that are truly trans-disciplinary. There has been also been prior related work in the areas of non-linear storytelling that can provide a vehicle to integrate these various disciplines [28], but much of this work focuses on cinematic approaches that do not readily transfer to live performance contexts.

Our project embraces these leading edge approaches to integrating the arts and technology, but this dynamic context poses new challenges. Importantly, while these areas have received extensive attention in the research community, there has been little work in the areas of arts education. For example, while state and national standards define the fields of Music, Theatre, Dance, and Visual Art [29], there is little mention of digital media in the existing standards. Furthermore, comprehensive assessment methods have yet to be proposed for these emerging fields. As a consequence, our project demanded collaboration and flexibility in defining the field of study for and with our students. Moreover, we worked to develop pedagogical approaches that leverage the affordances of our technological and conceptual infrastructure.

One of the suggestions for project was that the semester should conclude with a culminating public event that showcases and celebrates the students’ work. In a conventional arts context, such an event might take the form of an art gallery opening, a theatre staging, or a musical performance. Our group was challenged to develop a similar culminating event for an area that is not yet well defined and is without a formal performance practice.

Evolution of Tools and Approaches
A unifying element throughout the 15-week program was the exploration of the story of Peter and the Wolf. By borrowing from existing inter-arts practices, we developed a number of exercises that help the students to develop a deep understanding of sound, movement, and visuals. These exercises served to enrich students’ understanding of concepts that drive storytelling and narrative such as setting, mood, climax, and character development. Because these exercises laid a foundation for the understanding of traditional narrative devices, they did not necessarily give way to more innovative forms of interactive and non-linear narrative. In the beginning weeks of the project, we struggled as educators to devise
supporting exercises that would bridge from these familiar narrative structures to the new expressive forms that can emerge from the nexus of the arts and technology.

Midway through the program, we realized the need to construct a space in SMALLab with embedded rule-based interactions for non-linear storytelling. Based on our experiences in working with these students, we formalized a set of interaction rules, implemented in code within SMALLab. These rules would serve as a foundation for story exploration of Peter and the Wolf in a new expressive form, and they arose from our intuitions of the students’ capacity to conceptualize such a framework. Once this basic set of interactions was in place, we worked with the students for the remaining weeks to develop collaboratively authored audio and visual content for the story. Because the students were able to grasp the concepts of embedded action rules, they easily developed their own rule-based movement sequences that were to be enacted in SMALLab. Finally, we collaborated with the students to devise a logic that would allow audience members to explore aspects of the Peter and the Wolf story in a participatory fashion.

**Figure 7. Students enact the ‘Duck’ movement**

For example, we developed the ‘Pond Scene’ that depicts a host of characters from Peter and the Wolf in a pastoral setting. The students created a series of paper drawings of the Duck, Bird, Peter, and the world that were scanned and incorporated into the scene. These drawings reflected their study of the elements of visual language. Similarly, the students created audio recordings of each character that reflected their study of the attributes of sound that can convey meaning. Finally, teams of students developed movement sequences that relate to each character that would be enacted in synchrony with the digital elements. A simple logic allowed the audience of family members and friends to move through SMALLab and in each quadrant of the space a new character from the story was introduced through a sonic, visual, and movement-based depiction. In total, the students developed four such scenes that illustrated the characters, settings, and important events from Peter and the Wolf.

**Evaluation**

One important outcome of this process was our observation of the students’ great capacity for understanding the notion of non-linear storytelling. Once we were able to formalize and describe a rule-based framework, the students thrived as they developed media content to articulate their ideas. We were greatly impressed with the students’ apparent aptitude for working productively within this abstract storytelling space.

During the final debriefing discussion with the students, they communicated how much they enjoyed interacting with their media content. This format clearly fostered an important sense of ownership over the project and motivated the students’ exploration of the story elements. We observed that this sense of ownership came not only from individual students, but emerged from the collective efforts of the group as they collaborated to develop each scene.

After the final sharing event, observers noted how engaged the students were with their work. The event reflected the process of construction and demonstrated their commitment to the project. However, audience members reported that it was at times difficult to understand the underlying Peter and the Wolf story given the abstract nature of the depiction.

**Future work**

In our future work we will further develop exercises and activities that can prepare students for the creation of new expressive forms. Young students are clearly capable of working within non-linear structures that computing structures provide, but we must improve our approaches to curriculum design in order to avoid extended reliance on traditional forms that might impede the creative process.

Second, we must develop effective strategies to communicate the nature of these new forms to new audiences. In order for students to communicate their achievements to family and friends, these supporters must understand the nature of interactive media, the consequences of this dynamic form of creation, and the language of non-linear storytelling. As a first step, in future events, we intend to ‘prime’ the audience for active engagement by inviting them to freely play with storytelling scenarios within the space before the formal student sharing event.

**CONCLUSIONS AND FUTURE WORK**

We have presented our research in the development of new frameworks for education that integrate emerging technologies, innovative curriculum design, and empirical research with students and teachers. We have discussed the outcomes of a recent case study undertaken at Whittier Elementary School. Based on this experience we have presented our findings with regard to our ongoing efforts in designing for learning through media manipulation, supporting cooperative and collaborative learning, and fostering the creation of new expressive forms of interactive media. Through this 15-week program we have provided an innovative after-school educational program.
for students, and we have ourselves greatly benefited from student feedback and responses throughout the process.

Our future work will focus on improving our current sensing and feedback infrastructure to better support collaboration within SMALLab and SMALLab Lite. We will continue to develop new pedagogical approaches that address students’ clear ability to think in abstract, non-linear form. Finally, we will work to formalize our findings through better defined evaluation metrics that leverage the computational sensing and archival infrastructure of these learning environments.

ACKNOWLEDGEMENTS

We gratefully acknowledge that these materials document work supported by the National Science Foundation CISE Infrastructure grant under Grant No. 0403428 and IGERT Grant No. 0504647. We thank Michelle Palazzolo and Sally Lindsay of the Scottsdale Museum of Contemporary Art for inviting us to participate in this initiative and for serving as invaluable liaisons between our group and Whittier Elementary School. We would like to thank Ray Romo of Whittier Elementary for his wonderful efforts in onsite coordination this program. Finally, we are grateful for the students of Whittier Elementary School for their wonderful enthusiasm and inspiring dedication to learning.

REFERENCES