CHANDRA ASTROPHYSICS INSTITUTE 2005
PRELIMINARY EVALUATION REPORT

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This document is not intended for wide circulation.

EXECUTIVE SUMMARY

Program summary (p. 4)

The Chandra Astrophysics Institute (CAI) is a yearlong program intended to give motivated high school students and their science and math teachers from underserved populations an opportunity to take part in authentic x-ray astronomy research. The program is implemented by staff from the MIT Kavli Institute education and public outreach (MKI EPO) office with support from MKI researchers. CAI 2005 consists of a month long, 6 hour per day summer session, and x-ray research projects mentored by MKI EPO educators and MKI researchers during the school year. CAI eventually culminates with presentations of students' research projects at a community-wide science day in the spring.

Educational approach (p.5)

During the summer session, physics, astrophysics and data analysis tools are explored using the Interactive Science Learning Environment (ISLE) developed by Rutgers University faculty for the Rutgers Astrophysics Institute (RAI), the parent program to CAI. In summary, ISLE is a method of science teaching that mirrors the development of scientific knowledge and viewpoints by a working science community, with the goal that students will then easily be able to engage in authentic research.

Instruments (p. 5)

Several instruments are used to obtain data on the effect of the CAI on participants' knowledge, skills and attitude towards science. They include pre and post-testing with items validated in much larger populations, feedback questionnaires, summer and school year written reflections, peer reviewed research presentations, surveys of attitudes toward science and related careers and CAI faculty observations.

Demographics (p. 8)

Although the Rutgers Astrophysics Institute was originally designed for high achieving students, we wanted to expand the scope of the program to include students on the base of their motivation and independently of academic achievement. Our participants were 23% female, spanned a wide range of ethnic classifications, including 46% from Hispanic backgrounds, and 62% had households where conversations are held sometimes or never in English. Only 14% of students had taken over 2 years of physical science, and 57% had not yet taken a formal course in physics, one of the requirements of the Rutgers program.

Goals

The overall goal of the program is broken into three parts and evidence for attainment of each of three focus areas is examined.

Focus area 1: *Did students learn physics, astronomy and the nature of science? (p. 9)*
Although the CAI curriculum was changed significantly from that of the RAI to reflect the needs of our participants, experience from the first implementation of CAI, suggests specific changes in the CAI curriculum order and content. On the 43 item pre- and post-

test, students showed average normalized gain of 0.29 and educators 0.42. Typical gain for traditionally taught introductory physics courses is around 0.2. Some weaknesses in presentation brought on by time constraints are reflected in specific content subcategories, emphasizing the need to try to more efficiently streamline the already large amount of content in the course. (Recall that students are brought from middle school space science knowledge to research capability in one month.) One highlight is the significant gains on questions designed to probe participants understanding of the nature of science and willingness to engage in scientific debate. Preliminary comparison of participant responses to much larger student and teacher groups show that our students have progressed beyond baseline levels.

Focus area 2: Were participants engaged by the CAI constructivist approach and activities? (p. 22)

On a scale of 1 to 5 indicating learning value of all 30 major activities, the average student rating of 3.9 and average educator rating of 4.5 indicates success in this category, with students showing particular preference for less "traditional" activities. Of 12 elements of the CAI teaching approach, average student rating was 3.5 and average educator rating was 4.4, with particular emphasis by both groups on quantitative problem solving with individual attention.

One mismatch between student expectations and the CAI as implemented is the de-emphasis of observational focus in favor of developing physical and quantitative tools. However, there was strong feeling among participants that the ISLE process and the connection of mathematics and science were the most valuable things taken from the summer session. The best indicator of the success of the CAI in adapting the approach and curriculum to the specific group's needs is the fact that 8 out of 12 students and all teachers surveyed would recommend the program to a friend *and* unequivocally do the program again.

Focus area 3: Are participants able to effectively do research? (p. 30)

Work on research projects has just begun and no significant data has yet been collected, but tools are currently in place or under development for this purpose.

Suggested changes to the CAI program

Four areas with specific changes are suggested by the evaluation data obtained: curriculum and content, teaching approach, "boundary conditions" of program—what happens before, after and outside the program, and the evaluation plan.

Summary of CAI 2006 (p. 35)

The strategy for the above changes is laid out in a picture of how CAI 2006 will be implemented, focusing on the development of a relationship with a new school, the John D. O'Bryant School for Math and Science in the Boston school district, as well as maintaining our previous Lynn and Lawrence partners. A more in-depth recruitment approach should help CAI faculty learn enough about the new participant population to adjust the program to meet their needs. Based on experience with CAI 2005, the goals of

CAI 2006 have been adjusted and stated as succinct, measurable statements that are aligned with specific instruments already in place or under development.

Conclusion: (p. 37)
Gains on a test assembled to measure knowledge in several content areas show that in almost all areas average gains were positive, for both student and educator populations. The questions probing the participants' understanding of the nature of science and willingness to engage in it show particularly strong gains.

Overall, participants felt that the constructivist approach to learning and connection between math and science was valuable and applicable to their future studies.

In summary, the willingness of a majority of students to do the program over again indicates that CAI has successfully (if not completely) adapted the approach and curriculum of the RAI to fit the needs of our very different student and educator populations.

Program summary (CAI 2005)

The Chandra Astrophysics Institute (CAI) is a yearlong program intended to give motivated high school students and their science and math teachers an opportunity to take part in authentic x-ray astronomy research. The CAI was designed, implemented and evaluated by the CAI faculty—staff from the education and public outreach (EPO) office of the MIT Kavli Institute for Astrophysics and Space Research (MKI, formerly Center for Space Research)—with key contributions from MKI researchers. The concept, educational approach and initial curriculum ideas for the CAI were originally developed for the Rutgers Astrophysics Institute (RAI), a program currently implemented at Rutgers University after which the CAI was modeled.

The program is implemented in three phases:

1. Lead up

Educators from the Lynn, MA and Lawrence, MA school districts were recruited in early Spring 2005 to take part in the CAI as a professional development program: learning physical and astrophyiscs content and the constructivist educational approach of the CAI. Educators were also in charge to recruit students for the program. Recruitment for the CAI focused on motivated students, regardless of educational background, who may not have access to advanced science courses or experiences, thereby making them an underserved population. In this the CAI differs from the RAI that was originally intended for gifted and talented students. Additionally, Lynn and Lawrence school districts have a large proportion of students from groups underrepresented in science. The application process included questions about science background and motivation for attending the CAI. Due to time constraints on further recruitment, all 16 students who applied were selected. Two students left after an introductory meeting, and one student left after the summer session due to family and work constraints.

2. Summer session

A four week, 6 hour per day summer session includes approximately two weeks of learning physics and astronomy content. The method followed in CAI (ISLE, see below) leads students to learn science by applying the methods that scientists use to create new knowledge. This makes is in preparation for the shift into doing actual research in the third part of the program. The second two weeks of the summer session are spent learning data analysis software (ds9 and FTOOLS), downloading x-ray archive data from Chandra and other satellites, and building realistic models of astronomical x-ray sources under the guidance of MKI researchers. Before leaving the CAI summer session, students arrange themselves into groups of 2-3 students with a mentor teacher, and choose one of several research projects suggested and mentored by an MKI researcher.

3. School year research

Student/teacher research groups meet for 2 hours per week in an after-school environment, using Virtual Network Computing (VNC) software to easily access data and analysis tools on a remote Linux server. The students report progress and ask questions of CAI faculty and MKI researchers via the Virtual Educational Space resource (VES, http://ves.doe.mass.edu) made available by the Massachusetts Department of

Education. Monthly meetings of all participants at MIT allow for presentations of research updates and clarification of future research goals, as well as social time for group cohesion. Students will write research summary papers and make presentations at a community-wide symposium/science "family day" in Spring 2006, in an effort to demonstrate to the community the enthusiasm and capability their youth have for science and math-related pursuits. By the end of the whole program, students obtain independent study credit through their individual schools, following recommendation from the MKI EPO office.

Educational principles

The underlying principles of the science instruction for the CAI are based on the approach followed in the Rutgers Astrophysics Institute (RAI). Eugenia Etkina and collaborators, who serve as advisors for the CAI, based the RAI on their development of the Interactive Science Learning Environment (ISLE). In summary, ISLE is a method of science teaching that mirrors the development of scientific knowledge and viewpoints in a working science community: observations of a phenomenon are performed and patterns are identified; multiple plausible explanations and models for these patterns are generated, including mathematical descriptions; further experiments are performed to test predictions of alternative models; incorrect models are ruled out; and finally, the likely model is applied in a useful situation (http://www.rci.rutgers.edu/~etkina/ISLE.htm). This approach can be said to rely heavily on the constructivist viewpoint, as the teacher in these situations does not tell students the correct model for a given set of phenomena, but rather leads them to develop and rule out models of their own creation.

As an example of the ISLE approach, examine the discussion of the development of a model for the x-ray source Cen X-3. After downloading ROSAT data for the source, the light curve observations show patterns of a short periodicity (5 second period) and a much longer periodicity (2.6 days). Participants brainstorm reasons for the short periodicity: source increasing or decreasing in size, source moving close and far from observer, a rotating hotspot. By using the relationship of flux, distance and luminosity developed earlier, participants rule out the first two possibilities as requiring motions that are unreasonably fast to produce a 40% change in flux. Further work with Newtonian gravitation and circular motion led to a plausible model of a rotating neutron star. Further ideas and models for the long periodicity eventually led to an eclipse model, giving Cen X-3 a binary character. Similar patterns of investigation were used for other sources.

Instruments

Several instruments were developed to gather data as to the effect of the program.

Pre- and post-testing:

Considering that content knowledge is essential to undertake the research project, a set of 43 test items aligned with the intended curriculum was assembled by the CAI faculty.

Subsets of these questions were administered to students and educators as pre-tests just before relevant topics were covered, leading to some missing data due to absences. On the final day of the summer session, all questions were administered as a post-test, including some additional items related to specific x-ray source analyses.

The 43 items are divided into the following 6 subsections:

- Mathematics (2 multiple-choice [MC] items)
- Nature of science (8 MC items, 5 short answer items)
- Astronomical size and scale (6 MC items)
- Motion/forces/gravitation (7 MC items)
- Light (7 MC items)
- Stars / stellar models (8 MC items)

Short answer items were graded on a 3 or 4 point scale, leading to a total of 55 points on the instrument.

In addition to examining relative improvement of our participants, we hoped to place their performance on an absolute scale by including several appropriate test items with data that had been tested with a larger comparable population. The 43 items come from the following sources:

- 9 science items and 2 mathematics items from several state-mandated MCAS examinations. Data has been collected on these exams includes typically 1000 students.
- 17 items from the 200 developed, tested and validated by the Science Education Department (SED) at the Smithsonian Astrophysical Observatory to accurately measure student and teacher space science content knowledge using the NRC *National Science Education Standards* and AAAS *Benchmarks* with NSF and NASA support. Data has been collected for our questions from about 1000 students and 100 educators.
- 15 items developed specifically by CAI faculty, several based on nature of science questions developed by RAI faculty.

See Appendix for complete listing of pre-/post-test questions.

Feedback questionnaires:

On the final day of the summer session, feedback questionnaires consisting of scaled (1-5) ratings and open response comments were administered to 12 of the 14 student participants and 6 of 6 educator participants. The sections of the feedback form addressed the following topics:

- Instructor ratings (8 rating items)
- Course pace and difficulty
- Learning value of major activities (30 rating items)
- Learning value of teaching methods employed (12 rating items)
- Personal value/applicability of CAI to participant (7 short answer items)
- Suggested changes to CAI (2 short answer items)

See Appendix for complete listing of feedback form.

Summer journal entries/weekly research updates/final papers:

Writing samples provide not only a chance for participants to reflect on their own knowledge, but also give insight into their difficulties and increasing communication skills.

Each day during the summer session, the last 20 to 30 minutes were set aside for participants to reflect on their learning by answering the following questions:
- What did you learn today?
- How did you learn it? / Why do you believe it?
- What questions and/or comments do you still have?

This approach is used in the RAI as well, and is intended to help participants crystallize the value of each part of ISLE instruction (observation, pattern-finding, model building, model testing, model application) as related to their own knowledge acquisition.

Each week during the school year research project, each student is to answer the following questions in an online posting to the CAI discussion groups hosted by the Massachusetts Department of Education "Virtual Education Space":
- What were your goals for this week and did you accomplish them?
- What did you learn about your source?
- How did what you learned relate to your current model of the source?
- What questions were raised or left unanswered?

All writing samples, including the final paper summarizing research project results are to be analyzed using a rubric designed to measure demonstration of desired scientific communication and research skills. This instrument is currently under development in a collaboration between CAI and RAI faculty, so only anecdotal evidence of these skills is available at the time of writing.

Monthly/final research presentations:

At each monthly research update meeting, each group presents its progress. All other student participants complete a peer review of the presentation. The peer review is based on guidelines that reflect desired scientific abilities and it is under further development by CAI and RAI faculty. In preparation for the final presentation, CAI faculty and MKI researchers will provide feedback to the presenters using this peer review as well.

Monthly questionnaires:

A short questionnaire to gauge the impact of CAI on participants' approach to schoolwork and teaching will be administered at each monthly meeting.

Attitudes toward science and related careers surveys:

The Epistemological Beliefs Assessment for Physical Science (EBAPS) is being administered at the beginning and end of the school year portion of the program to evaluate changes in participants' views of the following categories:

- Coherence and structure of scientific knowledge
- Effective ways to learn science
- Applicability of science to real life
- Evolving nature of scientific knowledge
- Natural ability vs. hard work in success in science

In addition to this measure of "attitudes toward science," we include questions relating to the desire and willingness of students to pursue a science and/or math-related career.

Demographics of students:

Although the Rutgers Astrophysics Institute was originally designed for high achieving students, we wanted to expand the scope of the program to include highly motivated students from all student groups, independently of academic achievement. Our participants were 23% female, spanned a wide range of ethnic classifications, including 46% from Hispanic backgrounds, and 62% had households where conversations are held sometimes or never in English. Only 14% of students had taken over 2 years of physical science, and 57% had not yet taken a formal course in physics, one of the requirements of the Rutgers program. Table 1 gives percentages of students and educators with given background information responses.

Table 1: Background information for students (N=13) and educators (N=6). Numbers are individuals.

Gender?	Students	Educators
Female	3	3
Male	10	3

Race?	Students	Educators
American Indian/Alaskan Native	1	
Asian/Pacific Islander	2	
Black		
White	4	5
Multi – racial	4	1
Omit	2	

Hispanic Origin?	Students	Educators
Yes	6	1
No	7	5

Conversations among adults at home?	Students	Educators
Only in English	5	4

Sometimes in English	4	1
Never in English	4	
Omit		1

Grade this year (2005-2006)?	Students
11th	3
12th	9
College	1

Years of physical science?	Students (N=14)
1	6
2	6
3	2

Taken formal physics?	Students (N=14)
Yes	6
No	8

Goals and outcomes:
The overall goal of the design and implementation of the CAI can be stated succinctly. CAI should give motivated students the opportunity to learn physics, astrophysics and data analysis in a way that engages them in holding up their explanations and models to data they themselves can observe and quantitatively describe, instead of simply taking an "expert's" word for it. This mirrors the way working scientists use quantitative description and effective communication to create new knowledge, and so will allow the students to be effective astrophysical model-builders when they undertake research projects of their own.

The rest of this report focuses on evidence for this outcome, by analyzing a set of focus areas based on this statement. Note that although all focus categories refer to the entire program, most data comes from the summer session of CAI 2005. Other data will be labeled as such.

Focus area 1: Did students learn astrophysics and data analysis?

First, we examine the topics actually covered in the CAI summer session, and differences in content from RAI. We show in Table 2 the CAI curriculum as designed and as implemented.

Table 2: CAI Summer 2005 curriculum

Day	**Actual agenda**	**Intended agenda**
0	**Size and Scale**	**Size and Scale**

	• Modeling the Universe • Scale model of galaxy • Revising models	• Modeling the Universe • Scale model of galaxy • Revising models
1	**Models / Motion** • Building simple alternative models • Developing example quantitative relationships • Examples of accelerated, non-accelerated motion, look for patterns	**Models / Motion** • Building simple alternative models • Developing quantitative relationships • Linear motion (position, velocity, acceleration) • Circular motion
2	**Motion / Gravitation** • Motion detector to measure force, velocity, acceleration of moving cart • Online gravity simulators, using inquiry approach to look for patterns • Room-sized model of gravitational field (students as test particles)	**Gravitation** • Online gravity simulators, inquiry to look for patterns • Application: satellite motion • Energy o Conservation of energy using simulated craters
3	**Applications of gravitation** • Quantitative form of gravitational force • Short lecture on circular motion with demo • Application: satellite motion	**Light and Matter** • "Atoms in Motion" simulation to connect thermal energy to temperature • Particle model to explain behavior of light • Filters
4	**Light** • Developing simple models to explain observations of light behavior, end with particle model. • Application of model of light to filters	**Structure of Matter** • Early atomic models • Bohr model
5	**Atomic structure / Energy** • "Discovery of the Electron" article about how scientific models change • Electric force analogy with gravity • Room-sized electric field model, with students as test particles • Draw and label Bohr model of atom, including parameters • Discussion of conservation of energy using simulated craters	**Blackbodies / Measuring light: Qualitative** • Observe spectra of light bulbs o Connect thermal motion to blackbody spectrum • Qualitative Wien's Law • Solar spectrum • Intro to flux
6	**Bohr model** • Mini lecture to explain form of GPE • Hydrogen spectrum: quantitative observations • Derivation of Bohr energy levels • Students make connection that light energy comes from transitions, predicted photon energy from model.	**Blackbodies / Measuring light: Quantitative** • Flux from a light bulb (1/r^2) • Wien's Law / Stefan-Boltzmann Law • Electromagnetic spectrum •

7	**Light as a wave / spectral observations**
	• Guest lecture: wave characteristics of light / sound
	• Observations of 7 different light bulbs, characteristics of spectrum
	• Prediction/application: lines from different elements different, why
	• Begin to talk about solar spectrum
	•
		Light as a wave
		• Guest lecture: wave characteristics of light/sound
		• Telescope properties
		    o Angular size
		    o Resolution
		    o Light gathering

8	**Wien's Law / Intensity**
	• Groups present model for solar spectrum
	• Heated filament: examine shift in spectrum with temperature
	• Build idea of intensity (number of photons per time per energy range)
	• Relate energy of photon to wavelength of wave
	• Looked at spectra of hot and cold bulb: qualitative Wien's law
		Individual stars: descriptions
		• Doppler effect
		• ID card for a star
		    o Luminosity / flux/ distance
		    o Mass
		        ♣ Kepler's 3rd Law
		        ♣ Binary star mass examples

9	**Temperature and Blackbodies** • Hot/cold water/"Atoms in Motion" simulation to develop idea that motion of particles is thermal energy • Define blackbody: light source with spectrum depending only on temperature • Room model propagation of EM wave • Connect temperature and BB spectrum: range of acceleration of particles leads to light production at all frequencies.	**Individual stars: models** • Ideal gas model • Energy generation in the sun (fusion) •

10	**Measuring light / Linux I**
	• Review spectrum generation mechanism, fill out first line on worksheet
	• Wien's Law from simulation: get E_peak = f(T)
	• Intro to flux: measuring flux from CandyStar into bowls
	• Tutorial I:
	    o Downloading data
	    o 7FTOOLS light curves
		Groups of stars / Linux I
		• HR diagram
		• Linux Tutorial I

11	**Quantitative light / Stellar parameters** • CandyStar with spectrum to relate intensity, flux and luminosity • Parameters of a star model discussion • Fusion discussion • Masses: online extrasolar planets simulation—fitting models to data • FTOOLS failed b/c of computer problems • HR diagram	**Stellar Evolution I** • Present model of stellar evolution • Group projects on NS, WD, BH
12	**Stellar Evolution** • HR diagram with stellar evolution • Present stellar evolution model in video/reading • Group projects on NS, WD, BH, present in afternoon	**Stellar Evolution II / Linux II** • Group presentations on NS, WD, BH • Linux Tutorial II
13	**Introduction to X-ray data / ds9** • ds9 "Getting started" tutorial • Cas A activity: turning counts into images • Guest lecture on x-ray detectors	**Introduction to X-ray astronomy / Linux III** • X-ray emission processes • Cas A activity: turning counts into images • Linux Tutorial III
14	**Cas A activities I** • Mini-lecture on angular size • Online Cas A tutorial, including light curves with ds9	**Cen X – 3 analysis**
15	**Cas A activities II** • More about light curves, binning • Re-explain absorption lines, solar spectrum model • ds9: fitting spectra, connecting models to data • Introduce methods of spectra production with Chandra movies / pictures	**GK Per analysis (guest)**
16	**Cas A / Cen X-3** • More fitting spectra with ds9 • Discussion about fitting models, weather example • Cen X-3: o Light curves with FTOOLS o Alternative models for short periodicity	**Cas A analysis (guest)**
17	• **Cen X-3:** o Develop and present model for eclipse • **GK Per (guest researcher)** o Light curves with different bin size o Intro to power spectra with FTOOLS	**3c273 analysis (guest)**
18	• **GK Per (guest)** o FTOOLS efold to check period o FTOOLS spectral fit to calculate flux, get distance o Model for GK Per not too clear… • **Cluster analysis (guest)** o Rule out models by looking at how far they would be based on angular size o Build spectrum of galaxy from spectrum of stars o Doppler effect demo with rotating buzzer o Hubble expansion using balloons	**Cluster analysis (guest)**
19	• GK Per / Cen X-3 model comparison • **Cluster analysis (guest)** o Hubble diagram: distance from velocity o Get linear size o Get luminosity o Speculate on model of what is making this: hot gas! • Present research projects, schedule for fall	**Present group research projects**
20	• Final evaluation • Meet with science groups • Feedback, written • Feedback, oral • Celebration	**Evaluation**

Comments on material/curriculum:

- One large difference between RAI and CAI is the RAI requirement that a year of high school physics be taken prior to the program. A majority of our students did not have this background. An extra day was spent on motion to review the concepts of velocity, acceleration and force. Although most students were familiar with these concepts, few had mastered them in a formal physics course. However, students did show improvement in these areas (see "Motion/gravitation post-test results.) **Possible change:** Depending on initial preparation of students, this section should be given more or less time in the schedule.

- The connection between the model of light as a particle and the model of a blackbody as the source of light was muddled by the definition and relationships of more complex physical quantities like intensity, energy and flux. **Possible change**: Make a stronger distinction between developing *models* and defining new physical quantities that are, in essence, *observations*.

- The connection between spectrum production in blackbodies, Bohr emission and absorption and the resulting astrophysical model for the solar spectrum (i.e. "gases in the atmosphere of the sun absorb particular photon energies produced by the opaque blackbody solar surface") had to be revisited several times after its initial presentation. **Possible change**: Reorganize the curriculum order to emphasize the steps leading to the solar spectrum model. It is vital that participants understand how the first astrophysics model is based on our understanding of the previous physics models.

- By the time we got to the source analyses, it was realized that emphasizing techniques for determining important parameters of a "generic" stellar model (i.e. measuring parameters of distance, mass, luminosity, age, size, temperature, etc.), would more strongly motivate the physics models we had built before (i.e. motion, light, blackbodies, ideal gas). Although most of the RAI students had some interest and experience with physics, most of our students came to CAI with expectations of astronomy content only, and sometimes struggled to see the connection of the physics in weeks 1 and 2 to the astronomy in weeks 3 and 4. **Possible change**: Time should be focused on models, techniques and physical quantities to enable the measurement of parameters of stellar system models, as well as using simple optical data to build these models along the way.

Comments on source analyses:

- Although tutorials for ds9 (image processing software) are online and straightforward, it is worthwhile to interactively see if students really get the important points of these self-contained activities. Sometimes, too much emphasis was put on smaller data details (i.e. exact binning methods, counts/sec vs. counts/bin) that should be left out in favor of spending more time building alternative models of the source that produced the data being analyzed. Students did not fully understand the object analyzed in the ds9 tutorial, Cassiopeia A, as the tutorial did not clearly follow the model building process developed in the first two weeks of the summer session. **Possible change:** Spend time during first month of year redoing Cas A analysis, focusing on building model of object instead of learning data analysis tools.

- The cluster analysis seemed particularly successful, and went more smoothly than other source analyses because of the application of an authentic setting of tools previously developed: i.e. angular size, luminosity from flux and distance. However, this analysis took too much time building other tools and models that should have been already in place: i.e. Doppler effect and Hubble expansion. **Possible change**: Focus curriculum more on "toolbox" approach, developing only those tools known to be used in source analyses.

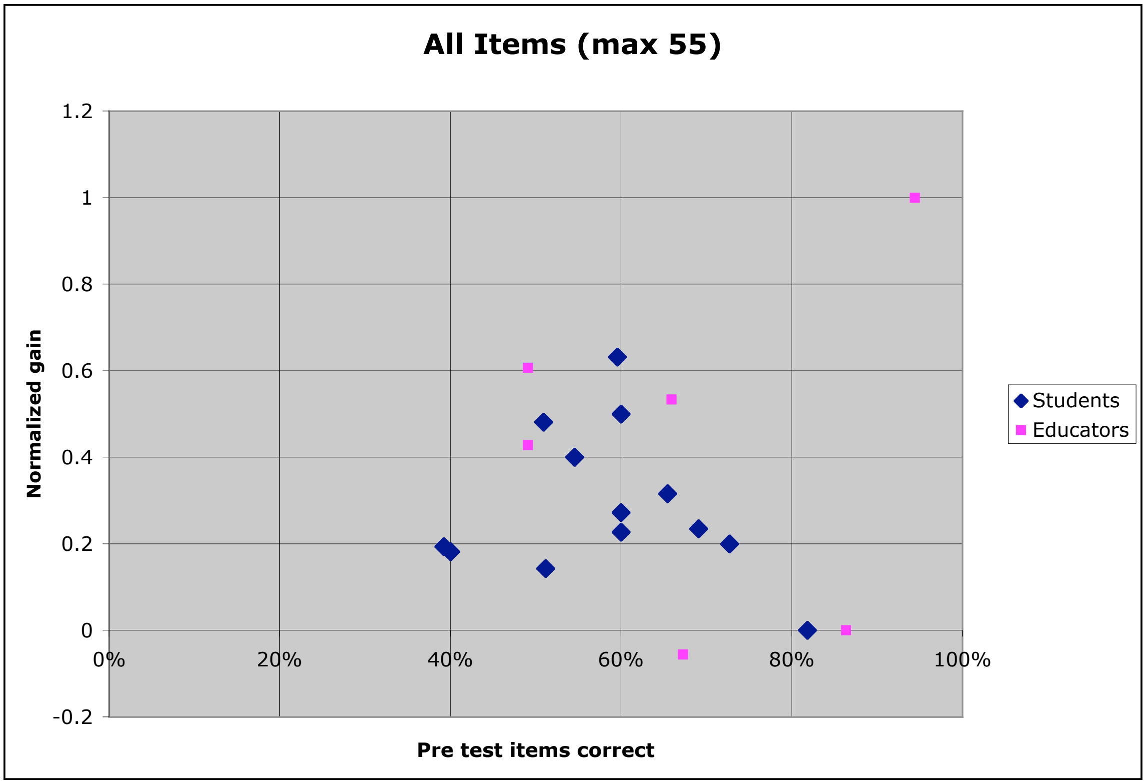
- Order of analysis is questionable, given that Cas A and Cen X-3 are very complex objects with which to start. **Possible change**: Do simpler object (GK Per, other) first.

Pre- / Post-test results

Under the assumption that our pre-/post-test items reflect accurately the content knowledge we aim to impart to participants, the normalized gain (post percent correct – pretest percent correct / 100% - pretest percent correct) made by all participants on the entire test and individual subsections is presented below. Given that some participants did not fill out both pre and post test evaluations for certain questions, the total number of points available for each participant may be less than the maximum number for each of the 13 students and 6 educators. Significant deviations from the maximum of 55 points include a student who answered a matched pre/post set of questions with only 43 points possible, and two educators with only 18 and 22 points possible**.** Gains are measured only on those questions where pre and post test answers are available. Participants who scored perfectly on the pre-test for a given item are not shown and not included in the average gain for each section.

Overall:

All items showed average student gain of 0.29 and average teacher gain of 0.42:

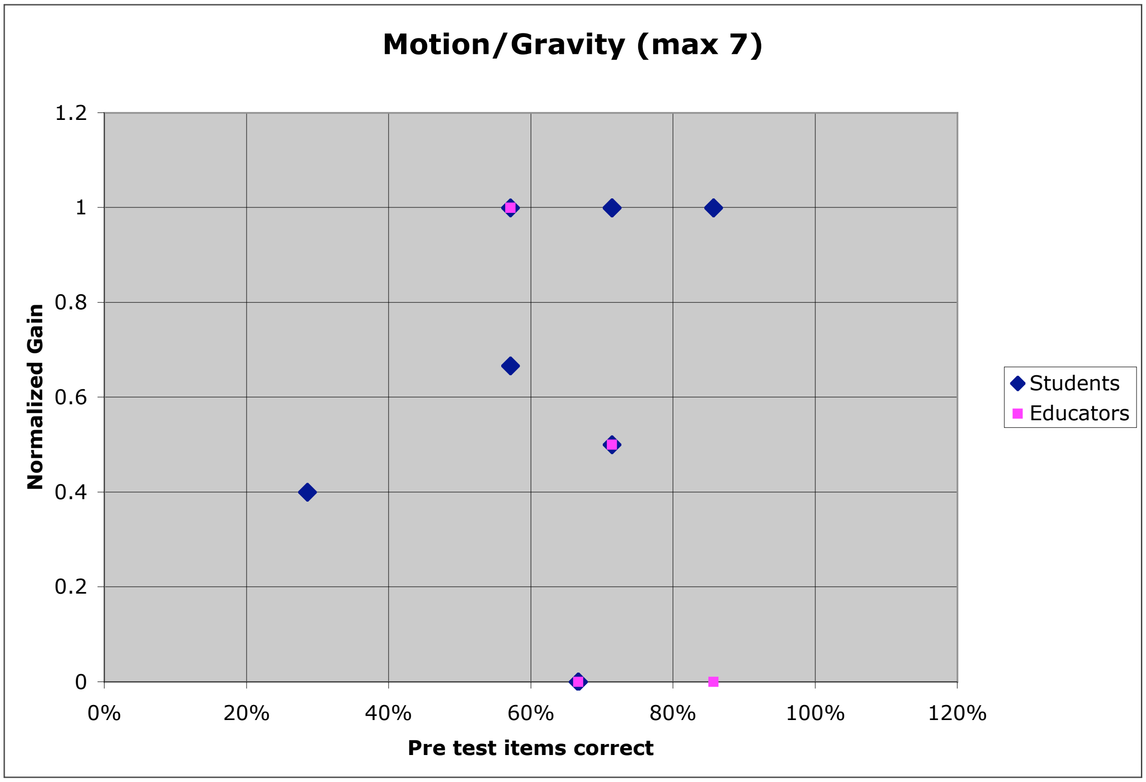


Overall, we notice that the spread of the ability of our students (as indicated by their performance on the pre test) is well-matched to the "difficulty" of the exam (i.e. not every one scored really well or really badly). No participant showed a decrease in overall score.

Typical gains on instruments such as the Force Concept Inventory or Mechanics Baseline Test during traditional introductory physics courses are 0.2. "Reform" introductory courses (i.e. those taught with a more interactive, constructivist approach similar to the CAI) achieve average gains of 0.4 to 0.7. Of course, these instruments have been tested and validated as accurate measures of the Newtonian physics viewpoint, whereas our test instrument has not yet undergone rigorous testing. We intend to work with science education specialists at the SAO SED to better align this instrument with our content goals, using their validated items. Nevertheless, our students do show significant gains on space science related content knowledge that is at least nominally connected to our content goals.

***Motion, force and gravitation**:*

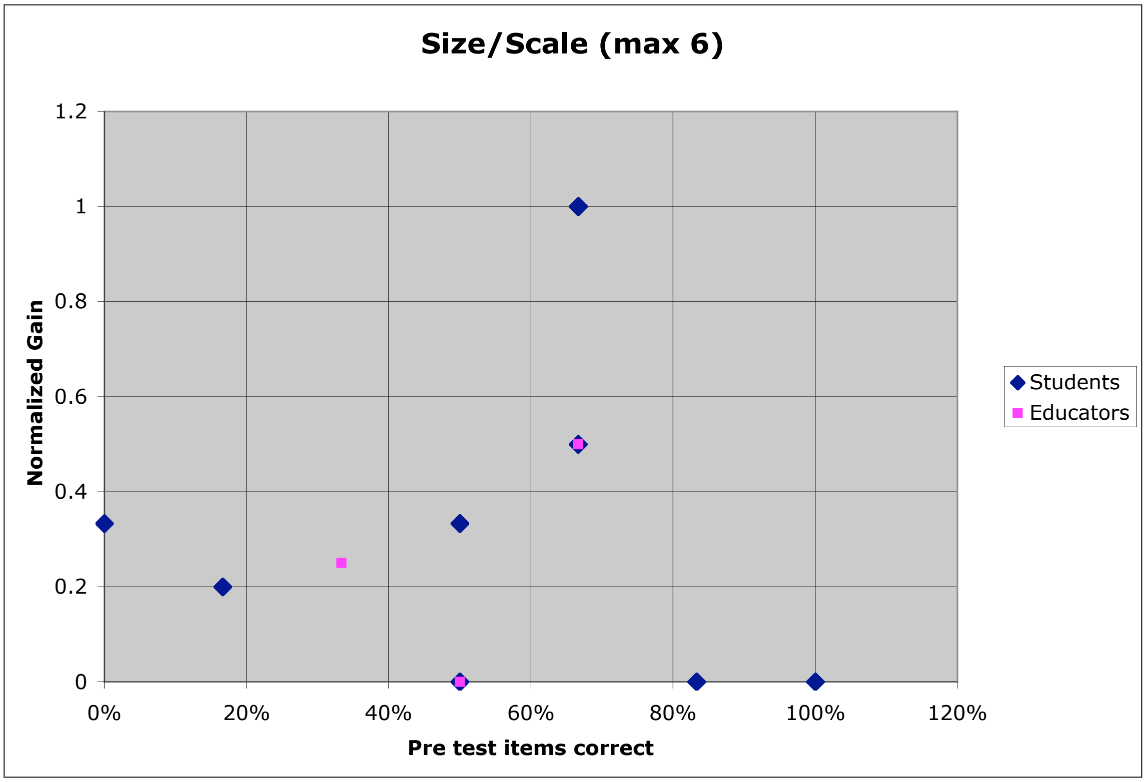
Items about motion, forces and gravitation showed average student gain of 0.69 (2 omitted by perfect pretest, 6 with gain = 1) and average teacher gain of 0.50 (1 with perfect pretest, 2 with gain =1):



Given that 6 of 7 questions in this section are based on the MCAS exams for 8th and 9th grade students, this data with its range of pre-test scores from 30 to 100% supports our feeling that our students show a wide range of incoming basic physics knowledge that must be supplemented to get to some of the more advanced material. Relatively high average gains here show that our students did pick up this basic knowledge.

Size and scale:

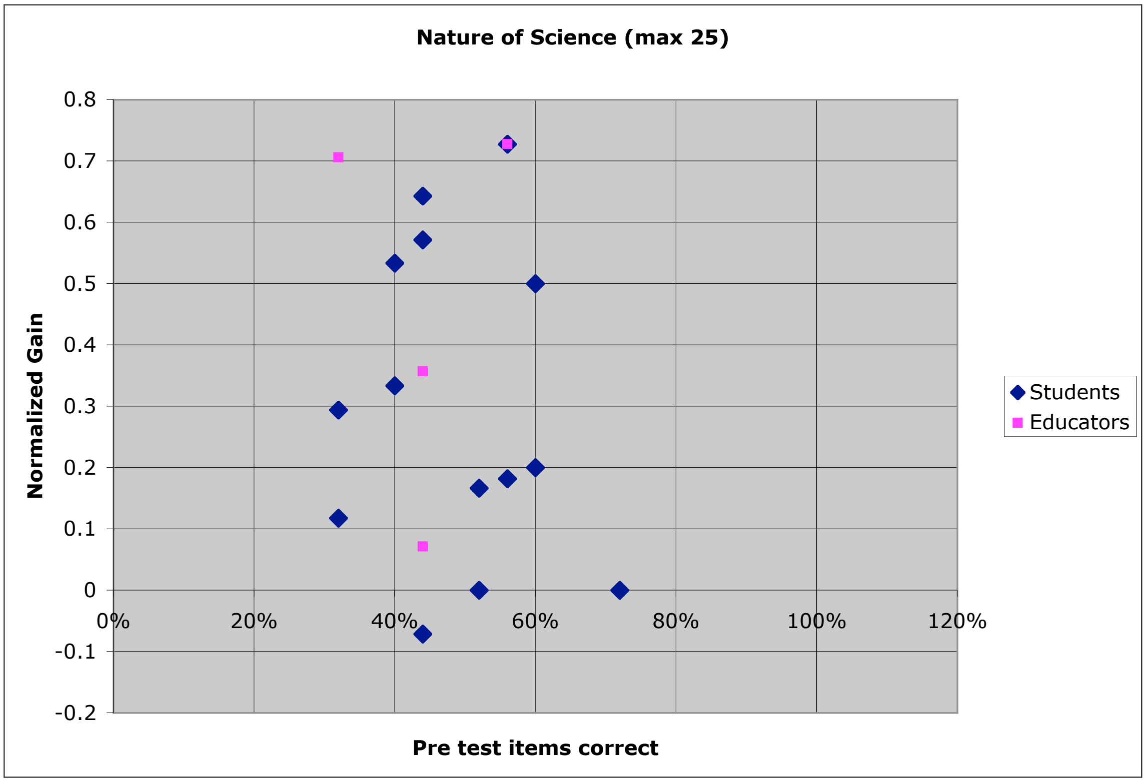
Items about astronomical size and scale showed average student gain of 0.42 (3 with perfect pretest, 3 with gain = 1) and average educator gain of 0.25 (1 with perfect pretest, 2 absent):



Even though CAI did not focus specifically on size and scale beyond the first day, the applications of mathematics in the program should have allowed students to answer questions correctly. Given that large numbers are particularly useful for describing astronomical systems, this may be a key area to strengthen the math/science connection built into the program.

Nature of science:

Items about the nature of science showed average student gain of 0.27 and average educator gain of 0.47 (2 absent):



Probably the most important outcome of our program is a better understanding of the nature of science and the use of models in research. Our educators show a greater average improvement than our students. Several of these questions are the short answer questions discussed specifically below.

The performance of participants on three "Nature of Science" short answer questions (measured with a 4 point scoring rubric) serves to illustrate large gains in their willingness to engage in scientific thinking (see Appendix for grading rubric):

12. One dark night on a lonely beach on Cape Cod, Mary and Harry both make the following observation:

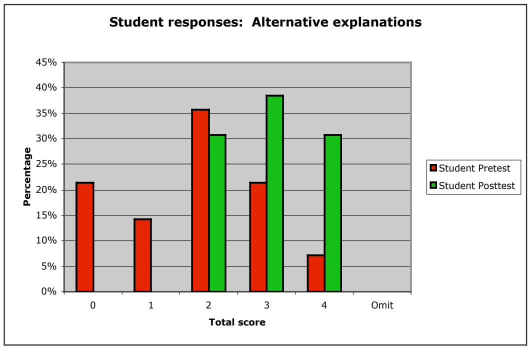
> There are green streaks of light which show up in the night sky and disappear about a half a second later.
>
> They each come up with an explanation for what they just saw…

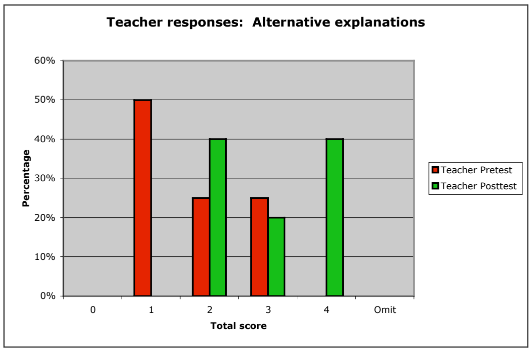
Mary:

> Each streak is a piece of something that heats up as it goes through the atmosphere until it glows. It stops glowing when the thing burns up and is all gone.

Harry:

> Each streak is a small piece of something that was hot enough to be glowing already. We don't see it until it gets close enough (and therefore big enough) for us to see. It stops glowing because it cools down--the upper atmosphere is cold, like at the top of a mountain--and falls to earth.
>
> Each of their explanations is perfectly valid for that one observation. What could you do to find out which explanation is better? What evidence or data could you collect?

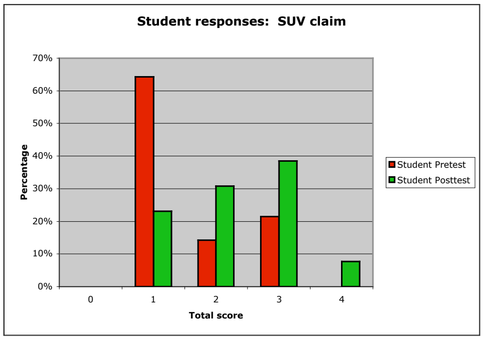


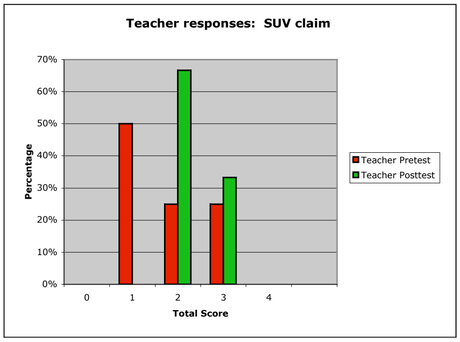


This question illustrates the ability of the student to connect an observation with the predictions of two different models and developing a test experiment to determine which reasonable explanation is actually correct. Both students and educators show significant increase in this ability.

11. An ad for the new Gasco brand SUV makes the following statement:

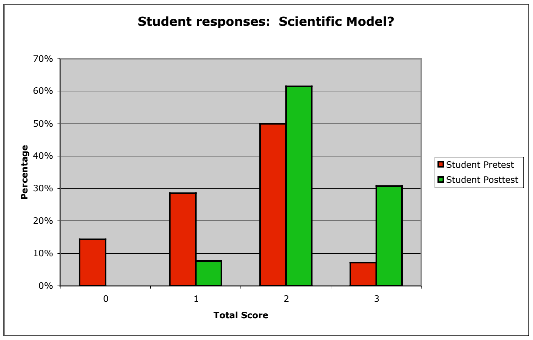
> Our new SUV, the "Fuelinator" is so efficient that it can cross the state of Massachusetts in one tank of gas!
>
> Does this explanation convince you that the vehicle is gas efficient? If not, what would you do to convince yourself that this statement is true?

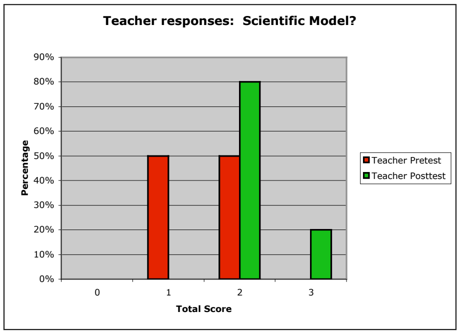




This question tests the willingness of participants to engage with a scientific claim of the sort they may see in everyday life. CAI strives to point out that claims must be backed up by evidence that is (usually) possible for an individual to investigate herself.

14. What is a scientific model, as you understand it? Give an example.





Here, the question probes the level of understanding of the nature of the models we've been building: we see a move from a simple "smaller representation" scheme to a more sophisticated "network of testable ideas" scheme.

At the start of CAI, participants are uncomfortable with the exact meaning of the word "model", as expected. The data from "nature of science" question 14 above shows that the majority of the original conceptions reflect Carey & Smith's "Level 1" conception of a model as simply a copy of reality. It may be too much to expect them to distinguish this without more guidance. **Possible change**: Instead of asking "What is the model that explains this observation?", have them answer "Why is this happening?" to a fictional younger sibling to avoid confusion with the term. Later on, introduce the idea that a model is the answer to this question for a particular set of related observations. Possibly only introduce this definition of "model" after developing mathematical relations and predictions as well as simple "explanations" or "ideas." It would then be easier to explain that a "math model" is really just one aspect of an "idea" model.

***Mathematics**:*

Due to small numbers, mathematics gains are not represented, but percent correct answer among student population changed from 64% to 85% (item 1) and 86% to 92% (item 2) from pre- to post-test. Percent correct answer among teacher population stayed at 100% for item 1, and dropped from 100% to 67% on item 2.

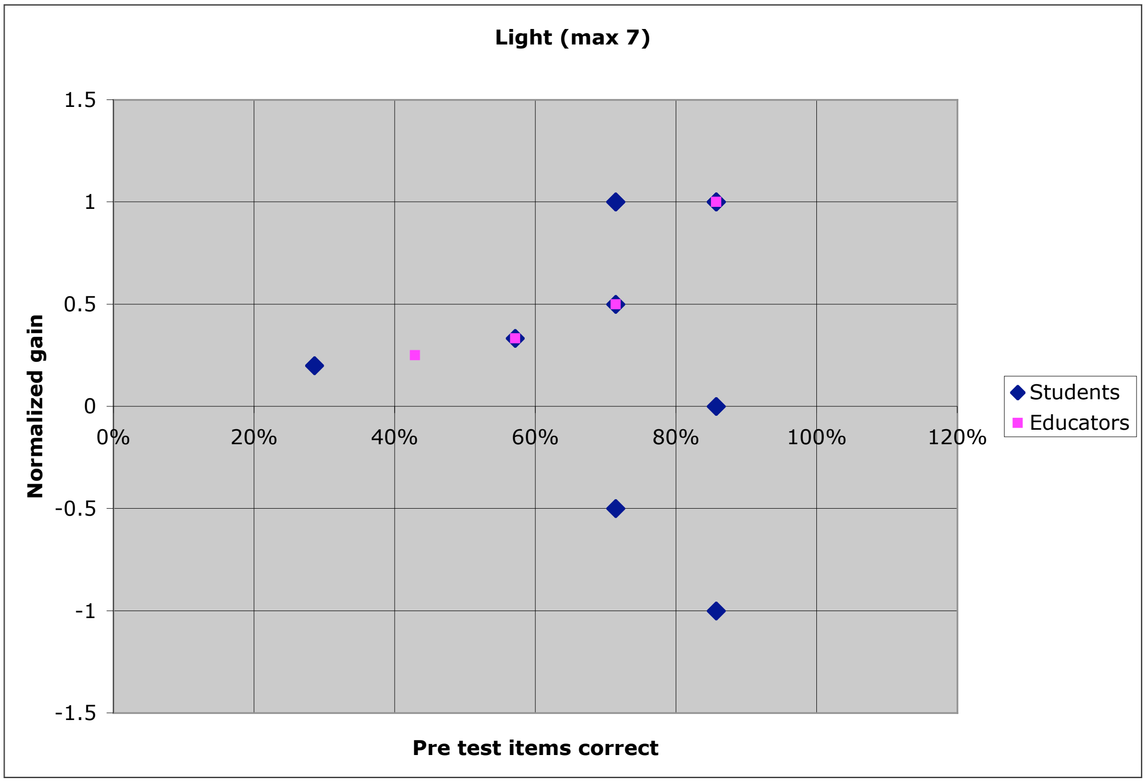
Comments on mathematics/science connection:

- Although several worksheets were used in an effort to give the students a framework within which to approach solving problems and developing mathematical patterns (i.e. direct relationship, inverse relationship, etc.), it was difficult to keep the students in the habit of following steps in a variety of situations. **Possible change:** Take more time near the beginning of the course to go through several simpler, more familiar examples of utilizing these problem solving techniques. This may help to cement a process that many students (even those with significant science and math background) are not familiar with: i.e. thinking about what one aims to accomplish in a certain problem instead of just plugging in numbers to "get an answer".

- The fact that the “traditional” problem solving exercises in the last part of the ISLE cycle took much more time than anticipated (due to a lack of math skills by the students) also made following this process to completion unreasonable for all activities in the institute. It became clear in the third week that at least a few students had significant difficulty with simple algebra in terms of solving equations for a single variable. **Possible change**: Make a simple algebra test a prerequisite for applying to the program.

Light:

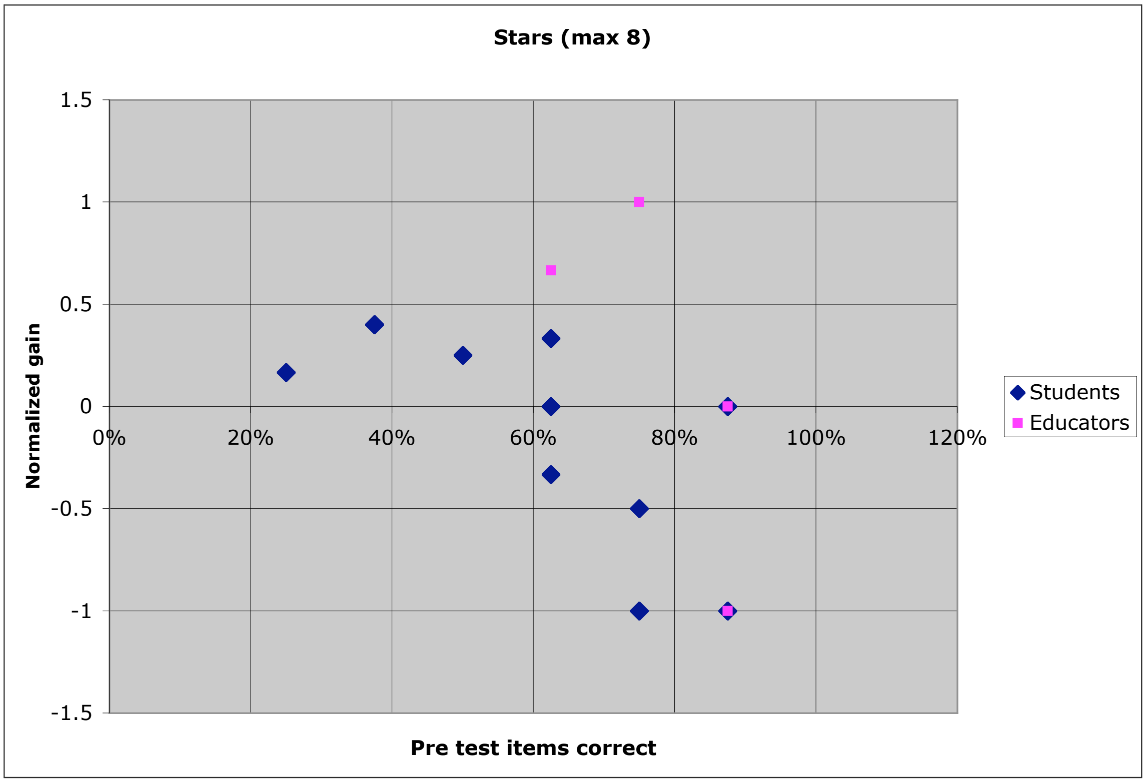
Items about light showed average student gain of 0.41 (2 with perfect pre-test, 5 with gain =1) and average teacher gain of 0.62 (1 absent, 2 with pretest = 86%):



It is clear from several questions in this section that the idea of the electromagnetic spectrum beyond optical and x-rays and its utility in observational astronomy were not clearly communicated. This is in part due to the fact that an in depth analysis of the electromagnetic spectrum was shortened for time constraints. The single highest gain on any question was for item 30, asking about the effect of a filter on incident light: Students correct pre to post: 64% -> 100%; Educators correct pre to post: 60% -> 100%. An entire afternoon of CAI was devoted to the action of filters and their relation to the model of light. A possible compromise is to extend this discussion into non-visible wavelength filters and build upon existing knowledge.

Stars / stellar models:

Items about stars showed average student gain of –0.09 (2 with gain = -0.3, 2 absent) and educator average gain of 0.17 (2 with perfect pretest):



The data show some evidence for decreases in scores, possibly from reinforcement of misconceptions. We interpret this as a shortcoming in the amount of time we spent on building good models for stars and covering astronomical systems, due to time constraints. A suggestion (outlined below) is to motivate the learning of physical models and tools with the building of a stellar model from optical data, beginning on the first day.

Large sample comparisons

In order to compare our students on an absolute scale, the Table 3 shows data from several items also administered to much larger populations.

Table 3: Comparison of pre/post CAI performance with MCAS results

Item	Category	Grade/Test	% Correct: Pre CAI 2005	% Correct: MCAS Lynn school district	% Correct: MCAS State / SED results	% Correct: Post CAI 2005
1	Math	10/Math	64	58	67	85
2	Math	10/Math	86	82	89	92

3	NOS	8/Sci_Eng	64	38	47	62
21	Gravity	8/Sci_Eng	83	69	72	100
22	Gravity	8/Sci_Eng	75	38	46	85
42 (not included on pre-test)	Math	10/Math		65	74	69

We can see that our student population is representative of the mathematics ability of their peers, and higher than those of younger students on the science examinations (sample groups of about 1000 for statewide results). Gains made show that the CAI approach is effective even for evaluation items not specifically designed by CAI faculty.

Additional data from the SAO Science Education Department study for a comparable population is forthcoming to establish the typical knowledge of similar age science students in the size and scale, light and stars categories. More MCAS data will address the motion and gravitation category. See preliminary results of these comparisons in the Appendix.

Focus area 2: Were the students engaged by the CAI constructivist approach and activities?

Pace and difficulty numbers

On a 1-5 Likert-type scale, students (N=12) and teachers (N=6) rated the difficulty of the summer institute as 2.9 and 3.1, respectively, and both gave the pace an average rating of 3.0, indicating that participants were able to handle the material as presented. This is an indicator that our approach was at the correct level, or that we could possibly push our students to do more.

Activities feedback

During the written feedback session on Day 20, we asked all participants (N = 12 students, N = 6 educators) to rate the 30 major activities on a scale indicating how much he or she learned from each. 1 indicates feeling that nothing was learned, 5 indicates that he or she could explain the most important aspect to someone else at the time of rating.

The overall average of the average student rating of each activity was 3.91 with standard deviation 0.25. The overall average of the average educator rating of each activity was 4.50, with standard deviation 0.30.

To identify most effective activities, those with average rating one standard deviation or more **above** the overall average determined for each population are listed in Table 4.

Table 4: Activities with "learning rating" 1 SD above average

Activity	Student group	Educator group
Motion sensor lab	4.36	
"Atoms in Motion" computer simulation	4.27	
HR diagram/Mayfly lifecycle analogy discussion	4.36	
Angular size lecture	4.17	
ds9 software tutorial	4.17	5.00
Satellite motion calculations		4.83
Crater demonstration/discussion (Conservation of Energy)		4.80
"Light as a wave" guest lecture		5.00
Doppler effect demonstration		5.00

Activities with average ratings one standard deviation or more **below** the overall average for each population are listed in Table 5.

Table 5: Activities with low learning ratings

Activity	Student group	Educator group
Crater demonstration/discussion (Conservation of Energy)	3.60	
"Discovery of the Electron" article analysis	3.36	
Computers in data analysis lecture	3.55	
Cen X-3 source analysis	3.67	
Spectral fitting demonstration	3.64	4.17
GK Persei source analysis	3.64	4.17
Angular size lecture		4.17
Extrasolar planet model building simulation (self-guided)		4.17
Building models of light lab		4.00

Spring lab		3.67

Overall, students feel they learn more using technology and equipment new to them, and learn less from "traditional" approaches. Educators seem to latch on to new content they may not have seen before, and are frustrated by activities that are intended as introductory for new learners: they most likely are already familiar with these concepts. One important note is the low learning ratings on some of the source analyses and software tools demonstrations—adjustments of the schedule may have made for poor preparation for these activities.

Teaching style feedback

Participants were also asked to rate 12 elements of our teaching approach on what they felt they learned the most from. A rating of 1 indicates doing things this way was a barrier to their understanding, and "5" indicates this approach helped them understand material better than another approach would have.

The 12-item average of the average student rating of each element was 3.53, with standard deviation 0.63. The overall average of the average educator rating was 4.43 with standard deviation 0.5.

To identify most effective elements, those with average rating one standard deviation or more **above** the overall average determined for each population are listed in Table 6.

Table 6: Teaching elements 1 SD or more above average

Teaching element	Student	Educator
Short lectures	4.42	
Group observing	4.25	
Math in class, roaming teacher	4.50	5.00

To identify least effective elements, those with average rating one standard deviation or more below average for each population is listed in Table 7.

Table 7: Teaching elements 1 SD or more below average

Teaching element	Student	Educator
Homework problems	2.75	
Peer review worksheet		3.67

The striking feature in Table 6 is the desire to have a roaming CAI faculty and MKI researchers help when students attempt quantitative problems. The average rating for the comparable "Math in class, on the board" is 1.5 and 1 scale unit lower for students and educators, respectively. Giving more ownership of quantitative problems is slower unless several faculty are present, but apparently much preferred. Inconsistent application and expectation for homework problems and early drafts of the peer review criteria most likely explain their low rating.

Comments on approach to teaching

- Many students, understandably, have a difficult time coming up with alternative explanations for phenomena, given that they are not asked to do this in a traditional school setting. In fact, it is their tendency to believe whatever science knowledge is "given" to them that CAI tries to replace with a willingness to engage in scientific research. **Possible change**: Begin by outlining alternative explanations for phenomena participants observe, and ask them to defend or reject that idea in the face of their observations. For example, make observations of force, motion and gravitation and give Newtonian **and** Aristotelian models for discussion starter. Later, participants come up with their own alternate explanations.

- Students did not fully develop comfort with engaging other group's models, questioning their validity and suggesting model revisions in the context of the larger group: only a few times did a student spontaneously question a model's prediction without guidance of the CAI faculty. One explanation for this observation could be significant cognitive distance between their starting knowledge and the beginning CAI material, saying nothing of more advanced topics. However, the first activities performed were simple model building exercises requiring no specialized knowledge, so there should be no cognitive discomfort with putting out one's ideas and critiquing others' ideas. **Possible change:** Build social confidence of group before putting out ideas and make this exchange explicitly required in first few days of CAI summer session. Refer back to initial activities frequently. Require asking one question during class as well as during journal reflections.

Feedback—Suggested changes to CAI

Several questions about changes to specific program aspects were asked of all participants.

How, if at all, was the summer session of CAI different from your expectations?

	Students (12)	Educators (5)
Better	4	2
Same		2
Worse	3	
Blank/unclear	5	1

Student comments:

- "I thought I would be looking at stars and all the pretty pictures, not learning a new way to look at things."
- "I learned more than astronomy and physics in this program"
- "Actually doing a lot of stuff that astronomers themselves do—also it made me realize how important computers are."
- "We didn't look in telescopes"; "not much astronomy, a ton of math"
- Longer per day than expected

Educator comments:

- Not as difficult to tackle as I thought it would be…

If you were teaching CAI, what would you have done differently?

Students:

- Make grading expectations clear, but "I think not doing so was highly beneficial…We learned not for the grade and that was very useful!"
- "More breaks, less math, more visual information, less time on lectures, more group time to think"
- "Tell answers more often, so we won't have to go so long with a conversation, because after a while nobody listens."

Educators:

- Require anonymous questions to be handed in, to avoid students feeling that they are asking "stupid questions"
- Don't rush the journal entries: suggest 10 minutes for review, 20 minutes for writing
- Reinforce the point when inquiry got to the desired result.

The mismatch between some students' expectations of a more observational focus and our approach to the CAI is clearly shown by these data. In addition, the implementation of the ISLE method of student-driven inquiry was taught with the CAI curriculum for the first time: the appropriate balance between guiding student observation and discussion and summarizing results is still in flux.

Comments on organization

- The first few days, after group discussions, every student group presented their ideas/results: this is problematic in terms of time if each group is reporting on a different observation or task. For subsequent observing tasks/activities, the number of different tasks was limited to 3 or less, and one group was chosen to report their results/model. **Possible change**: Limit number of different experiments/observations done by the set of student groups.

- Reflections were the same format (individual written reflection) and completed in class at the end of each day. Problems arose with time constraints, as well as using the same 3 questions for reflection each day: *What did you learn? - How did you learn it? - What questions do you have?* Sometimes, we asked more pointed questions in an effort to probe understanding of a particular point. Short times (less than 10 minutes) for reflections resulted in poor performance, but CIA faculty made comments on entries each night and participant questions guided the half hour review the following morning. In addition, it was clear that some students never really got the point of the journals as opportunities for their own gain and meta-cognitive "stretching." **Possible changes**: Vary lead-up to reflection time (5 minute faculty-led review, students present big ideas, etc.) and sharing the writing evaluation rubric (in development) at the beginning of the institute. It may be very helpful to take 5 minutes at the end of each activity to have the students summarize the importance of that activity, instead of waiting until the end of the day. Later in the summer session, this approach was taken.

Feedback—personal value of CAI

Several questions about the utility and value of the CAI were asked of all participants.

How did summer CAI compare to your past experiences in school with science and math classes? What was better? What was worse?

	Students (12)	Educators (5)
Better	7	3
Worse	1	
Both	2	
Blank/no clear comment	2	2

Students:

- "The experience I had at this institute is far more valuable to me than any of the previous math or science courses I have had."
- "The summer institute tried hard to make me learn more than school did"
- "That was the way I liked it the most—asking questions and answering them by ourselves. There is no flaw in this system. Period."
- "It was a totally different approach. Instead of the teacher giving us the answer, we found out the answer and I felt like I was totally unrefined ad unprepared, but now I understand things better."
- "This was the best experience in learning I had ever experienced…"
- Better = "weren't given a book with all the answers, and have to study it everyday"; worse = "5 hours in one classroom"

Educators:

- I "really enjoyed the connection to math"

- Teaching in this manner “may not always give the best ‘hard & immediate’ results, (but it) yields long lasting retention…”
- “Inquiry approach was highly successful although slower in result than I would have liked personally”

How will this experience affect your approach to any and all classes in school next year and beyond?

	Students (12)	Educators (5)
Yes, it will have an effect	6	3
No, it won’t have an effect	3	2
Unclear	2	

Students:

- To question different aspects of the subject
- “Sometimes it’s going to be hard to go back to the “system of learning” in school
- “Before, we memorized equations in math—now we don’t have to if we understand.”
- “I will now organize my math, and always use units to see if it is correct.”

Educators:

- I will be “more comfortable giving my students a much longer wait time”
- It is important to let students try to figure out how to solve a problem, without telling them.
- I’ll use the method to introduce new topics in class, but not ALL topics
- I’ll renew my effort to get class to think through problems

What was the most valuable thing you think you got from the CAI summer session?

Students:

- “Ability to work things out in a process or by a set of steps”
- “Thinking why I believe something”
- “That math actually has a structure…I learned more in math than in astronomy”
- describing a situation with numbers
- “How hard people work to get these answers”

Educators:

- “Better sense of how astronomers do their work”
- “ I learned more about physics than I thought I was capable of”
- “Method of teaching was terrific. I will model it in my classroom.”
- “An experience to share with my students where I experienced confusion about a topic.”

Although a few students mentioned specific content knowledge as what they will take away, in general, the method of approach to learning science and the connection to mathematics is what a majority of participants felt was most unique, useful, and valuable.

A few students may not have seen how the mathematics used was really a further application of the ISLE method of making observations, models and predictions, but many students and educators confirm that the connection between math and science was understood and valued.

It is true that even if students think this approach is valuable, the real test comes in their comfort with and ability to complete research projects. In the meantime, feedback about the impact of the program on participants' school performance and comfort level will be gathered at monthly update meetings.

Would you recommend this program to a friend? Why?

	Students (12)	Educators (5)
Yes	7	5
No	2	
Only if their interest is astrophysics	3	

Students:

- "More importantly, we learned the PROCESS of learning…and for that alone I would recommend it highly"
- "Only if they were interested in the math part of the universe"
- "You get experience of how to take notes in college classes"
- No, because "this program's too long"

Educators:

- As a way to examine and enhance their own teaching methods. "That's where my experience here matched my motivation in attending."

What else could you have been doing this summer? Was it worth it to be here instead? Why?

	Students	Educators
Yes	9	4
No	1	
Blank	1	1

Students:

- I could have been working, but "maybe this will get me money in the long run"
- "Because I learned a lot and now I feel prepared for AP Physics and AP Calculus"
- It was worth it "because I am pretty sure I will never be in a program like this."

Educators:

- "I learned so much here that I feel my family (my son mainly) will benefit from me being more knowledgeable in this subject"
- The opportunity to work with MIT folks is hard to pass up, "although I am so relieved I can climb back into my comfort zone again"

Given the chance to do over, would you do CAI again?

	Students (12)	Educators (5)
Yes	8	5
No	2	
Depends on other opportunities	2	

Students:

- My only regrets are "the large time sink…and the large loss in financial gain"
- "I wish school was this way…and I think if I ever became a teacher I will try to teach this way."

The large majority of participants who answered positively to these questions is perhaps the best indicator that the program was successfully tuned to the needs and interests of the particular group. This indicates that the adaptation of the RAI program to a very different group of students is possible, and was accomplished in CAI. An interesting note is that the two students who said they would decline to be involved again have proved to be the most enthusiastic when approaching their research project.

Focus area 3: Are participants effective, critical astrophysical model builders, able to justify conclusions in a research setting?

Research projects have not started yet, as participants are using the first two months of the school year to refresh their memory on data analysis by performing a more in-depth analysis of two sources presented during the summer session. Once monthly meetings begin in earnest, there will be considerable data to be collected.

Currently, there are several tools already used at monthly meetings (first meeting was 10/15/2005): EBAPS attitudes survey, STEM career interests survey, and the monthly questionnaire about ongoing CAI impact. (See Appendix for listing of these tools.) These measures will also be taken for a control group consisting of students from the CAI educators' classrooms, to make an objective measure of the impact of the program.

In addition, there are several tools under development, most notably the writing and presentation rubrics, with help from RAI faculty. (See Appendix for preliminary peer review presentation rubric.)

The change in these measurements over the course of the school year will be examined as data comes available.

Suggested changes to the CAI program

There are several areas where evaluation data and reflection of CAI faculty show the need for some important changes to the program: Curriculum/content, teaching approach, "boundary conditions" and the development of evaluation tools.

1. Curriculum / content

Refine data analysis skills taught to students to only what is needed for success in research projects

Given that our students have just started their research projects, it remains to be seen which tools they will find most useful. However, the list of software tools to have them practice can be refined to include only those that are found most useful with a majority of students. This also builds their confidence to then learn other software tools on their own that might be needed during the research project.

Refine models presented so they all lead to a set of tools for building astrophysical models

Although it is important to make sure students have some of the basic physics knowledge required to develop a scientific view of the world, the CAI program has the specific aim of bringing students to a level of understanding required to undertake research. Thus, although the curriculum of CAI was developed with the approach of the RAI, the curricula continue to evolve. In particular, refinement of the CAI curriculum should include a stronger emphasis on developing only the models, quantitative concepts and tools that allow successful building of models of astrophysical sources. For example, this could include less emphasis on answering the question "What *is* light?" (i.e. models of light as particle and wave), focusing instead on how the properties of light are related to the properties of the source which produced it. This also equates to an emphasis of what can be learned from multi-wavelength observations of one source—something not fully emphasized in the current implementation of the CAI.

Connect physics knowledge and tools to astronomy early on:

As some of the students had different expectations of an "astronomy program" (see below), they sometimes had trouble seeing the use of basic physics models to the astronomy in which they were interested. Although the ISLE approach allows space for application of models, it would be advantageous to identify some important aspects of an astrophysical model first, to motivate the learning of seemingly disparate physics elements, instead of learning the physics elements and bringing them together two weeks later. For example, the data from a binary star system could be introduced on day 1, and the questions about this source would then guide the development of tools to describe motion, gravitation and light. We hope that this will serve to "cushion the blow" before jumping into the approach of using mathematics and physics as a tool for really understanding astrophysics.

Ensure basic comfort with mathematics:

Students had widely varying comfort with the mechanics of calculating and using algebra. This was a stumbling block in several ways, most notably in calculating quantitative parameters and predictions with which to rule out models. In the future, it is imperative that we gauge the student's basic math ability and either put this as a qualification on acceptance to the program, or give the promising student resources on how to bring him or herself up to the level of doing algebraic manipulation and working with powers of ten.

Part of the goal of the program is the break down of the division between math and science indicated by our students and teachers, to help avoid the common opinion that "I like science but can't do the math" which could hamper a student's willingness to continue on in science. By helping students see the value of using quantitative analysis to easily validate or refute models, we hope this will encourage them to work harder to connect mathematics to their science learning.

2. *Teaching approach/organization*

Balance small group work with classroom discussion

For students to see the value of a self-consistent idea, we have them take time to reduce their observations into a consistent model or apply an assumed model and predict the outcome of a certain related situation. However, due to time constraints, the amount of material presented in the program must be reduced to allow this inquiry approach. Striking the correct balance between engaged group work and whole classroom summarizing of results is imperative.

Build scaffold for participant reflection

Given the importance of personal reflection for students to cement their own learning, more time and clearer guidance must be given during reflection times. Because of the separation of skills into discrete classes they experience in schools (i.e. writing, science, mathematics) students find it difficult to reflect and write down their ideas about a science activity. Thus, more scaffolding must be in place to help students begin to reflect and experience how science is done in the real world. To this end, we should consider including a final large or small group discussion of the purpose of the day's activities, either at their conclusion or the conclusion of the day.

Maintain consistent approach to material (observations->models->predictions ->applications)

Although the MKI scientists who facilitate the analysis for different sources may vary from year to year, their overall goal in presenting should be to fill in the missing parameters for a plausible model of an astrophysical source. This means that by the time participants progress to week 3, they should have a firm idea of the process that will be used to investigate. Thus, the models previously presented must adhere to the ISLE presentation method. Several times, the application part of the cycle was shortened in order to proceed to more material. This gives even more reason to focus the content only on the building tools for relevant astrophysical model.

3. "Boundary conditions": What happens before, after and outside the program

Student expectations

Some students may have been put off by the mismatch between what they think an "astronomy program" is and what we intended it to be. This may have led to two of our students withdrawing from the program after the first session. It is our intention to work more closely with the educators and schools where we draw students from, to help them create an accurate picture for their students and identify those who may most benefit from our approach.

The mission of the MKI EPO program is to reach out to underserved students. Although some schools we work with may offer advanced science and math courses (unlike the Lynn school district), their student populations are still underserved in the sense that they have no opportunity to practice the research skills and tools developed in science class in an authentic research setting. It is the students who are genuinely interested in this opportunity (regardless of academic preparation) that we want to target.

Teacher involvement

Having one group of teachers who have already experienced the program back at involved schools will make it easier for them to encourage students whom they think would find the program most rewarding. In addition, it is possible that other teachers from the same school could attend future programs, leading to the development of a cadre of teachers at a particular school who could supervise the research projects of students from that school. It is our idea that we could eventually form teams of a science and a math teacher who would work together to mentor students.

4. Evaluation

Refine evaluation instruments and connect to specific goals

Although results from the current implementation of CAI support the idea that students have learned enough to attempt research projects, there is room for improvement of the alignment of the assessment and the curriculum goals. CAI faculty will continue to work with SAO science education specialists to refine the quality of our pre and post test instruments. In addition, RAI faculty will continue to provide assistance in developing robust rubrics for assessing science writing and presentation skills.

Evaluation plan for CAI 2006

Given outcomes of old evaluation, we have refined our goals and align them more specifically with instruments to measure them for the two major parts of CAI. Tools for the measurement of each objective are listed at the end of each statement, and then described below.

Summer session:

Objectives:

- To engage participants in the ISLE approach to learning as a way to bring them to a working understanding of physics and astronomy necessary to build astrophysical models from data in a research setting: Tools 1 – 3
- To bring participants to a working understanding of detection and data analysis techniques, so they can be comfortable with extracting information from astronomical images: Tools 1, 3
- Increase participants' ability to effectively communicate and debate the merit of alternative scientific ideas and models: Tools 2, 4
- Increase participants' ability to describe situations quantitatively and see the connection between math and science: Tools 1 - 4

Tools:

1. Pre/post summer session testing on
    - Content, including quantitative estimation and problem solving
    - Detection and data analysis methods
    - Nature of science, models
    - Attitudes and interests in STEM and related careers
2. Daily reflective journals: evaluated with rubric reflecting desired understanding and communication and questioning abilities. Includes formative feedback on types of activities best for participants' individual learning styles.
3. Anonymous polling system: immediate feedback on conceptual problems and simple data analysis tasks to measure activity success in real time.
4. Student roundtables: weekly reflection on and application of our teaching/research approach to case studies of real scientific investigations.

Indicators of success:

- Average participant gain of greater than 0.3 on pre/post content testing.
- Positive movement toward self-reported relevance and importance of STEM in the real world and accepted viewpoint of knowledge building in science.
- Increase in average communication and questioning abilities for each student, as measured by writing and discussion rubrics.
- Increasing willingness of students to engage with real world research problems related to CAI content.

School year research:
Objectives:

- To increase students' skill and participation in the methods of science: collaboration, peer review, communication of results, inherent uncertainty in conclusions: Tools 1, 2, 4, 5, 6
- To have students complete a research project report and presentation, making steady progress on research goals throughout the year: Tools 2, 4, 5

- To increase teachers' confidence in their ability to teach from a constructivist viewpoint and to guide research projects in a similar way: Tool 3, 6
- To increase student interest in STEM and related careers: Tools 1, 6

Tools:

1. Post-year testing on the following:
    - Nature of science, models
    - Attitudes and interests in STEM and STEM careers
2. Weekly online journaling/posting: evaluated with journal rubric guidelines above, and to monitor regular progress and identify when additional help is needed.
3. Teacher reflection/idea sharing: online communication forum where teachers reflect on how to adapt our content approach to their own classrooms, and difficulties they had guiding research projects.
4. Monthly research progress reports and guided peer review of all student groups.
5. Final paper/presentation of research results at community symposium.
6. Participant letters: after completion of the program, participants will be asked to reflect on how the program has changed his or her approach to learning/teaching and long term goals.

Indicators of success:

- Statistically significant increase in confidence rating of ability to do STEM-related career (even if not student's ultimate goal).
- Continued increase in communication and questioning abilities for each student, as reflected in writing samples.
- Increase in teacher application of inquiry (student-driven) approach, and comfort guiding their students in this manner.

Increasing peer review scores on presentations, reflecting important aspects of good science.

Summary of proposed CAI 2006

The Chandra Astrophysics Institute (CAI) will continue to be a yearlong program to bring high school students and teachers to the knowledge level to do x-ray astronomy research. We refined our exact goals and outcomes to be more specific and easily measurable by instruments currently under development. (See appendix for details of the CAI 2006 evaluation plan.*)* The current CAI faculty will be joined by two returning MKI researchers, three additional scientists with successful Chandra science proposals, and two scientists from last year that have expressed interest in continuing their involvement with source analysis and research mentoring.

1. Lead up

In addition to drawing participants from Lynn and Lawrence school districts, a new focus will be placed on the John D. O'Bryant (JDOB) School for Mathematics and Science in the Boston School district. With support from the JDOB administration and by starting the educator recruitment process earlier, we aim to increase the number of applicants to the program. To provide students with a clearer idea of the expectations of CAI, and attract those most motivated, CAI faculty will preview the approach of the CAI with activities presented to students and teachers at JDOB. The application process will include more specific information about the student science background and may include a simple mathematics screening exercise, as well as questions about motivations for attending CAI. The goal is for 6 educators and 20 students to participate in CAI 2006.

One particularly unique aspect of CAI 2006 is the establishment of another MKI EPO program at JDOB during the school year 2005-2006: the After-School Astronomy Project (ASAP). ASAP is a ten-week after-school program aimed at high school students with interest in science and possibly astronomy. Participants engage in hands-on astronomy activities and in youth-led investigations of the night sky. Youth learn to take color optical images with online robotic telescopes using the SAO MicroObservatory project (http://mo-www.harvard.edu/MicroObservatory/). They then compare their optical images with images of the same object at other wavelengths. By establishing the ASAP and CAI program at the same school, we aim to provide a natural feeder for CAI based on the experience that students gain with ASAP. The familiarity with processing digital images and a constructivist approach similar to the one used in CAI, will lead the more interested ASAP participants to apply for the next step in their exploration of science astronomy as provided in the CAI. This two-tiered approach is being modeled at JDOB this year, and is expected be extended to Lawrence High School next year.

2. *Summer session*

The educational approach to the summer session worked well, as shown above, but some changes to the content and order in which it is presented will be implemented. This is mostly to streamline models and tools developed to the most useful subset for building astrophysical models. More time will be spent connecting multi-wavelength data to these models, and also interpreting images—the expectation of a more observational focus was a common complaint about the CAI. This may also be a gap that the ASAP program would help fill for JDOB participants.

One particular focus point will be the development of written research vignettes which will be the focus of weekly discussions/debates during summer and several during the school year monthly meetings. Real examples of conclusions drawn from research studies related to material presented in CAI will be debated as to their strengths and weaknesses. The willingness of students to engage in this kind of discussion (somewhat lacking in CAI 2005) and their ability to use their content knowledge to talk intelligently about a particular issue will be a measure of “do participants know enough to do research”. This issue is currently only addressed by the successful completion of a research project, and CAI faculty would like to gauge this ability before the program is over!

3. *School year research*

Given that school year research has just begun for CAI 2005, changes beyond those already stated would not yet be informed by experience.

Conclusion

The goal of this report was to provide evidence that the CAI had met its stated goal:

CAI should give motivated students the opportunity to learn physics, astrophysics and data analysis in a way that engages them in holding up their explanations and models to data they themselves can observe and quantitatively describe, instead of simply taking an "expert's" word for it. This mirrors the way working scientists use quantitative description and effective communication to create new knowledge, and so will allow the students to be effective astrophysical model-builders when they undertake research projects of their own.

This was examined in three focus areas:

1. Did participants learn physics and astrophysics?

Gains on a test assembled to measure knowledge in several content areas show that in almost all areas average gains were positive, for both student and educator populations. The questions probing the participants' understanding of the nature of science and willingness to engage in it show particularly strong gains. However, the treatment of the multi-wavelength nature of light and stellar models must be refined. Given that CAI covers nearly the same amount of physics and astronomy material as the typical ASTRO 101 course, and in some cases requires more specific data analysis knowledge, it is inevitable that time constraints will cause refinement of curriculum from the first year of implementation. Discussions with RAI faculty reveal that anecdotally, CAI faculty are addressing questions and issues with presentation that RAI did not address even after several years of implementation.

2. Did participants benefit from the unique approach of CAI?

Out of all activities and teaching elements, only one (Homework problems for students) received an average participant rating lower than 3 out of a possible 5. Overall, participants felt that the constructivist approach to learning and connection between math and science was valuable and applicable to their future studies. Further confirmation of this applicability will be forthcoming in future data collection.

3. Did participants become effective astrophysical model builders?

Because the school year portion of the CAI has just started, evaluation of this question has yet to be settled. However, several tools are already being developed and applied to accurately assess writing and presentation skills as well as attitudes toward science and related careers.

In summary, the willingness of a majority of students to do the program over again indicates that CAI has successfully (if not completely) adapted the approach and curriculum of the RAI to fit the needs of our very different student and educator populations.

Appendix:

Scoring rubrics for "nature of science" questions:

Scoring Rubric for "Alternative explanations" short answer question (Cape Cod):
- 0: Blank
- 1: "Ask the expert" or "do research" without saying how.
- 2: Describes observations to do or data to collect, but does not relate possible outcomes to either of the two models.
- 3: Describes a testing experiment, and relates outcome to definitively choosing one as "correct."
- 4: Lays out a prediction that one theory makes, suggests a testing experiment (i.e. "measure temperature above the atmosphere" or "look for pieces on the ground") but leaves open the possibility of further data undermining their conclusion.

Scoring rubric for SUV claim question:
- 0: Blank
- 1: Trusts the authority or says "I don't believe", but does not give a reason why.
- 2: States things you'd "need to know" (miles per gallon, size of tank, etc.), but not how to find or measure them.
- 3: States an experimental design to verify this claim—something they could do themselves.
- 4: Complete description of testing experiment, including some mention of vague assumptions of claim or uncertainties in measurement.

Scoring rubric for scientific model question:
0 – Blank
1 – Simple copies of reality, smaller or bigger.
  - Useful because they provide copy of real thing or behavior.

2 – Model of reality, but there is a purpose for which model is constructed—
  - Does not have to be an exact copy of something, and that's okay—
  - BUT still focus on reality, not the IDEAS portrayed.
  - Can be tested to see if they really represent *reality* correctly, not a test of the ideas involved.

3 – Model developed to test ideas/explanations, not just a copy of reality.
  - Predictions are tested to see if underlying *idea* of the modeler is correct.