RESEARCH REPORT

Persistent and Encouraging Achievement Gains on Common Core-Aligned Items for Middle School English Language Learners:

ASAMI— Hands-On Astronomy for After-school Science and Math Integration[1,2]

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Abstract

ASAMI—*Afterschool Science and Math Integration*—integrates skills of mathematics with interesting concepts and hands-on activities in astronomy-based science in the middle school. Common Core Mathematics Standards and Next Generation Science Standards (NGSS) are used as ASAMI effectively teaches algebra standards/concepts with Hands-On Universe (HOU) curricula to engage 12–14-year-old English Language Learners (ELLs). In our 2014–15 school year pilot and field tests of ASAMI, students classified as ELL met twice a week for a total of four hours a week at a middle school in California, USA. The evaluation of ASAMI shows that these learners improved their test scores on Common Core Mathematics Standards-aligned items [Gain = (post-test−pre-test)/pre-test] by 46 percent in our first six-week trial and by about 93 percent in our second semester in the school year. Two other pilots resulted in similar gains. The main algebraic focus and assessment items focused on ratios, proportion, and linear equations, which are used throughout the curriculum of the HOU. Our assessments show that ASAMI is a very effective tool to help focus instruction, and students demonstrate success in learning through the integration of math and science. While the desire for integrated math and science curricula has been expressed for decades, few quantitative studies of achievement gains have surfaced (Czerniak, et al. 1999).

Background and Introduction

Hands-On Universe

Afterschool Science and Math Integration (ASAMI) is based on Hands-On Universe (HOU) astronomy activities that are often computer/technology based. HOU was based for many years at the Lawrence Hall of Science (LHS) at the University of California, Berkeley, and developed significantly within the Hall. Alan Friedman's leadership at LHS in astronomy education help build the discipline of "Hands-On" astronomy. HOU has many linkages directly traceable to Alan, and the appendix describes the heritage of HOU through Alan.

Over its almost 25 years of activities, HOU has brought the wonder and the data of the Universe into classrooms all around the world. Approximately one thousand American teachers have been in HOU teacher workshops. Through the Galileo Teacher Training Program (GTTP), approximately 20,000 teachers in 100 nations around the world have been in HOU workshops. Formal external evaluations submitted to the U.S. National Science Foundation have usually demonstrated that HOU changed students' attitudes positively towards STEM careers and helped students appreciate math, science, and technology. In HOU students measure objects on and off the computer and make models of celestial systems. We currently plan to start a new round of United States HOU Teacher workshops and are actively seeking funding. ASAMI is the most recent version of HOU. It uses HOU's images, software, activities, and methods, adopted for English Language Learner (ELL) middle school students.

Program Goals

One goal of ASAMI is that students master enough math so that they can explore careers in STEM fields. Our pre-tests of the ELL students demonstrated that these students were lacking important skills and would have difficulties pursuing STEM careers. All citizens of the world are now facing major technological and scientific challenges. Every student needs to become an active, well-informed and educated citizen. The ELL students in our study required some additional interventions in their education to succeed in the disciplines of math and science. We wanted these students to to engage in and appreciate math and science, using HOU-inspired activities, both on and off the computer.

NGSS Middle School Topics

The Next Generation Science Standards (NGSS) recommend that science education in grades K–12 be built around three major dimensions: scientific and engineering practices; crosscutting concepts that unify the study of science and engineering through their common application across fields; and core ideas in the major disciplines of natural science (http://www.nextgenscience.org/three-dimensions). *The Framework for K-12 Science Education* (Quinn, et al. 2012) also identifies seven crosscutting concepts that bridge disciplinary boundaries, uniting core ideas throughout the fields of science and engineering. Among the seven crosscutting concepts presented in Chapter 4 of the *Framework* is the following: "Scale, proportion, and quantity. In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance." (p. 84)

The first three standards of Middle School - Earth Science Standards of NGSS (NGSS, 2013) support well our objectives in ASAMI:

1. MS-ESS1-1. Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons. [Clarification Statement: Examples of models can be physical, graphical, or conceptual.]
2. MS-ESS1-2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. [Clarification Statement: Emphasis for the model is on gravity as the force that holds together the solar system and Milky Way galaxy and controls orbital motions within them. Examples of models can be physical (such as the analogy of distance along a football field or computer visualizations of elliptical orbits) or conceptual (such as mathematical proportions relative to the size of familiar objects such as their school or state).] [Assessment Boundary: Assessment does not include Kepler's Laws of orbital motion or the apparent retrograde motion of the planets as viewed from Earth.]
3. MS-ESS1-3. Analyze and interpret data to determine scale properties of objects in the solar system. [Clarification Statement: Emphasis is on the analysis of data from Earth-based instruments, space-based telescopes, and spacecraft to determine similarities and differences among

solar system objects. Examples of scale properties include the sizes of an object's layers (such as crust and atmosphere), surface features (such as volcanoes), and orbital radius. Examples of data include statistical information, drawings and photographs, and models.] [Assessment Boundary: Assessment does not include recalling facts about properties of the planets and other solar system bodies.]

Such topics in the NGSS were included in ASAMI and were found in all of the activities. (See Appendix 2.)

Common Core Seventh- and Eighth-Grade Math

The NGSS clearly require the inclusion of the mathematical concepts of scale and proportion. Meanwhile the State of California has also adopted the Common Core Mathematics Standards,which include, for grade seven: "Analyze proportional relationships and use them to solve real-world and mathematical problems," and for grade eight: "Understand the connection between proportional relationships, lines, and linear equations." Many middle school students have had difficulty in understanding these concepts. The Trends in International Mathematics and Science Study (TIMSS) reports: "Students also found the proportionality items difficult. For example, one of the least difficult problems in this area asked about adding 5 girls and 5 boys to a class that was three-fifths girls. On average, fewer than two-thirds of the students across countries correctly answered that there would still be more girls than boys in the class" (Beaton 1996,3). Such students are subsequently unable to achieve mastery of algebra, the gatekeeper to more advanced mathematical and scientific courses. Research referenced in this article shows that an integrated curriculum provides opportunities for more relevant, less fragmented, and more stimulating experiences for learners.

Target Audience

ASAMI had its first pilot study done at a diverse middle school in El Cerrito, CA, during 2012–2013. Then the leaders of ASAMI identified three middle schools in Hayward, CA, as appropriate schools for collecting research data about its effectiveness. The principals of these schools wanted ASAMI to serve their many students who are English Language Learners. Table 1 below indicates that ELLs are a significant segment of learners in California overall and in Hayward in particular. Our pre-tests indicate this population is very challenged to master the standards of Common Core Mathematics.

To meet the needs of the English Learners, the ASAMI program included several tutors who are bilingual in English and Spanish. Although the lessons were taught in English, the tutors were always available to help the English Language Learners to understand the assignments and to feel accepted. Here are data from Ed-Data of California from the year 2013–2014:

TABLE 1. Demographics of Schools in Target Area

School or Educational System	Hispanic or Latino Students	English Language Learners	Free or Reduced Price Meals
California	53.3%	22.7%	59.4%
Hayward Unified School District	61.1%	30.9%	70.5%
Winton Middle School	76.9%	22.2%	78.9%
Bret Harte Middle School	51.1%	10.1%	67.8%
Cesar Chavez Middle School	67.3%	27.8%	81.1%

The ASAMI program provides all of the hands-on materials and often sends the students home with items they constructed. Leaders at the schools help greatly by recruiting the students, monitoring their attendance, and phoning the parents of absentees. From interviews (to be published), it was very clear that parents want their children to succeed in STEM and are eager to cooperate with this after-school program. Our interviews indicate that many English Language

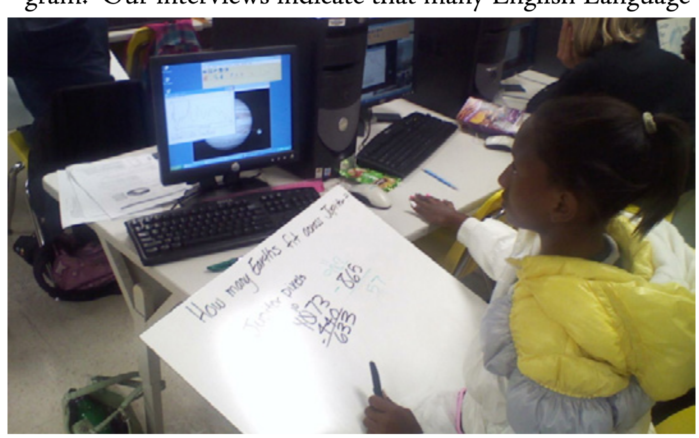

FIGURE 1. ASAMI Student at Work

Learners struggle to learn a new language and simultaneously keep up with the pace of study in the classroom.

M. Calderon (2007) has stated: "The Hispanic dropout rate is the highest in history." We have observed that ELL students often become discouraged, fail to compete, and are ready to drop out of participation in school activities. The ASAMI program is achieving a caring, enjoyable environment where the students are making progress.

Fry observed: "An analysis of recent data from standardized testing around the country shows that the fast growing number of students designated as English language learners (ELL) are among those farthest behind" (2007, i). The ASAMI project has been used successfully to serve this needy population. The faculty of ASAMI have endeavored to use the best practices (Rolstad, et al. 2005; Short and Echevarria 2004) to serve these students. Many of the previous studies tended to focus on language acquisition. The ASAMI program adds the acquisition of science and math to the literature. Integrating inquiry-based science and language learning brings success to ELLs, according to Stoddart, who wrote: "The authors of this article take the alternate view that the integration of inquiry science and language acquisition enhances learning in both domains" (2002, 664).

ASAMI Activities

Table of Some ASAMI Activities

An exemplary list of ASAMI activities is shown in Appendix 2. Each activity usually required one to two hours in an after-school session.

Modeling Pedagogy and Support of the NGSS Practice Matrix

ASAMI endeavors to implement at the middle-school level the Modeling Pedagogy, which is widely used in many high-school physics classes. The lead ASAMI teacher, Jennifer Perazzo, uses these instructional strategies. Moreover, creating and evaluating models is a major goal of NGSS.

The website of the American Modeling Teachers Association explains: "Modeling Instruction . . . applies structured inquiry techniques to the teaching of basic skills and practices in mathematical modeling [and] proportional reasoning" (http://modelinginstruction.org). Modeling Instruction has proven to be one of the most reliable pedagogies to improve student learning. In the Modeling Instruction pedagogical

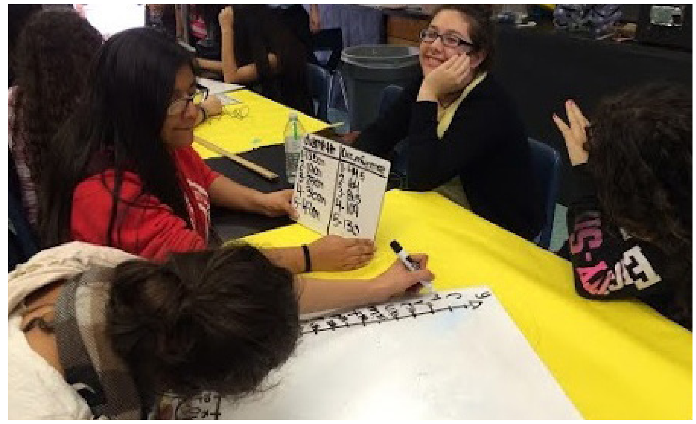

FIGURE 2. More ASAMI Students at Work

approach, students work in groups of three. They voice their preconceptions, collect experimental data, build a model in their small groups, and document their ideas on whiteboards. Then the students assemble with their classmates for a "board meeting" to present their work and develop a class consensus model.

An example of how we implemented the model in ASAMI is shown in the diagram below.

Students explore and investigate beautiful and engaging images and learn Salsa J image analysis program. Students break into groups of 3.

↓

Students get excited about images and image processing. The classroom buzzes!

↓

Students measure real sizes of solar system objects using Salsa J on their computers, and then make new models.

↓

Students are challenged to "make a scale model of the solar system (with playdoh)" – There is no use of real data at this point. Students use their existing knowledge to make a best-estimate scale model of our solar system.

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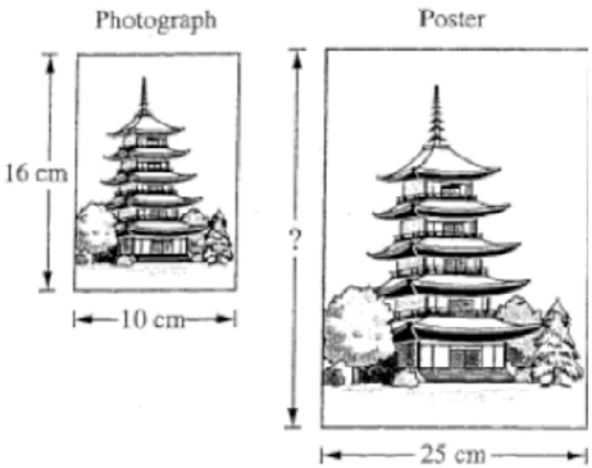
All groups meet, share their results, and make a "classroom size model."

FIGURE 3. Typical Modeling Instruction Pedagogy in Action (2-hour Session)

DIAGRAM 1. Typical ASAMI Common Core Math Assessment Item



A photograph is enlarged to make a poster.
The photograph is 10 cm wide and 16 cm high.

The poster is 25 cm wide. **How high is the poster?**
Describe how you figure it out.

(The MAC Performance Assessment Task "Poster" is published with the permission of its authors, the Silicon Valley Mathematics Initiative.)

ASAMI Assessments of Common Core Math

The first goal of the evaluation was to assess the effects of students' participation in ASAMI on their understanding of proportional reasoning. To measure these outcomes, evaluators developed pre- and post-program content tests and surveys. Math assessments only were developed and implemented. The content tests contained five proportional reasoning items taken from four sources: (1) the California STAR test database; (2) the National Assessment of Educational Progress (NAEP) item database; (3) the New England Common Assessment Program; and (4) the Silicon Valley Mathematics Initiative's Mathematics Assessment Collaborative project.

An exemplary assessment item is shown in Diagram 1.

The lead teacher, who was also the main content developer, had not studied the assessments and was unaware of the detailed questions. Her focus was to develop and teach activities that were hands-on activities emphasizing Common Core math principles and tools.

Results of Assessments

Test Scores

We deployed our five assessment items in pre- and post-test sessions at the beginning and end of ASAMI. At Portola Middle School, only interviews were undertaken. All of the Common Core Math assessments were administered in the school years 2013–2014 and 2014–2015. While these assessments are viewed as a preliminary study, it is clear there was a gain in students' capabilities. Before starting ASAMI, students' skills were very low. Every group of ASAMI students had test scores that improved significantly beyond the control group's gains. In summary, students had about double the learning gain, compared to a preliminary control class. Hence, we view the ~2X more learning as a lower limit, compared to traditional learning.

The number of students assessed was typically about twenty per class, and the standard deviations were usually around one point. When we combine the data, the results become much more significant, with the summed results approaching significance at greater (1/sqrt(4)), at a 4 sigma significance. These results are very encouraging.

TABLE 2: ASAMI Pre- and Post-test Results

Date of ASAMI	Cohort	Pre-test Score	Post-test Score	Absolute Gain over Program	Length of Program	Normalized Gain/6 Weeks
Spring 2014	7th- 8th Grade Winton and Chavez	2.4	3.5	46%	6 weeks	46%
Fall-Winter 2014-2015	7th Grade Winton	1.7	3.3	93%	12 weeks	48%
Fall-Winter 2015 Control Group	7th Grade Winton Technology Elective	1.6	2.54	56%	12 weeks	28%
Spring 2015	8th Grade Winton	1.29	3.11	142%	8 weeks	106%
Spring 2015	7th Grade Bret Harte	1.15	1.85	60%	6 weeks	60%

It is interesting to note that the eighth-grade ASAMI students, who had undergone normal math education for most of a year, had pre-test scores similar to those of entering ASAMI seventh graders. These incoming eighth graders had learned little in the year and a half of math education since their entrance into middle school.

Student Interviews and Informal Observations

Interviews and observations were done at Portola Middle School, with parental consent and student assent forms per the UC Berkeley Committee for the Protection of Human Subjects Protocol # 2012-03-4125. These data suggest that students found the ASAMI activities to be highly engaging and quite different from typical classroom practices. Students worked diligently in groups on complex math and science problems, persisting on new and challenging tasks with the help of their ASAMI leaders. During one session, for instance, evaluators observed students using Salsa J software to calculate astronomical distances. A group of four students sat or stood in front of a computer, with one student running the program and the others providing guidance. The students were so engaged in the activity that they wanted only a brief snack break before returning to their work.

The root of ASAMI's appeal may be in its "useful application" approach to mathematics. Rather than teaching proportional reasoning as an abstract skill, ASAMI embeds it into science problems that pique students' interest. In fact, one student described the program as "an astronomy program which sneaks in math," noting that she often didn't "realize how much [math] you're doing" until later. It was only in the hours after ASAMI that she felt the full mental impact of what she had done: "My brain's tired. I've done too much math."

Another student also praised the ASAMI's activities, calling them "Math in a fun way. You don't know you're doing math but you are," she said. "I liked how they put the math. They didn't just give you like a paper with math problems and say do this. It was in a way where it was math but it wasn't just math, it was something else like astronomy." This same student commented that ASAMI was a very different from her regular math classes: "Most of the time now in school the teacher's on the whiteboard, we do problems, we do our homework and our work, but it's nothing like this, with measuring, with astronomy, with ratios, you know, it's not like how they put it." Before ASAMI, she didn't think that mathematics had much to do with science. "I didn't really think I needed science to do math. I just thought science was science and math was math and they were two different things." Now that she has been through the program, she wishes that all students could have the same experience. "By them [math and science] being joined together it makes it more interesting and more fun because you're not just doing math and you're not just doing science, but you're doing both of them at once."

General Observations and Success Factors

We believe there are several reasons why ASAMI has worked well.

- **Individual Tutoring**

We employed two or three Spanish-speaking high school and community college students in the ASAMI sessions. Hence, ASAMI participants received a lot of individual tutoring, and with the help of their own peer groups, were convinced to undertake rigorous work and struggle with Common Core topics.

- **Fun and Exciting Activities**

Math was always fun and often had instant consequences/feedback if you got things wrong. For example, in the playdoh recipe scaling activity, at least half of the students got the ratios wrong (many subtracted instead of using ratios) and they made playdoh with much too liquid a consistency. There was always fun and excitement in the hands-on activities, and we could keep them both involved and working rigorously, competing against other after-school activities. Students, when asked if this work was more fun and interesting than their normal math classes, would give staff a condescending look and say "Duh…"

- **Parent and Community Support**

We had great support from the parents. The leader of ASAMI community relations, Mr. Jesus Heredia, continually cultivated a strong relationship with the parents. The parents wanted ASAMI for their children, and if children did not attend the ASAMI sessions, the parents were informed, and usually the students came back. For these reasons, there was very low attrition in the student population (<12%). ASAMI was observed by staff to be desired by the parents as it promoted Common Core learning with an emphasis on technology, college, and jobs.

- **Strong Support from Our Hosting Schools**

Winton Middle School and Bret Harte Middle School provided superb hosting of our system. We had support from the administrators and from the after-school programs (Youth Enrichment Program), and custodial staff.

- **Strong Support from the School English Learner Advisory Committee (ELAC)**

We undertook very careful communications and briefing with the ELAC, especially at Winton Middle School; they were convinced of ASAMI's value, and they felt that ASAMI was their program.

- **Strong Support from the Hayward Unified School District (HUSD) Office and School Board**

ASAMI benefitted from great support from the HUSD central office. The whole development of our program, the funding systems, the invoicing and multiple layers of approval (including School Board approval) were all undertaken with vigor and enthusiasm by District staff.

- **Undying Dedication to Rigor and Common Core Math in Every Instance**

We did not have to dig deeply to find how proportions and ratios are used in our science problems, so we could both emphasize Common Core and complete these activities. For example, students learned in HOU that proportion and scale are used widely in the Universe and that, in fact, the Universe makes no sense without proportion and scale.

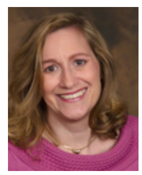
- **Buy-in from ASAMI Teachers**

One new instructor, Mr. Ben-Shalom, writes of ASAMI: "At first I was skeptical that struggling students would want to participate in yet more academics during their after-school time, and yet this program has amazed me. ASAMI will not work for everyone, but those students who it has reached have shown a kind of dedication and enthusiasm about math and science that I thought not possible. And this is due to ASAMI's solid repertoire of lessons and activities that are engaging and will help these students succeed."

Future Work

We are confident of our test score gains and students' indications of excitement about STEM topics. Future work (proposals are in the planning stages) will include a deeper study of these results and a more thorough explication of the success factors. As one local collaborator noted: "The ASAMI initiative has snowballed through the science department and inspired more student-centered and hands-on activities, generally." We will endeavor to spread ASAMI throughout the Hayward Unified School District and then beyond into other California schools, many of which are blessed with students and families eager to master the Common Core STEM topics and need some extra help from ASAMI as their language acquisition and skills develop.

About the Authors

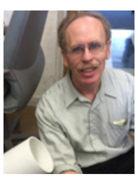


Kristin M. Bass is a Senior Researcher at Rockman et al, a San Francisco-based external evaluation company. Kristin's areas of expertise include assessment development and validation, program fidelity, research design, and quantitative analysis. At Rockman, she primarily directs projects related to formal and informal STEM education. Kristin has a B.A. in psychology from Yale University and a Ph.D. in education and psychology from the University of Michigan.

Gabriel Ben-Shalom is a recently graduated teacher, who finished his student teaching with Ms. Lobo at Winton Middle School and became available to teach ASAMI for eighth-grade students. Gabriel benefitted in his own education from hands-on and conceptually deep activities, and he was eager to be involved in ASAMI, particularly as he witnessed U.S. Science and Math education move into an era of Common Core and NGSS. He was very delighted when he found the students tackling hard problems and making progress in their own learning. In fact, as we note in the paper, the eighth-grade students in Gabriel's class had very large gains on the math Common Core assessment items, which is a tribute to his teaching skills.

Jesus Heredia is an English Language Learner (ELL) Specialist at Winton Middle School in Hayward, CA. He was formerly a teacher, but moved into ELL work when he saw the tremendous potential of these students, coupled with their strong need for activities that engaged and supported their core learning. Hence, ASAMI spoke naturally to his sense of what the students needed. Jesus was diligent in working with the families of the students, and through his efforts, we saw very low attrition in the ASAMI classes. Jesus helped convince the English Language Advisory Committee that ASAMI was in their children's best interest. Jesus also played an essential role in the total running and management of ASAMI and was in the ASAMI classroom almost continuously.

Rainbow Lobo is a teacher in the Science Department at Winton Middle School in the Hayward Unified School District. She teaches science and technology and has been an advocate of hands-on, student-centered learning for most of her career. Students in her technology elective class demonstrated large gains in their grades after a year of Lobo's class. She provided ASAMI's home (her classroom), ideas on classroom management, and continuous input and ideas in this study.



Carl Pennypacker is a physicist and educator who has been fortunate to play pivotal roles in some decent projects. He received his B.A. from UC Berkeley in 1972, with the group of Luis Alvarez. Together with Richard Muller, Pennypacker has helped form and develop many of the central ideas that have led to the discovery of Dark Energy. He and his team were winners of the Gruber Prize and the Breakthrough Prize for this work, and the student he co-advised, Saul Perlmutter, went on to accrete the Nobel Prize for this work. Pennypacker helped co-found, with a group of great teachers and educators, the Hands-On Universe project. This project has led to the training of 1000 teachers in the United States, and about 20,000 around the world, and is part of the French National Curriculum and the Bavarian State curriculum.

Jennifer Perazzo is a Hands-On Universe Teacher Lead. She is also a certified Modeling Instruction teacher. During the school year she is a Science Specialist for an elementary school in Pleasanton, CA. She introduces students and teachers to the EU-HOU astronomical image analysis tool, Salsa J, a software program dedicated to image handling and analysis in the classroom. Jenifer created and taught most of the ASAMI activities for the seventh-grade class.

David R. Stronck is a Professor in the Department of Teacher Education, California State University, East Bay. Oregon State University awarded him an M.S. in Biological Sciences and a Ph.D. in Science Education. He is the sole author of 22 articles reporting statistical research in major journals of learned societies. He has a total of more than 200 publications, including eight books. For ten years, he was the editor of journals for science teachers. Stronck has been the director of projects that have been funded at more than $3 million. He has directed or co-directed 15 grants for the National Science Foundation. The Genentech Foundation for Biomedical Sciences funded his projects serving high-school students, for more than one million dollars. He has also directed four grants from the U.S. Dept. of Education. He presents at an average of five different conferences annually, e.g., the National Science Teachers Association.

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Appendix 1: Alan Friedman and HOU

Alan Friedman established and directed the Lawrence Hall of Science Planetarium (University of California, Berkeley) in 1973. For over a decade his leadership set the legacy of audience participation planetarium shows and hands-on science at Lawrence Hall. He was a pioneer in the field and involved hundreds of planetariums through Participatory Oriented Planetarium (POP) workshops and the publishing of the Planetarium Educator's Workshop Guide, which evolved into Planetarium Activities for Successful Shows (PASS; now at http://www.planetarium-activities.org/). To this day LHS helps bring that style of show into the digital age and encourages other digital planetariums to include live audience participation in their repertoire of shows, rather than just recorded programs. Among the planetarium shows Alan developed were Stonehenge and Finding Your Star (now Constellations Tonight), in which the presenter hands out star maps to all the audience members and teaches them how to use them. Using star maps was to become a favorite tool of HOU observers in the guise of Uncle Al's Hands-On Universe Starwheels. Cary Sneider became Planetarium Director after Alan Friedman, and it was under Cary that the first connection with HOU was made in 1991. Cary had been invited to the seminal HOU organizing workshop but was unable to attend and asked Assistant Director Alan Gould to go in his stead. At the workshop, Alan presented an activity from one of the planetarium shows, Moons of the Solar System, in which the audience members kept track of the moons of Jupiter and discovered the relationship between the moons' orbital periods and their orbital radii. That ultimately evolved into one of the favorite activities in the HOU high school curriculum. Years later, Alan Gould became Co-Director of HOU for a number of projects.

Appendix 2: Typical ASAMI Activities

ASAMI Activity	What Students Do	Math Common Core Concept
Derive a correct recipe and then make playdoh	Students scale from a recipe that requires too much of one ingredient	Ratios and proportion
Make a scale map of their school, from Google Maps	Use Google Maps and HOU image processing to measure true diameters of objects and measure their school, culminating in a scale map of some buildings, etc.	Ratios, proportion, scale, measurement
Make a scale solar system	Students take an existing playdoh recipe and scale it for the smaller amount of materials they are given	Ratios and proportion
Lunar Craters - find a lunar crater as big as your county from computer images	Students find a crater as big as their county, plot a map of the State of California on a moon map, use different map scales and compare maps.	Proportion and ratios
Asteroid Impact - drop various size stainless steel balls into birdseed on a tray	Students drop various mass spherical objects into bird seed (works better than flour) from various heights, and plot crater size versus height, mass, etc.	Energy, proportion, mass, etc.
Water Rockets	Build and launch, then measure and graph results from experiments with water rockets	Proportion