CHANDRA ASTROPHYSICS INSTITUTE 2006
PRELIMINARY EVALUATION REPORT

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This document is included as supporting documentation to the Chandra Cycle 8 proposal "Chandra Astrophysics Institute." This document is not intended for wide circulation. A final Evaluation Report will be made available by the MKI EPO Program for wide dissemination by December 2006.

EXECUTIVE SUMMARY –

NOTE: The Chandra Astrophysics Institute was first funded through a Chandra Cycle 6 EPO grant and then again through a Chandra Cycle 7 EPO grant. In this document Cycle 6 CAI refers to the first CAI program that was offered in summer 2005 and during the school year 2005-2006. Cycle 7 CAI refers to the second CAI program that was offered in summer 2006 and during the school year 2006-2007.

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. Cycle 7 CAI consists of a 23-day, 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 of 2007.

Program evaluation approach (p. 6)

We apply a logic model approach to program evaluation: First, we cast the goals as an "if…then…" statement of change. Then, we define the desired changes in knowledge, attitudes and behaviors of our participants (outcomes). Finally, we specify what tools we can use to actually measure these changes (indicators).

Educational approach (p. 8)

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. In addition to this "model building" approach of teaching science, our program design emphasizes the group skills necessary to actively take part in a scientific community: communication, collaboration and argumentation. The design of the CAI aims to include the two elements of "practice-based mastery of skills" and "the importance of student voice," as cited by Boston teens as part of what they desire in an ideal out-of-school time program.

Instruments (p. 14)

Pre- and post- concept inventories

Pre- and post-testing using the MOSART content items based on specific NSES science standards showed that our group of students made a statistically significant positive improvement overall, comparing pre- and post scores both directly after the program (average Hake gain factor = 0.39) and one month later (average Hake gain factor = 0.23).

Attitudes toward science survey

Results from an instrument intended to measure student epistemology of science (i.e. their beliefs about how science works and what it is) showed statistically significant changes in sophistication in certain areas--a rare occurrence, according to the instrument's developer. Most notably, these include the organization of science as a connected, coherent whole, and the idea that science is a continually evolving body of knowledge.

Probes of student-perceived value of the CAI

When asked about the most valuable aspect of the CAI over the course of the summer session, student responses showed a shift away from simply learning more about astronomy (70% to 40%) toward understanding and appreciating the personal skills--including communication, collaboration, argumentation and model building--that are useful beyond science (10% to 70%). To us, this is a vital indicator that CAI appeals to those students already engaged in science, but if we can emphasize the development of these other skills during recruitment, we can attract a wider audience.

Student writing

Although complete analysis of daily journal entries is still underway, an anecdotal examination of student writing provides support for the conclusion that students recognize that research science is not the same as school science, and that students do value the inclusion of their voice/input in the CAI. "Solving the problem and finding the answer isn't good enough anymore. Explaining how you found the answer and even as far as what led you to ask that problem in the first place matters more in this program."

Comparison to cycle 6 CAI

A comparison of student demographics, retention rates, feedback ratings and performance on common content evaluations supports the idea that several changes made for cycle 7 CAI have had their intended effect. (For the cycle 7 CAI, with a short-notice open recruitment effort beyond our original target schools, we were able to recruit 16 students. Of these 16, we still have 15 actively participating in October 2006, compared to a drop from 14 to 8 by October 2005 during the cycle 6 CAI.) However, more must be done to appeal to our target student group.

Conclusions and Implications (p. 35)

Based on these indicators, we conclude that students have progressed in both their content knowledge and understanding of the way science is really done. However, students must continue to be pushed more toward feeling comfortable with suggesting their own conclusions and challenging those of others, as well as applying this approach to real-world situations. In addition, the opportunity for continued practice of skills to the point of mastery must be made clearer in both the CAI program and the recruitment effort which comes before it. A revised outline for the evaluation of the next cycle of CAI is presented.

CAI program summary

The goal of the CAI is to provide an opportunity for students underrepresented in STEM to build the background skills and knowledge necessary to understand how research science is done, by actually doing it. Students practice these abilities during a 5-week summer session at MIT. They then apply these skills to undertake research projects in x-ray astronomy involving Chandra data that are proposed, developed and mentored by MKI Chandra researchers.

The approach to CAI has remained the same over the past two years: Help participants learn fundamental astrophysics by developing, applying and questioning models and explanations based on their observations. This approach mirrors methods of research science.

CAI occurs in 3 phases:
Recruitment:
Exposure to NASA resources and data will first occur during recruitment sessions, in a way that demonstrates our teaching approach during the CAI summer session. These sessions include accurate examples of what will happen during CAI, current student testimonials, and an explicit way of demonstrating the value of scientific skills to possible participants.

Summer session:
Observations of several astronomical systems, beginning with visible light images and progressing to a multiwavelength approach using NASA images, motivate the introduction of specific content pieces such as motion, gravitation, models of light and stellar evolution.

During these system investigations, students learn to use appropriate tools to extract information from data. We begin with a simple image processing tool designed for the MicroObservatory robotic telescopes (developed with NASA funding), which students use to take their own visible observations. They then work up to using the ds9 image processing tool and its “Virtual Observatory” interface, developed by the Chandra EPO group, to gain access to Chandra (and other archive) data and standard x-ray analysis tools (FTOOLS, CIAO). Expertise from the CXC programmers at MIT allows us to maintain flexibility in the types of tools we can offer to our students, and thus the kinds of analysis and research projects we can plug into the CAI.

School year research project:
During the last days of the summer session, groups of 2 to 4 students begin work on projects, with guidance from MKI research mentors. Student teams continue to work on these projects throughout the following school year, using software tools easily accessed from computers at their school or nearby community technology centers. MKI researchers and CAI faculty also mentor the groups via an online forum.

Once per month, participants meet at MIT with MKI researchers and CAI faculty to discuss findings, make progress on analysis, prepare reports and presentations, and make plans for reasonable next steps. A final symposium was held in May 2006 where students present the results from their projects to invited guests, including the community at large.

Program evaluation approach

We use a logic model approach to program evaluation for the CAI, based on putting the goals of the program into an "if…then…" statement. At a basic level, this means that we are looking to achieve certain outcomes for how we'd like to change the knowledge, attitudes and behaviors of our program participants (outcomes), given the current (unsatisfactory) situation with our target audience. We then develop an intervention (namely the CAI program) that we hope can help bring this about. In order to measure these outcomes, we must develop specific, measurable indicators which answer the question, "If this outcome happens and the change occurs, what does it look like and where will you look to see change?" They are the evidence that the outcomes have been achieved.

The overall process can be outlined in these four questions:

- How are things now? (Situation)
- What should we do about it to make things different/better? (Statement of change about intervention)
- What knowledge, attitudes and behaviors of our participants are we trying to change? (Outcomes)
- What will it look like if we do change these things? (Indicators)

To give a concrete example for the CAI:

Situation: Students from groups underrepresented in STEM are not participating in STEM education. Schools do not have the time and resources for providing an authentic science experience. We have teaching resources and expertise about how research science really works, as well as access to a group of scientists who are interested in sharing their work.

CAI "if…then…" statement of change: If we provide an opportunity for interested, motivated students from underrepresented groups in STEM to learn enough astronomy and successfully undertake an research project, then those students will have a more complete understanding of the way science really works, and will value its application in their everyday and professional life.

Outcomes / Indicators (from CAI cycle 7 proposal, associated indicators in parentheses):

Summer session outcomes:

- Engage students in learning astrophysics by actively building models from observations and testing predictions as a way to build the working understanding necessary for conducting research using Chandra data (1-3)
- Increase participants' ability to clearly communicate and debate the merit of scientific ideas and models (2,4)
- Increase participants' ability to apply quantitative descriptions and calculations to science (1-4)

Summer session indicators/tools:

1. Pre/post testing on content, nature of science and models, and attitudes toward STEM
2. Daily reflective journals for content understanding, communication and questioning abilities measured via rubric
*3. TEAL room polling system for real time feedback on participants' conceptual understanding
*4. Weekly case study roundtable: student engagement in science process skills

Note: Given time and technology constraints, these tools are being used during the school year part of the CAI cycle 7 program.

School-year research program outcomes:

- Increase students' skill in research methods and scientific discourse through steady research progress (2,4,5)
- Increase students' confidence in ability to pursue STEM and related careers (1,6)

School-year indicators/tools:
1. Post-year testing on nature of science and models, attitudes toward STEM and related careers
2. Weekly online journaling to monitor students' regular progress and identify stumbling blocks
3. Monthly in-person peer review of student research progress reports
4. Final paper/presentation of results at community science symposium
5. Participant letter reflecting how the program has changed approach to learning/teaching and long-term career goals.

(See end of this report for Cycle 8 revision of outcomes and indicators.)

Educational approach/guiding principals

Below, we examine the most important parts of the teaching approach in CAI.

Interactive Science Learning Environment

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.

We introduce this process to our students as that of “model building”, and it is essentially a recasting of the scientific method in an inquiry form. During the summer session, we designed all investigations to follow this cycle as closely as possible.

As an example of the ISLE approach, examine the discussion of the development of a model for the flux variability of the x-ray source GK Persei.

Observations:

We explored the idea that astronomical sources do not always have constant flux by examining visible light images of the M3 globular cluster which show several sources with strong flux variability on a one night timescale. This produces a movie with “blinking” sources. Students were asked to represent this observation graphically, and thus, developed the idea of a light curve.

Models:

In groups of 3-4, students were asked to develop an explanation (model) for this varying flux. Based on their previous knowledge about concepts like flux, luminosity and blackbody radiation and observations of sunspots and eclipses, students developed and presented several plausible models to the group, including the following:

- The star is moving toward and away from us
- The star is getting bigger and smaller
- The battery on the detector periodically goes dead
- There is a bright or dark spot on a rotating star
- There is an eclipse with a second body

Predictions:

These models were examined to see if their predictions were consistent with a set of realistic (although hypothetical) light curves. (They would soon use their understanding of these models and light curves to interpret a real x-ray light curve.) The light curve had a 20 second period and a 20% drop in luminosity.

Each group had to decide if their model, if applied to this observation, gave reasonable predictions for the behavior of the system. Motion of the star or an eclipse assuming a typical scale of star system predicted motion faster than the speed of light, and were thus ruled out. A rotating star with starspots was a plausible model, but the ensuing discussion led to a refinement that the starspots must be unevenly distributed around the star, and that they could be either brighter OR dimmer than the rest of the star and still explain the observations. In this way, we see that the group interaction brings students to a deeper engagement with a model that was simple to begin with.

It is interesting to note that it took a full 10 minutes to dismiss one student's farcical suggestion that the detector battery varied in power output with the given period. The fact that it was challenging to suggest a prediction and additional comparison data to rule out an obviously weak argument shows that this approach can be valuable to students. (Ultimately, someone suggested pointing the detector at another source and checking its variability.)

Applications:
Now students have an understanding of what visible light curves are and what they can tell us. As a group, we then went through the process of using x-ray observations, models and predictions to build and support a plausible model for the object GK Persei.

Students were shown how to make a light curve of an x-ray source using a Chandra observation and found a 350 second period with a 40% change in flux. A plausible model (a rotating white dwarf with a bright or dim spot) based only on this observation was developed using Newtonian gravitation and circular motion to calculate a maximum rotational speed without breaking up the star. The group then refined and adjusted in the light of its predictions, and the resulting additional observations that were examined. (These were a long term x-ray light curve showing an eclipse with a 2 day period; measurement of x-ray luminosity: optical, infrared and x-ray morphology; and a long term visible light curve showing regular outbursts on a 3 year timescale.) Ultimately, an plausible model, consistent with all the observations is developed: a rotating white dwarf in a binary system with a main sequence companion which accretes matter to one "hot spot" on the white dwarf. The dwarf periodically builds up enough matter to ignite nuclear fusion on its surface every few years.

Skills of a scientific community: communication, collaboration, argumentation and model building

In addition to this "model building" approach of teaching science, our program design emphasizes the group skills necessary to actively take part in a scientific community. In this case, the scientific community we build is that of the students themselves, with input from MKI researchers and CAI faculty, but relying on the students' interactions to drive the production of knowledge. Although this is not directly informed by other research, our experience with CAI and other science programs for teens leads us to consider these additional skills vital to the development of a working scientific community:

Communication: bringing your own thoughts and ideas to others, verbally or in written form

Collaboration: working with a group to clarify ideas and come to a consensus

Argumentation: using evidence to back up claims, judging quality of evidence

Model building: the process of doing research science

- Observations: make them carefully and look for patterns
- Alternative models: Come up with several explanations that could possibly explain what was observed
- Predictions: from these models, make testable predictions about new situations that were not observed originally when coming up with the model, and use them to support or refute validity of model.
- Applications: Apply correct model to make additional useful predictions.

As an example of the way we develop these skills, consider again the example of the GK Persei analysis:
Communication:
Each small group develops and presents their model of flux variability by drawing models at their own whiteboard and having a spokesperson give a short oral presentation.

At the end of most investigations during the summer session (including the investigation of GK Persei, as outlined above), student groups have time to put together and present a overview of the observations, models and predictions that led to the final model. These presentations follow a "standard" format so students become familiar with presenting their ideas in a clear, scientific way, and we can track the progress of students in making good presentations.

At the end of each day of the summer session, there is a student-driven oral review of the progress made that day, and then a 20 minute period during which students reflect on their learning for that day by answering the following three questions:

1. What did you learn today?
2. Why do you believe this to be true? (What evidence did you see or hear about that convinces you of this?)
3. What questions do you still have?

Students not only practice communicating what they learned in writing, we also encourage them to think about what it was they did that actually helped them "learn" it. (I.e. to examine the process of how they are learning.)

Finally, students' oral responses and questions during large group sessions are critiqued for clarity and volume by the instructors and other students in real time.

Collaboration:
Students experience working in a small group (3-4) when they come up with their initial ideas for a model of flux variability, and must come to a consensus about one model to present. In this way, students gain an appreciation for the power of collaboration to put together a well-developed idea in a small amount of time.

Then, as an entire group, they review the models of each small group, showing them other possibilities they might not have considered in the first place.

Once the entire group has built a consensus model of the system at the end of the investigation, we give them an opportunity to formally peer review the presentations that each small group makes using our "standard" format.

Because they have all been a part of a collaborative effort to come up with this model, each student has the background necessary to make intelligent, valid comments about what should and shouldn't be included in an accurate, convincing presentation. This is in contrast to making judgments merely on surface qualities of the presentation, which would be the case if groups worked on different problems in isolation. Thus, the peer review discussion is a further way to promote the idea that collaboration is valuable in science and elsewhere.

Argumentation:
As outlined above, there must be convincing evidence in the form of a contradiction between predictions and additional observations in order to rule a model out. Through the whole group discussion of each alternative model, students learn what is an acceptable, convincing argument.

Although not used in the GK Persei investigation, we allowed students to undertake "independent consensus building." Toward the later part of the summer session, we would periodically allow the group of students to try answering a question or interpreting an observation as an independent group, assigning students to the roles of spokesperson and moderator, normally filled by instructors during a large group discussion.

This was a particularly powerful way to allow students to experience firsthand the value of communication, collaboration and argumentation skills. Because the instructors expected a clear presentation of a consensus answer after an allotted time, it was easy for the students to see if their efforts had been fruitful or not. Students were also more likely to take an active role in these discussions, due to their informal nature.

Supporting aspects of out-of-school time learning:
Boston teens underrepresented in STEM cited the two elements of "practice-based mastery of skills" and "the importance of student voice" as part of what they desire in an ideal out-of-school time program. (Afterschool Programs in Boston: What Young People

Think and Want, 2001, http://www.afterschoolforall.org/pdf/teen_study.pdf). The design of the CAI aims to include both of these elements.

The CAI is built on an apprenticeship model during which students get to repeatedly practice data analysis and group interaction skills (i.e. communication, collaboration and argumentation). By progressing multiple times through the process of observing, developing alternative models and examining predictions to rule out models, we hope to bring the students from being an observer of this process to being a driver of this process. In addition, the format for collaborating and presenting results of the investigations undertaken during the summer is the same in all investigations, and will continue in that form during the school year research project, as well.

It may seem difficult to balance the input of students about the progression of the CAI with the repetitive practice of skills we believe are essential for success in the school year research project. However, our approach is to give students freedom to explore from a launching pad of their own interests, so they develop a connection to the summer session investigations and ownership of the school year research project.

At the beginning of the summer institute, each student chooses a topic area (white dwarfs, neutron stars, black holes, supernova remnants or galaxy clusters) which interests him or her most. Students are given time over the first few weeks of the summer session to learn more about their class of object, independently and in a small group. They are encouraged to link their learning to the topics at hand; for instance, learning about the motion of their object when the large group discusses rotational motion and gravitation, or finding typical luminosities and locations of their type of object when the large group discusses the relationship of flux, luminosity and distance. In this way, when the large group undertakes an investigation of that kind of object, there is a panel of "experts" on hand to help put forth valid ideas for our preliminary models.

In addition to forming the basis of the summer session investigations, these topic areas also relate directly to the school year research projects. Thus, by developing "expertise" in one area, but getting experience working with other groups' area of expertise during the summer investigations, students can make an informed decision about which project they would like to work with during the school year.

We can see the value of this approach in the following anecdote:
When our student "experts" on galaxy clusters presented their findings to the large group, the resulting peer review feedback led to a clarification of their main point that dark matter must be present to hold a galaxy and a galaxy cluster together. However, one of the other students (who was a white dwarf "expert" by training) was unconvinced of what evidence really supported this idea, and was willing to question this conclusion. Although our following investigation of galaxy clusters focused more on their morphology and appropriate models for the x-ray spectrum, the unconvinced student chose to undertake the galaxy cluster research project with the intent of finding out more about the evidence for the existence of dark matter. Then, it was a happy coincidence that a Chandra press release about the first direct detection of dark matter in a galaxy

cluster came out less than 3 weeks after the end of the summer session. By giving students the chance to develop expertise, but also the flexibility to follow their interests, we retain students who are comfortable and enthusiastic about their projects.

Instruments

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

Pre- and post- concept inventories

Considering that content knowledge is essential to undertake the research project, a concept inventory consisting of misconception-based multiple choice items was assembled and administered to the CAI students on the first and last day of the summer session (CI-1). A second version (CI-2) was administered one month into the school year research project phase of the CAI. These test items are drawn from approximately 200 test items that were designed and tested to align with specific content knowledge standards in the NRC *National Science Education Standards* by the MOSART project of the Science Education Department (SED) at the Smithsonian Astrophysical Observatory. In collaboration with the SED, we chose items aligned with the following standards for grades 9-12 that we feel reflect the content goals of the CAI program:

Physical Science:
- Motion and forces:
  - (Motion/Forces) Objects change their motion only when a net force is applied…The magnitude of the change in motion can be calculated using the relationship F=ma…
  - (Gravity) Gravitation is a universal force that each mass exerts on any other mass…
- Interactions of Energy and Matter:
  - (EM waves) Electromagnetic waves result when a charged object is accelerated or decelerated…
  - (Spectroscopy) Each kind of atom or molecule can gain or lose energy only in particular discrete amounts…and can be used to identify the substance.

Earth and Space Science:
- The Origin and Evolution of the Universe:
  - Early in the history of the universe, matter…clumped together through gravity.
  - Stars produce energy from nuclear reactions…(and) led to the formation of all the other elements.

The makeup of the concept inventories is given in the following table:

	Motion/Forces	Gravity	EM Waves	Spectroscopy	Space Science	Demographics	Observation/Model characterization	Total
CI-1 (Day 1)	4	4	3	4 (2 repeats for consistency check)	3	10		30
CI-1 (Day 23)	4	4	3	4 (same 2 repeats)	3	10	21*	50
CI-2**	3	3	3	3	4			16

*In the post test version of CI-1, 20 additional items were added with statements that students had to identify as a model or an observation. These items are identical to those asked of the CAI cycle 6 students on the final day of the summer session. In addition, one short answer question was posed, identical to one asked of the CAI cycle 6 students on the first and last day of their summer session.

**The CI-2 concept inventory contains items that measure comprehension of the same standards, but contains different questions than CI-1, with the exception of 1 repeated question in each content category. This is done to minimize the effect of a test taker's memory of the questions, and provide a more robust estimate of the true understanding of the content.

<u>Results for group performance on concept inventories:</u>

	Mean score, CI-1, Day 1 N=13**	Mean score, CI-1, Day 23 N=13	Effect Size, CI-1, Day 1 -> Day 23**	Mean score, CI-2 N=12	Effect Size CI-1, Day 1 -> CI-2, 1 month post ***
Motion/Forces	57%	63%	0.18	61%	0.02
Gravitation	33%	44%	0.39	67%	0.97 *
EM Waves	56%	77%	0.68 *	86%	0.90 *
Spectroscopy	63%	87%	1.04 *	56%	-0.37
Astronomy	38%	59%	0.70 *	56%	0.75 *
Overall	53%	69%	0.80*	65%	0.45*

* indicates that a 1-tailed, paired t-test indicates less than 5% probability that this difference could have arisen at random, indicating that this is a statistically significant change.
**2 students did not take pre-test, and one left program before end of summer—their results are not included in the following analysis, leaving 13 students
***2 students did not take the CI-2 post test. Only paired test results are included in this analysis, leaving 12 students. (One missing student also did not take the pre-test CI-1)

Effect size is defined here as the difference in the mean of the distribution in scores on the pre- and post- tests, divided by the standard deviation of the combined distribution (pre-and post-) of test scores.

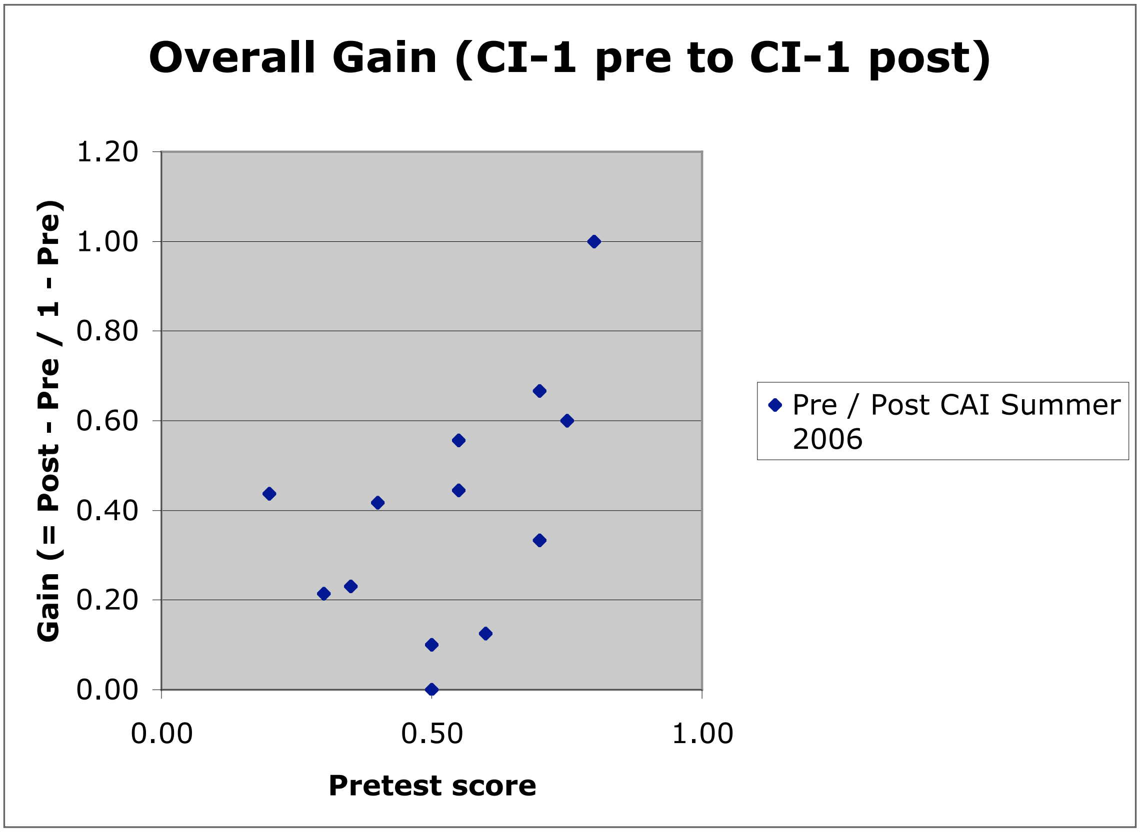
We see here that there is an improvement in the average scores for every category except for Spectroscopy between the CI-1 pretest and CI-2 posttest. However, the change is not statistically significant in the motion and forces (CI-1, CI-2), gravitation (CI-1) and spectroscopy (CI-2) categories. In all but one case, the effect size is under one standard deviation of the entire combined sample.

Interpretation of group results:
Although we did address the concept of Newton's second law, we did not spend appreciable time on some of the other elements of this category outside the context of gravitation. Thus, it is not surprising that performance in this category did not change significantly. It is interesting to note, that the results for gravitation show a more pronounced change on the second testing. This could be a real effect, but is more likely that the small number of questions included some items which students found easier. Finally, the spectroscopy category shows the largest change between the first and second post-test. This could indicate that our students' knowledge of spectroscopy is fragile and is not retained over time.

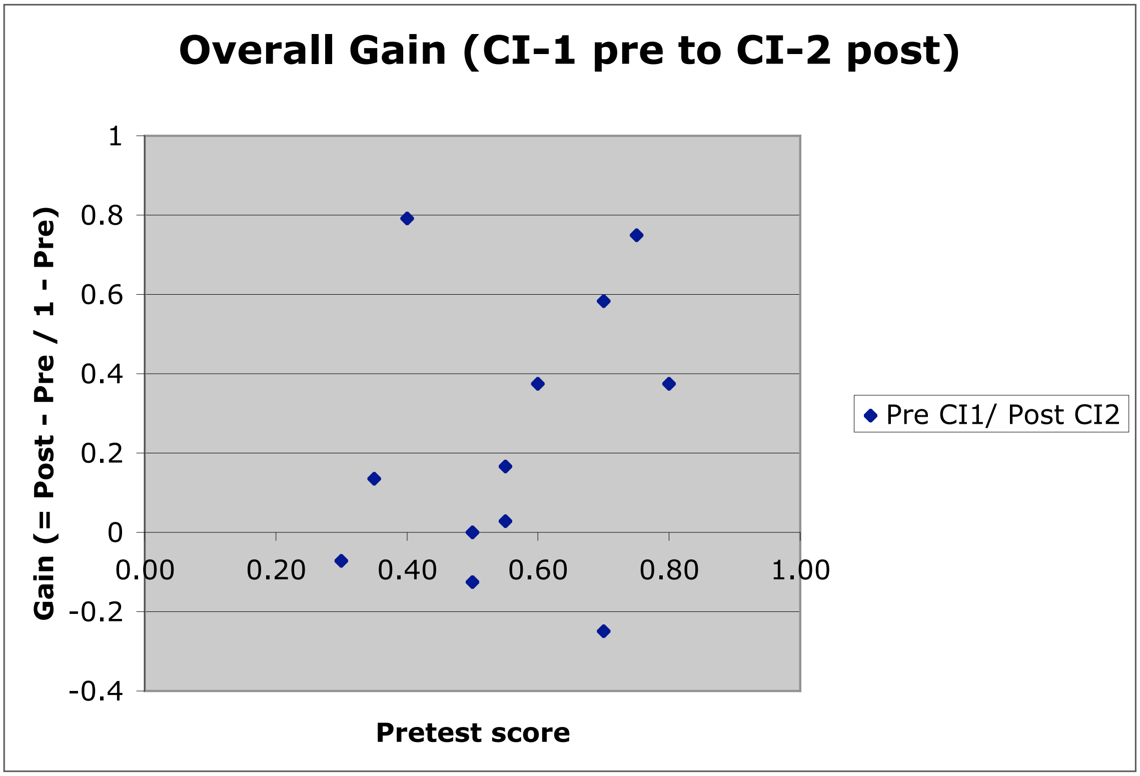
Results for individual performance on concept inventories:
To compare individual student performance on the pre-and post-tests, we calculate the normalized (Hake) gain factor:

G = (post-test fraction correct – pretest fraction correct) / (1 – pretest fraction correct)

This is a measure of the fraction of the theoretically possible increase in score that a student actually increased. Given the small number of items for individual subsections, we do not present graphs of gain on individual subsections, but do report the overall gain for each student on the entire instrument:



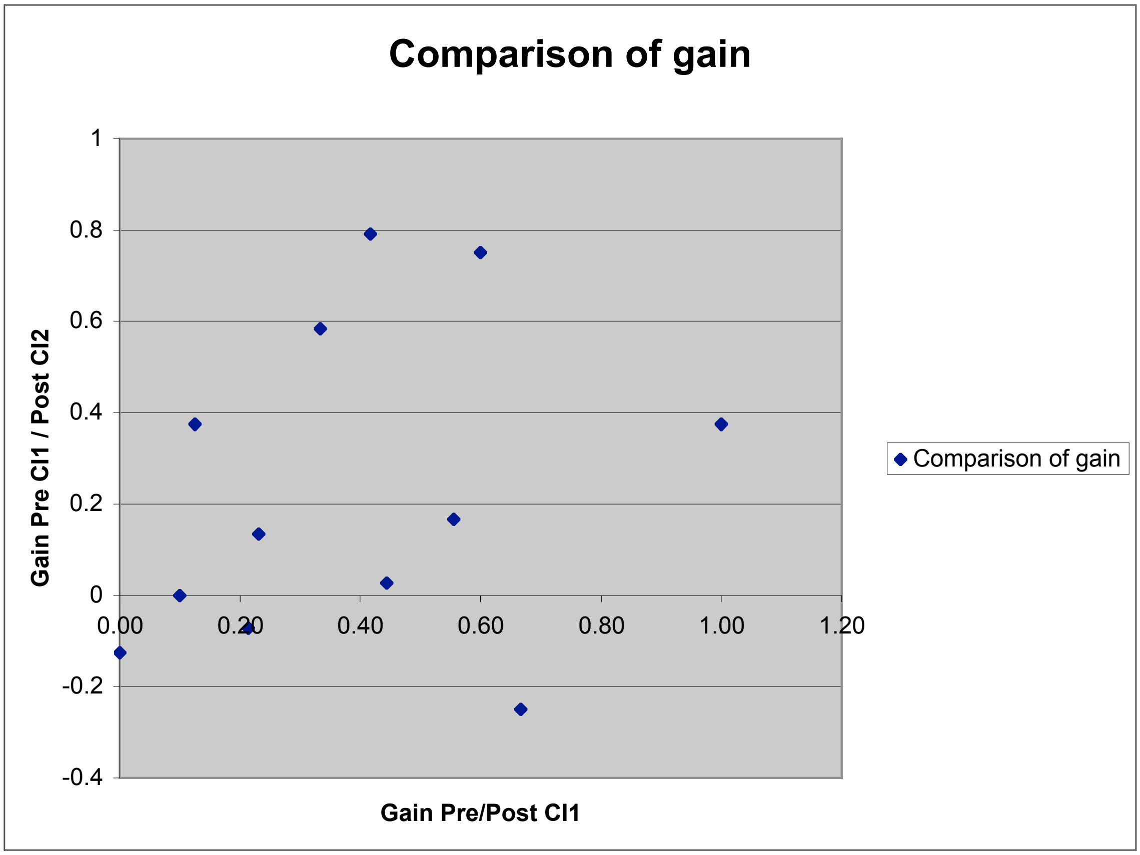
The average gain for these 13 students is 0.39.



The average gain for these 12 students is 0.23.

Interpretation of individual results:

We see that our students have a range of scores on the pre-test inventory, but do not saturate the high or low end of the score scale. Thus, the difficulty of these items is adequate to probe our population. There is a drop in average gain over time. It is interesting to examine if individual students all show a smaller gain on the second test. We do this by plotting the gain between the administration of the CI-1 pretest and the CI-2 posttest and the gain between the administration of the CI-1 pretest and CI-1 posttest (x-axis):



We see that there are two seemingly distinct populations: the 8 students who gained less on the second posttest and the 4 students who gained more on the second posttest. This gives us some confidence that the questions chosen for CI-2 are not universally easier or harder than those chosen for CI-1. (If students made the same improvement in score on both CI-1 and CI-2 posttests,, the data would lie along a line of slope 1 with intercept zero.)

Attitudes toward science survey:

The Epistemological Beliefs Assessment for Physical Science (EBAPS) was administered at the beginning and end of the summer session to evaluate changes in participants' views of the following non-orthogonal categories (http://www2.physics.umd.edu/~elby/EBAPS/home.htm):

1. *Structure of scientific knowledge*. Is physics and chemistry knowledge a bunch of weakly connected pieces without much structure and consisting mainly of facts and formulas? Or is it a coherent, conceptual, highly-structured, unified whole?

2. *Nature of knowing and learning.* Does learning science consist mainly of absorbing information? Or, does it rely crucially on constructing one's own understanding by working through the material actively, by relating new material to prior experiences, intuitions, and knowledge, and by reflecting upon and monitoring one's understanding?

3. *Real-life applicability.* Are scientific knowledge and scientific ways of thinking applicable only in restricted spheres, such as a classroom or laboratory? Or, does science apply more generally to real life? These items tease out students' views of the applicability of scientific knowledge *as distinct from* the student's own desire to apply science to real life, which depends on the student's interests, goals, and other non-epistemological factors.

4. *Evolving knowledge.* This dimension probes the extent to which students navigate between the twin perils of absolutism (thinking all scientific knowledge is set in stone) and extreme relativism (making no distinctions between evidence-based reasoning and mere opinion).

5. *Source of ability to learn.* Is being good at science mostly a matter of fixed natural ability? Or, can most people become better at learning (and doing) science? As much as possible, these items probe students' epistemological views about the efficacy of hard work and good study strategies, *as distinct from* their self-confidence and other beliefs about themselves.

The EBAPS items are a mix of Likert-type ratings of agreement/disagreement, as well as hypothetical conversations to which students respond using multiple choice answers to indicate how closely their own views match those of the conversation participants'. Each item is scored on a 4 point scale based on the level of scientific sophistication, and the subscale score is the average of all items which address that subscale. The number of items included in each category is listed in parentheses in the following table.

An analysis similar to the concept inventory above was carried out with the EBAPS. Fourteen students completed both the pre- and post-testing with EBAPS, with the following results:

	Mean Score Day 1	Mean Score Day 23	Effect Size Day 1 -> Day 23
Structure of knowledge (10)	2.62	2.89	0.56*
Nature of knowing and learning (8)	2.97	2.77	-0.39
Real-life applicability (4)	2.82	2.41	-0.48*
Evolving knowledge (3)	2.19	2.71	0.69
Source of ability to learn (5)	3.15	3.07	-0.18
Overall (30)	2.79	2.81	0.05

* indicates that a 1-tailed, paired t-test indicates less than 5% probability that this difference could have arisen at random, indicating that this is a statistically significant change.

Effect size is defined here as the difference in the mean of the distribution in scores on the pre- and post- tests, divided by the standard deviation of the combined distribution (pre-and post-) of test scores.

Results for group performance on EBAPS:
We see a move toward a more sophisticated understanding of the nature of science in two categories: structure of knowledge and evolving knowledge. (In the latter case, a 1-tailed, paired t-test indicates there is a less than 6% probability (instead of 5%) that this difference could have arisen at random, so we still see that this is a significant change. Indeed, this category has the largest overall effect size of any category.) We see a statistically significant move away from a sophisticated understanding in the category of "real life applicability." Thus, there is no significant change in the overall score of the EBAPS instrument.

Interpretation of group performance on EBAPS:
The gain on the "structure of knowledge" subscale is an indicator that students are moving away from a view of science as disconnected facts to a coherent tool. The largest overall gain (average 1.63 -> average 2.63) occurred on this item:

> 17. To understand chemistry and physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.

Our students seem to have absorbed our emphasis on developing intuition for the form of equations (direct vs. inverse proportionality) and focusing on answering the question of WHY these patterns show up in the first place.

We employ a constructivist approach to having students push forward their own questions and have them examine how they are learning (through written reflections). However, the items designed to probe their value of these approaches shows an average decrease in the group. The two items with the largest drops (pretest average -> posttest average in parentheses) in this category are the following:

> 11. When handing in a physics or chemistry test, you can generally have a sense of how well you did even before talking about it with other students. (3.0 -> 2.3, the largest absolute drop on the instrument)
>
> 12. When learning science, people can understand the material better if they relate it to their own ideas. (3.1 –> 2.7)

These items may indicate one of two things: even though students were encouraged to reflect on their understanding, they did not find it a valuable approach or even considered it a hindrance to what they feel is “learning new material.” Alternatively, students are simply not used to “trusting themselves” as the arbiters of whether they have learned something or not, and being given the opportunity to do so left them with a larger sense of uncertainty. We conjecture that students still cling to the “expert” as the final arbiter of scientific knowledge. (See interpretation of “evolving knowledge” category, below.)

The largest drop in sophistication occurred for the “real-life applicability” category. Some of these items point out that science may not appear immediately applicable to certain complicated problems. However, the investigations encountered during the CAI are simplified enough to allow us to guide students through while they are developing new skills. (We do hope that students will develop an appreciation for how the scientific method allows one to interpret more complex situations by working on their research projects.) One suggestion to appeal to this shortcoming would be to examine real-world situations that at first do not appear easily solved, but then analyzing how scientists did eventually apply methods that led to useful conclusions. In this way, students would not have to solve complex problems by themselves, but rather examine how the scientific process allowed others to do so.

The most promising indicator on the EBAPS instrument is the gain in the groups sophistication on the “evolving knowledge” subscale. We believe this indicates our students view science as a robust, flexible platform from which to make new discoveries, and not a fixed body of knowledge to be “consumed.” In other words, students are more willing to believe that all scientific ideas are tentative.

The largest gain in this category was made on the following item:

> 29.
> Jose: In my opinion, science is a little like fashion; something that’s "in" one year can be "out" the next. Scientists regularly change their theories back and forth.
> Miguel: I have a different opinion. Once experiments have been done and a theory has been made to explain those experiments, the matter is pretty much settled. There’s little room for argument.
>
> (0.9 -> 1.5, with 0.9 being the lowest score on any pretest EBAPS item.)

The most sophisticated answer in this case is agreeing equally with both participants. It is interesting to note that although students may be willing to concede that conclusions are not static, they still are uncomfortable with being the ones to engage with the science and deciding for themselves if the conclusions they draw are valid, as indicated in the “nature of knowing and learning” category.

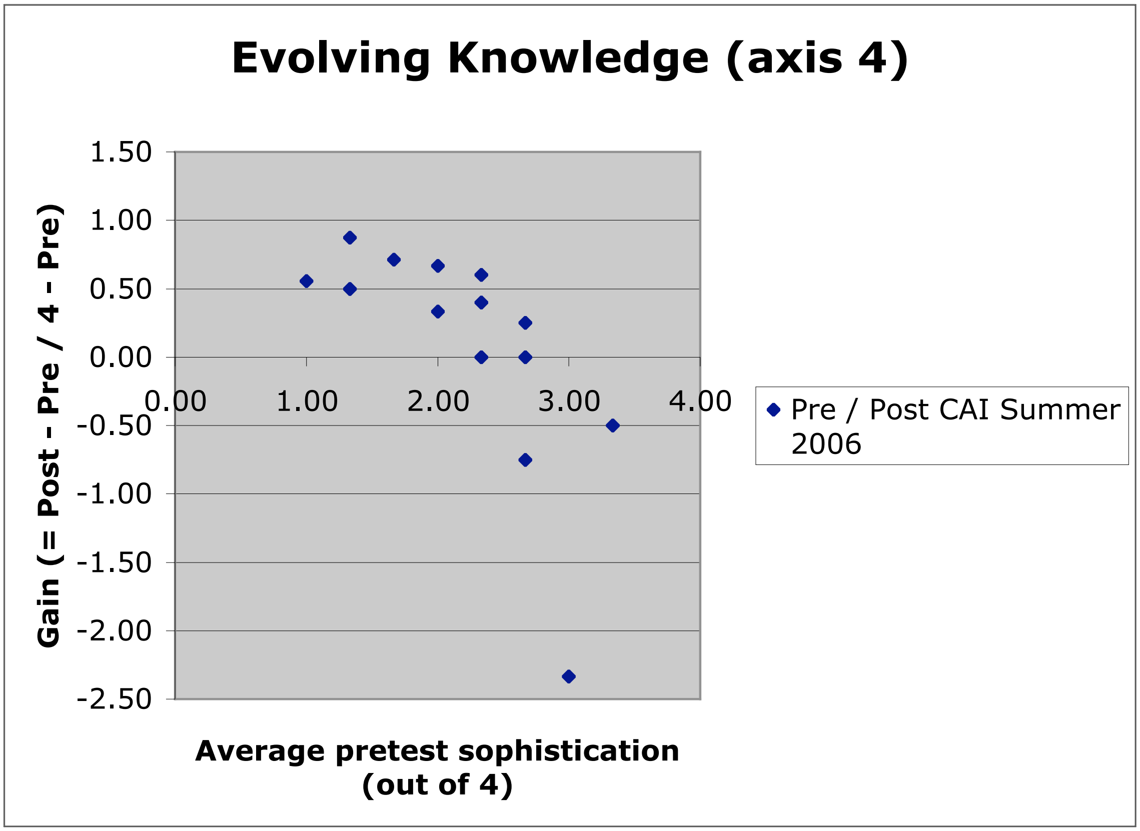
Results for individual performance on EBAPS:

To compare individual student performance on the pre-and post-tests, we again calculate the normalized (Hake) gain factor:

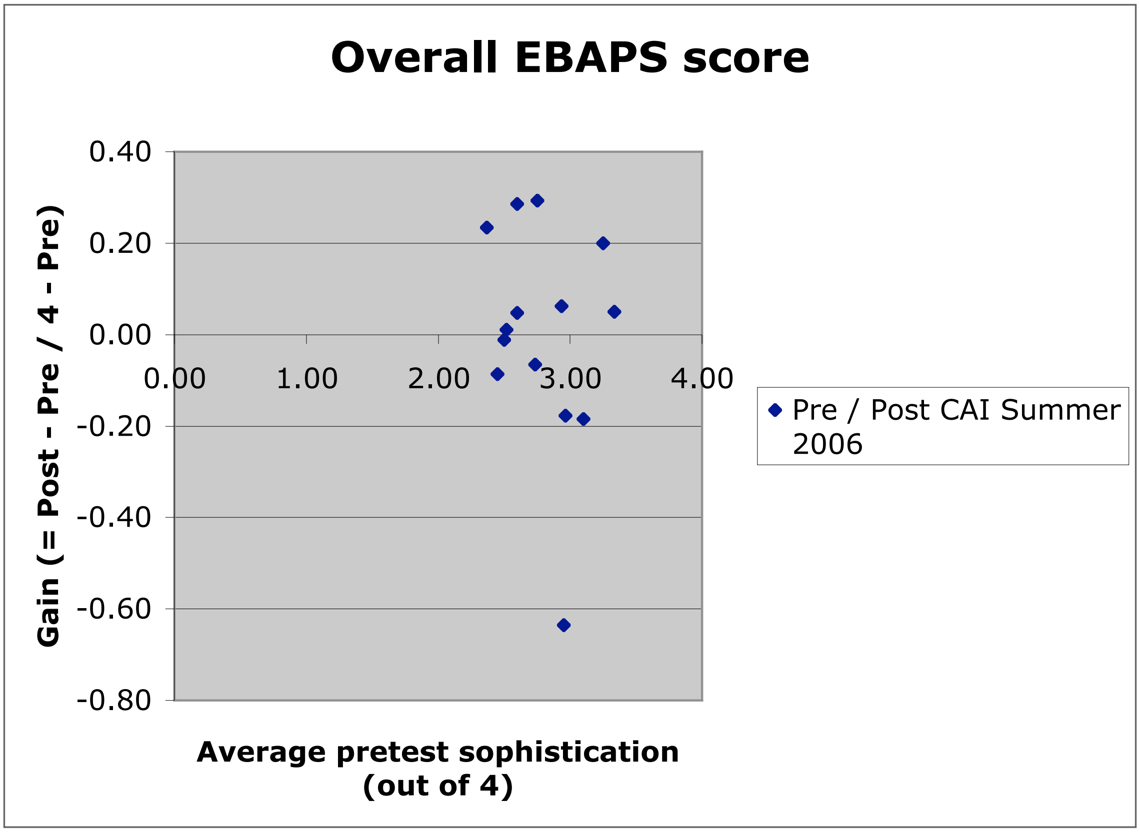
G = (post-test fraction correct – pretest fraction correct) / (1 – pretest fraction correct)

This is a measure of the fraction of the theoretically possible increase in score that a student actually increased.

We give results for the “evolving knowledge” subsection, and the overall gain for each student on the entire instrument. (See appendix for a complete listing of the gain vs pretest sophistication for each subscale of the EBAPS instrument.)



The average gain for these 14 students is 0.09.



The average gain for these 14 students is 0.04.

Interpretation of individual results on EBAPS:
The most notable pattern in the above results is found for the "evolving knowledge" axis. We see a trend of higher scoring students more likely to show negative gain in this category, but a significant gain for lower scoring students. This may indicate that students who are "novices" to the idea that scientific knowledge is tentative are more malleable in changing their opinion.

Probes of student-perceived value of the CAI:
Among the questions answered by students in written form over the course of the CAI were several relating to what they valued most about being a part of the CAI. We examine responses to the following questions:

1. (on application, filled out prior to Day 1): "Why are you interested in participating in the CAI?"
2. (day 15): "What has been the most valuable thing you've gotten out of participating in CAI so far, and why?"
3. (day 23): "What has been the most valuable thing you've gotten out of participating in CAI so far, and why?"

All responses were read, and a coding scheme was developed, based on the range of responses given. The codes are given below:

- Practical, personal skills: this includes communication, collaboration, argumentation, as well as other skills for working in a group, asking questions,, participating in discussions.
- Nature of science: understanding the real process of asking questions and finding out answers in an inquiry way, instead of being fed information from an "expert" source.
- Knowledge: learning more about astronomy
- Career exploration: learning what it takes to do a career in science/astronomy
- Access to resources: getting to interact with people and other resources (online telescopes, software)

The range of answers to each of these questions, and the number of responses included, as coded by the author, is given in the following table:

	Day 0 (n=15)	Day 15 (n=13)	Day 23 (n=15)
Practical, personal skills	7%	54%	73%
Nature of science	7%	23%	7%
Knowledge	67%	33%	40%
Career exploration	40%	17%	0%
Access to resources	7%	33%	20%

Results:

Student responses showed a shift away from simply learning more about astronomy (70% to 40%) toward understanding and appreciating the personal skills--including communication, collaboration, argumentation--that are useful beyond science (10% to 70%). In addition, we see a decrease in the number of students who considered career exploration a valuable outcome of the CAI.

Interpretation:

To us, this is a vital indicator that CAI appeals to those students already engaged in science, but if we can emphasize the development of these other skills during recruitment, we can attract a wider audience. We see that our students initially are interested in the CAI as a way to learn more content knowledge about astronomy. This is the hook that has worked for them. However, by the end of the program, the thing that they value the most leans toward the skills they learn during CAI that are applicable to science, but also to any group learning situation. Recalling again that Boston teens underrepresented in STEM cited the element of "practice-based mastery of skills" as part of what they desire in an ideal out-of-school time program, we think that by emphasizing the fact that our students will develop these skills by experiencing science, we have a chance to reach out to a wider audience of potential CAI students.

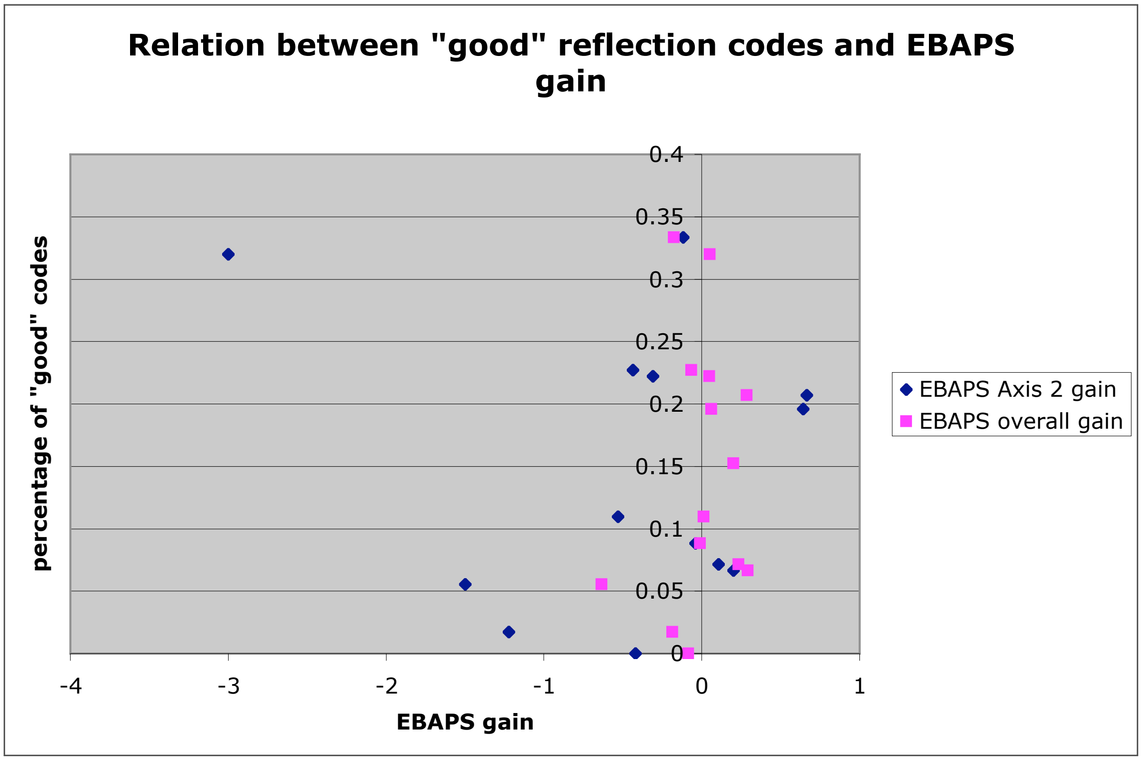
Finally, the decrease of responses about career exploration may be addressed by including explicit discussions about the range of possible careers in science and technical fields associated with astronomy. However, cycle 7 CAI students had the opportunity to ask the researchers involved in the program about their career paths, but very few actually took that opportunity.

Student Writing:
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?
- Why do you believe this to be true? (What evidence did you see or hear about that convinces you of this?)
- What questions 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. The coding scheme used to analyze these reflections is given in May & Etkina, 2002, although with minor modifications. (http://www.rci.rutgers.edu/~etkina/epistemological_self-reflection_and_its_relationship_to_conceptual_learning.pdf) Preliminary analysis of the first quarter of the student reflections was compared to the student's performance on the EBAPS instrument, as shown in the following plot:



We expected to see a correlation between those students whose writing contains a high percentage of "favorable" codes (i.e. indications that students are constructing their own knowledge based on active thinking about their observations, detailed in May & Etkina, 2002) and their gain on the "nature of knowing and learning" axis of the EBAPS instrument. We hoped that by writing to clarify their own knowledge, they would come to appreciate and understand the value of this personal constructivist approach for learning, which the "nature of knowing and learning" axis of EBAPS is designed to measure. With this preliminary data, we see here only a weak correlation between these two measurements: ignoring the upper left data point, we measure a correlation coefficient of 0.42 between the percentage of "favorable" codes and the gain on the EBAPS "nature of knowing and learning" axis, and a correlation coefficient of 0.14 between the percentage of "favorable" codes and the gain on the overall EBAPS performance. (Keep in mind that this coding and analysis of the student reflections is ongoing, and will eventually include the other 3/4 of the students' writing.)

In addition to writing daily journal reflections, students generated anonymous responses to several questions posed near the end of the summer session.
By examining these responses, we can characterize some changes that students had undergone as a result of their participation in the CAI thus far:

Research science is not the same as school science.
Students were asked the following questions:

- What is similar and what is different about your experience learning science in the CAI versus your previous experiences learning science in school?

- How, if at all, was this program different from your expectations?

The pattern of answers to these two questions brings out two important points. First, that students expected the CAI to be like school:

  - i thought i was going to be better at it because like in 8th grade i was the one who knew everything in our astronomy section but what we learned here is so much different. there was just so much more math and thinking than i thought there would be
  - I thought that it would be like school, that's why a lot of my friends was confused i would do this, because I dislike school.
  - I expected this program to be yet another school-like lecture based practice style learning, but it turned out completely different. I was introduced to an entirely new way of learning, and I do enjoy learning this way.
  - i just thought that I would learn about astrophysics. I ended up learning different skills that I can use in school and other places.

Indeed, this conclusion is also supported by the 70% of students who reported “learning knowledge” as the reason why they are interested in the CAI on their application.

Second, instead of a school-like experience, they are learning basic facts as a way to build a solid foundation for investigation on your own.

  - We never memorized facts, and we constantly tried to learn the fundamentals. This is different from other science courses because many high school teachers try to plow through the fundamentals without the students really understanding it. … The complicated stuff can come later and much easier so, because I know the basics that I learned from CAI well enough.
  - In previous classes the teachers usually just hand you a textbook, tell you to read a ceratin part, ask you question, and then later on tell you if your right or wrong. In CAI, the instructors tell' you some basic information, but you have to figure a lot on your on. The way the instructors teach you know if you are right without them telling you, so it diefferent.
  - At first, I was very unsatisfied with the lack of answers we were getting to our questions..because I wasn't expecting it. But, just as I was told, this form of teaching helped me to pay close attention to my own instincts when it comes to answering my own questions. Learning in this form has been much more helpful and succesful than any other way of being taught.
  - This is the way science should be taught, yes... it does take a lot of time, sometimes we do have to reinvent the wheel to sort of understand it, but knowing the basics is a thousand time more important then knowing the complicated ideas just because you can.
  - Knowing how to complete a problem and finding the answer isn’t good enough anymore, explaining how you found the answer and even as far as what led you to ask that problem in the first place matters more in this program.

We believe this indicates that they are beginning to see that research science is not the same thing as school science.

Students value the inclusion of their voice/input:

One of the emphases of the CAI is giving students the opportunity to drive their own learning, and to listen to their input about the direction of the program. Several other anonymous questions led to feedback about this aspect of the CAI:

- What is similar and what is different about your experience learning science in the CAI versus your previous experiences learning science in school?
    - If I asked [my school science teacher] a question about why something worked the way it did, like with atoms, then she'd give me an extremely short, useless answer, and continue… If she's not interested in what I want to know, then I'm not interested in what she has to say. However, Here at the CAI we're encouraged to probe our brains to try and find an answer on our own, but at the same time to ask questions constantly. This method worked absolutely great for me because i've always been the one to question ideas and facts, and i'll always be the first one to ask if I don't understand it. I like that our questions aren't treated as an inconvenience, but are rather congratulated.

- If you were teaching the institute, what would you have done differently?
    - I would do anything to try and inspire the students to want to move forward and learn more. By doing so, the students will pretty much be its own self-sustaining bubble of energy that will inspire students to learn more, thus dictate a faster pace so that we can learn more. … I don't know how to go about inspiring students though.
    - The thing that i would do differently is letting the students to figure more things out things be themselves and then I would let them solve in a group and them talk it out.

We believe this second student is talking about the "independent consensus building" activities. Although he or she may have felt that we did not do enough of this kind of activity, it indicates that this activity was considered particularly valuable.

- What else could you have been doing this summer? Was it worth it to be here instead? Give specific reasons.
    - …it was worth being here instead because if you have a question, you will eventually get it answered. Everyone has a say in their learning experience, and it's more of an open discussion. If you don't get your views out and have everyone talk about it, you are first of all not going to understand what you mean, and you are not going to see why you are wrong (as you probably are) since it is harder for you to disprove yourself if you are focused on your model being correct.

Comparison to CAI cycle 6:

It is useful to compare some of the same indicators for both cycle 6 CAI and cycle 7 CAI, to see if the changes made between the two have had a positive effect.

Student demographics:

The following tables give demographic and background information for cycle 6 CAI students (N=14) and cycle 7 CAI students (N=16). Numbers are individuals.

Gender?	**Cycle 6**	**Cycle 7**
Female	3	5
Male	11	11

Race?	**Cycle 6**	**Cycle 7**
American Indian/Alaskan Native	1	0
Asian/Pacific Islander	2	12
Black	0	0
White	4	3
Multi – racial	4	1
Omit	3	

Hispanic Origin?	**Cycle 6**	**Cycle 7**
Yes	6	1
No	7	15
Omit	1	

Conversations among adults at home?	**Cycle 6**	**Cycle 7**
Only in English	5	2
Sometimes in English	4	8
Never in English	4	6
Omit	1	

Grade at time of CAI application?	**Cycle 6**	**Cycle 7**
9		3
10	3	3
11	10	10
12	1	
Omit		

Years of physical science? (Chem/Physics/Earth Science)	**Cycle 6**	**Cycle 7**
1	6	4
2	6	8
3	2	4

Taken formal physics?	**Cycle 6**	**Cycle 7**
Yes	6	13
No	8	3

Taken AP physics?	**Cycle 6**	**Cycle 7**
Yes	0	4
No	13	12

School District	Cycle 6	Cycle 7
Lynn	10	4
Lawrence	2	
Boston	2	8
Cambridge		2
Newton		2

As is evident from the table, there is a shift between the students successfully recruited between the two years of the program. There is a definite shift toward students of Asian (Chinese, Japanese and Indonesian) background, and also toward students with more formal background in physics. (One requirement of the Rutgers Astrophysics Institute is at least one year of high school physics, whereas we have relaxed this requirement to just one year of physical science—earth science, chemistry or physics.)

We believe this is more evidence that our recruitment effort must be in place early in the school year, and should be altered to appeal to those students who have an interest in science, but simply less formal background. Most of the students in the cycle 7 CAI who do belong to this "target group" were recruited through word of mouth from cycle 6 CAI students in Lynn. The recruitment effort with the JDOB and Lynn schools was able to draw a more diverse audience, but many of those students did not submit applications. Because of low application rates, we opened the CAI recruitment effort to other schools only a few weeks prior to the application deadline, and (not surprisingly) got applications from the "best and brightest" students from these schools. (This included the other two "exam schools" in Boston; Boston Latin School, Boston Latin Academy; as well as Newton North High School.)

Student retention rates:

Retention of students is also an indicator of their involvement and enthusiasm for the program. During the cycle 6 CAI, all 14 students finished the summer session, but the number of students desiring to continue with their research project by the start of the monthly MIT meetings in October 2005 dropped to 8. Although we had a very low return rate on an exit survey for these students, we believe that most students didn't feel they had the time that the research project would take during the school year, and never got started. Ultimately, 4 students (3 research groups) completed and presented a research project in May 2006. The students who left the program during this time were frustrated by lack of convenient access to software tools and felt that other activities kept their interest more.

The first issue of frustration with computing tools has been resolved by relying solely on the easily downloaded ds9 software tool. By working with both ds9 implementers and computing experts here at the Kavli Institute, we are able to add functionality to this flexible tool, if need be. In addition, the feeling that students had of not being prepared for the research projects has been remedied by our repetitive use of the same analysis steps and tools, as outlined above with respect to our apprenticeship approach. Finally, in the recruitment effort for cycle 7 CAI, we emphasized even more than cycle 6 that the school year research project is the main point of the program, and would take considerable time.

Of the 16 students who began the summer session of CAI cycle 7, only 1 did not complete the summer session. As of October 2006, all 15 of these students are continuing on with their research project.

<u>End-of-summer feedback questionnaire:</u>
On the final day of the summer session, feedback questionnaires consisting of scaled (1-5) ratings were administered to 12 of the 14 student participants in cycle 6 CAI and the remaining 15 student participants in cycle 7 CAI. The sections of the feedback form addressed several topics (see Appendix for complete listing), but there are several interesting comparisons.

(Note: Cycle 7 CAI values included the following choices: strongly disagree, disagree, agree and strongly agree, or a similar ranges of 4 values. In addition, cycle 6 CAI ratings also included a "neutral" choice. To compare results, half of all indications of "neutral" in cycle 6 results were changed to "agree" and half to "disagree." A numerical value of 1, 2, 4 or 5 was then assigned to each response.) All results are median values of the responses:

Category	**Cycle 6 (N=12)**	**Cycle 7 (N=15)**
Overall difficulty	2.0	2.0
Pace of course	4.0	2.0
Intellectually engaging/intersting?	4.0	5.0
Effective teaching approach?	4.0	4.0
Teaching approaches from which you learned best:		
Short lectures	5.0	4.0
Small group observation/model development	4.5	5.0
Small group presentations	4.0	4.0
Daily written reflections	3.0	4.0
Math problem solving, roaming instructor help	5.0	4.0
Math problem solving, on the board	3.0	4.0
Peer review process/worksheet	3.0	4.0

We see that a majority of cycle 7 students felt that the course took a slower pace, but neither group felt the CAI was beyond their reach in terms of difficulty, and agreed that the experience was interesting and effective.

The math preparation and comfort of the cycle 7 students was greater, shown here because they did not feel that having individualized "roaming" help was a particular strong point of the program, as students with less math background did last year.

We see that both groups particularly valued group work and presentations, although the cycle 7 students felt that our peer review process was more useful. This tool was altered significantly between cycle 6 and cycle 7.

Finally, we see that cycle 7 students felt better served by the written reflections and were less dependent on short lectures from the CAI instructors than cycle 6 students. We interpret this as more evidence that the students are willing to engage with material from their own perspective, which we see as important to developing good research skills.

Model/Observation comparison:

Although the concept inventory instrument used in cycle 6 CAI consisted of many different items than that used in cycle 7 CAI, there were 19 questions (taken from the RAI evaluation or developed by CAI instructors) which were asked of both groups at the end of the summer session. In these items, students had to characterize a statement as being either an observation or a model. This distinction has particular significance given that our teaching approach depends vitally on learning to do science using these constructs.

For the same 19 items, the 13 cycle 6 CAI participants who completed this comparison had an average score of 62% with a standard deviation in scores of 16%. The 15 cycle 7 CAI participants had an average score of 80% with a standard deviation in scores of 9%. (See appendix for a listing of these test items.)

We take this as evidence that the cycle 7 participants ended the summer with a better ability to distinguish observations from models.
However, whether this is a result of their experiences during the summer session or previous exposure to these ideas is not clear.

Interpretation of differences between cycle 6 and cycle 7 CAI:

We feel that several aspects of our approach to the summer session of cycle 7 CAI have led to the better retention and other characteristics of CAI as seen above:

- Long term development of “experts”: Cycle 6 CAI did not include the long term investigation of a type of object chosen by the student. Instead, students had only one day to research an assigned topic and present it.
- Multiple chances for presentation: This one presentation, mentioned above, was the only chance to practice presenting before beginning the research project in cycle 6. The fact that these students did not feel prepared to begin their research project led us to apply the apprenticeship approach here, as well: for cycle 7 CAI, each student was a part of 6 presentations (all following the same format):
    - “Expert” presentation about chosen topic
    - “Expert” presentation, after revision using peer and researcher feedback

  - GK Persei analysis (after instructor-led large group investigation, outlined above)
  - Cassieopeia A analysis (after instructor-led large group investigation)
  - Coma galaxy cluster analysis (after instructor-led large group investigation))
  - Initial research project presentation (after beginning work on school year research project during final days of summer session)
- "Independent consensus building": This approach was the most effective in getting students to interact with each other, thereby setting up the feeling that all students there are part of a community of learners with a common goal.

In the language we used earlier, students who dropped out did not feel they had a chance to practice enough to master the skills needed for undertaking the research project on their own.

Conclusions and implications

Given the results from the CAI cycle 7 evaluation of the summer session, several conclusions and implications for future implementation of the CAI summer session are evident:

Content:

- Students gained content knowledge in the areas we spent time with during the summer. A broad enough basic background should be addressed, so that students can learn more complicated ideas if needed for their research project.
- Students are beginning to appreciate the fact that scientific knowledge is not an absolute truth, but are still hesitant to see themselves as the ones who are there to challenge conclusions.
- Although students valued reflections more so than during cycle 6, there should be a mix of different kinds of direct experience with developing and challenging ideas (like the independent consensus building sessions) with enough scaffolding for students to realize and reflect on how they are making progress as a group.
- We should consider other examples of how the skills and process of science are applicable in real world situations to convince students of their personal value.

Recruitment/retention:

- To attract our target group of students, we must emphasize the practice-based mastery of skills and inclusion of student voice in the CAI. Unless students see the CAI as an opportunity to gain useful skills in a supportive, receptive environment, we'll continue to recruit just the best and brightest students.
- The apprenticeship aspect of repeated practicing with reduced guidance must be applied throughout the summer session. This should culminate in a chance to begin the school year research project, so students feel invested and able to make progress before going back to a more isolated environment.

The information gathered from the past 2 years of CAI have led to the following refinement of the Cycle 8 evaluation outcomes and associated indicators:

CAI is designed to attain the following outcomes (i.e. changes in knowledge, attitude or behavior of participants), with success defined in terms of an associated measurable indicator(s), listed in parentheses after each outcome.

Summer session outcomes:

- Students have learned enough astrophysics and data analysis skills to undertake a research project: (1)
- Students have a clearer picture of the way research science works, including the value of communication, collaboration and argumentation skills in making progress in a scientific community: (2, 3)
- Students become better at practicing and recognizing good implementation of the skills involved in doing research science: (4)

Indicators:
1. Increases on pre-/post- testing with science content instruments.
2. Positive changes in pre-/post- testing with “nature of science” and “attitudes toward STEM” instruments.
3. Overall positive changes in daily reflective journals analyzed for elements of self-reflection (May&Etkina, 2002) and questioning ability (Harper et. al., 2002).
4. More consistent scoring and increases in repeated peer review scores over the course of 6 student presentations.

In addition, there are several methods by which formative feedback to the CAI instructor is available during the summer session:

- TEAL room polling system (Personal Response System, PRS) allows for real-time measure of participants’ conceptual understanding.
- Daily journals include student summary of content understanding and most personally effective teaching approaches.

School-year research program outcomes:

- Students value the opportunity to take part in research science: (1, 4)
- Students consider opportunities in STEM careers appropriate to their level of interest: (2, 5)
- Students have a clearer picture of the way research science works, including the value of communication, collaboration and argumentation skills in making progress in a scientific community: (2, 5)
- Students become better at practicing and recognizing good implementation of the skills involved in doing research science: (3, 4)

Indicators:
1. Consistent participation in weekly online research updates and monthly online discussion of “case study” relevant to current research projects.
2. Positive changes in pre-/post- school year testing with “nature of science” and “attitudes toward STEM” instruments.
3. More consistent scoring and increases in repeated peer review scores of student presentations over the course of 10 monthly meetings.
4. Successful presentation of final paper at community science symposium.
5. Completion of “end-of-program” letter addressing how CAI has changed participant’s approach to learning and career goals.

Appendix
Listing of topics covered during cycle 7 CAI

Investigation 1: Sun / Moon / Earth system
Observations:
- Eclipse images, movies for solar eclipses from Earth, other solar system bodies
- Physical (scale) model of S/M/E system
- Linear motion of a variable mass rolling cart
- Circular motion of a variable mass and diameter
- Online gravitational simulations

Models/topics:
- Angular size
- Newton's second law
- Centripetal force
- Newton's universal law of gravitation

Predictions/Applications:
- Size / mass of Earth/Moon/Sun

Investigation 2: The visible sun as a star
Observations:
- Sun and light bulbs with various detectors (electronic and analog)
- CCD images of sun from MicroObservatory
- Spectra of sun and various light sources (discrete and continuous)
- Online simulations of stellar spectra
-

Models/topics:
- Particle model of light
- Flux / Luminosity / Distance relation (1/r^2 falloff)
- Basic image processing
- Properties of telescopes
- Fusion processes
- Blackbody spectrum / Wien's Law
- Bohr model of the atom

Predictions/Applications
- Luminosity of the sun / light bulbs
- Age of the sun
- Temperatures of stars
- Composition of stars

Investigation 3: Multiwavelength sun
Observations:
- Multiwavelength movies and images of the sun (SOHO, Trace, etc.)
- Stellar spectra at invisible wavelengths

Models/topics:

- Wien's law
- EM spectrum

Predictions/Applications:

- Temperatures of components of solar atmosphere

Investigation 4: Properties of groups of stars

Observations:

- Filtered stellar images
- Color-magnitude diagrams
- Multiwavelength Trapezium images (ds9 introduction)
- Visible light curves (M3 movie)

Models/topics:

- HR diagram
- Stellar evolution
- Mass-luminosity relation
- Fitting models to (spectral) data; judging quality of fit
- Light curves, models for varying flux from a star

Predictions/Applications:

- Stellar lifetimes / sizes
- Binary system masses, sizes, components

Investigation 5: GK Persei (eclipsing white dwarf binary system; polar CV)

Observations:

- Multiwavelength archive images
- Chandra observation:
    - Image
    - Light curve
    - Spectrum
- Long term visible light curve

Models/topics:

- Binary systems
- Break-up rotation speed (gravitation, circular motion)
- Accretion
- Stellar evolution

Predictions/Applications:

- Sizes/masses of binary components
- Plausible burst mechanism

Investigation 6: Cassiopeia A

Observations:
- Multiwavelength archive images
- Chandra observation:
  - Image
  - Light curve
  - Spectrum

Models/topics:
- Stellar evolution
- 2D vs. 3D models
- Angular size
- X-ray production mechanisms: blackbody, thermal bremmstrahlung, synchrotron radiation
- Fitting models to data
- Bohr atomic model

Predictions/Applications:
- Size, age, composition, temperature of SNRs

Investigation 7: Coma cluster

Observations:
- Multiwavelength archive images
- Chandra observation:
  - Image
  - Light curve
  - Spectrum

Models/topics:
- Cosmology, expanding universe
- Doppler effect/redshift
- 2D vs. 3D models

Predictions/Applications:
- Distance, size, temperature, mass of hot gas

End of summer feedback form

Please take a couple of sentences and respond to each of these questions:

1. What is similar and what is different about your experience learning science in the CAI versus your previous experiences learning science in school?

2. What has been the most valuable thing you've gotten out of participating in CAI so far, and why?

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

4. How, if at all, was this program different from your expectations?

5. If you were teaching the institute, what would you have done differently?

6. Would you recommend this program to a friend? Why?

7. What else could you have been doing this summer? Was it worth it to be here instead? Give specific reasons.

8. Given the chance to "do over", would you do this program again?

Rate how well you agree or disagree with the following statements:

1 = strongly disagree
2 = disagree
3 = neutral
4 = agree
5 = strongly agree

The institute instructors…

Had good understanding of subject matter………………………………. ________
Gave clear, well-structured presentations………………………………… ________
Used blackboards, visual aids, handouts well……………………………. ________
Were able to guide discussions and keep them moving………………….. ________
Answered questions well…………………………………………………. ________
Encouraged participation………………………………………………… ________
Were receptive to answering questions outside class………………………________
Were effective overall……………………………………………………………________

Rate the following aspects of the institute:

Difficulty overall (1= easy, 5=nearly impossible)………………………… ________
Pace of course (1 = too slow, 5 = too fast)………………………………. ________

Did you find the course intellectually engaging--did you find it interesting and did you want to learn more? (1 = strongly disagree; 5 = strongly agree)………… ________

Did you feel the program was effective as a learning experience? (This is a question about the WAY we taught, not WHAT we taught.)……………………… ________

Which approaches did you feel you learned the most from?
1 = Doing things this way is a barrier to my understanding
5 = I feel like this approach really helped me understand material better than a different approach would have.

Short lectures……………………………………………………………… __________
Individual groups making observations/brainstorming models………… __________
Individual groups presenting observations/models orally………………… __________
Reflections………………………………………………………………… __________
Readings included in your binders………………………………………….__________
Doing problem solving (with math) with a group and roaming instructor help
…………………………………………………………………………….. __________
Following problem solving on the board as a class……………………….. __________
Lecture presentations (Prof. Walter Lewin's lecture on light as a wave)…. __________
Using the "Solving Problems in Science" worksheet to organize your thinking about quantitative problem solving……………………………………………… __________
Using the "Peer Review" worksheet to give feedback to small group presentations…………………………………………………………….. __________

How hard did you feel that you tried to understand and participate in the summer institute? (1= I didn't try at all; 5 = I tried hard)…………………….. __________

Any additional comments/suggestions?

Observation/Model discrimination items:

Classify each of the following as an observation (O) or a model (M):

A. _____The Sun is a yellow color.

B. _____Gases occupy all of an enclosed volume.

C. _____Gravity keeps the planets moving in a circle.

D. _____Heat is transferred from a stove to your hand.

E. _____Light travels in a straight line.

F. _____Light is a wave.

G. _____Applying a force of 10 Newtons to a particular cart causes it to speed up from 0 m/s to 5 m/s in 5 seconds.

H. _____Temperature is a measure of the average energy of motion of the particles which make up an object.

I. _____Light is a stream of packets of energy called photons.

J. _____If you know the distance to an object and the flux you receive from it, you can calculate the luminosity of the object.

K. _____When light bulbs are hotter, they emit different colors of light.

L. _____Sources of light moving toward you are different in color than when they are moving away from you.

M. _____Nuclear fusion powers the sun.

N. _____The light curve of GK Per shows a period of about 350 seconds.

O. _____GK Per is most likely a rotating white dwarf.

P. _____The temperature of the center of the Cas A supernova remnant is hotter than the outside layers because it used to be the core of a red giant.

Q. _____The universe is expanding.

R. _____The luminosity of the Coma galaxy cluster is 100 billion times the luminosity of the sun.

S. _____High temperature gas held together by gravity produces the x-ray flux seen in the Coma galaxy cluster.

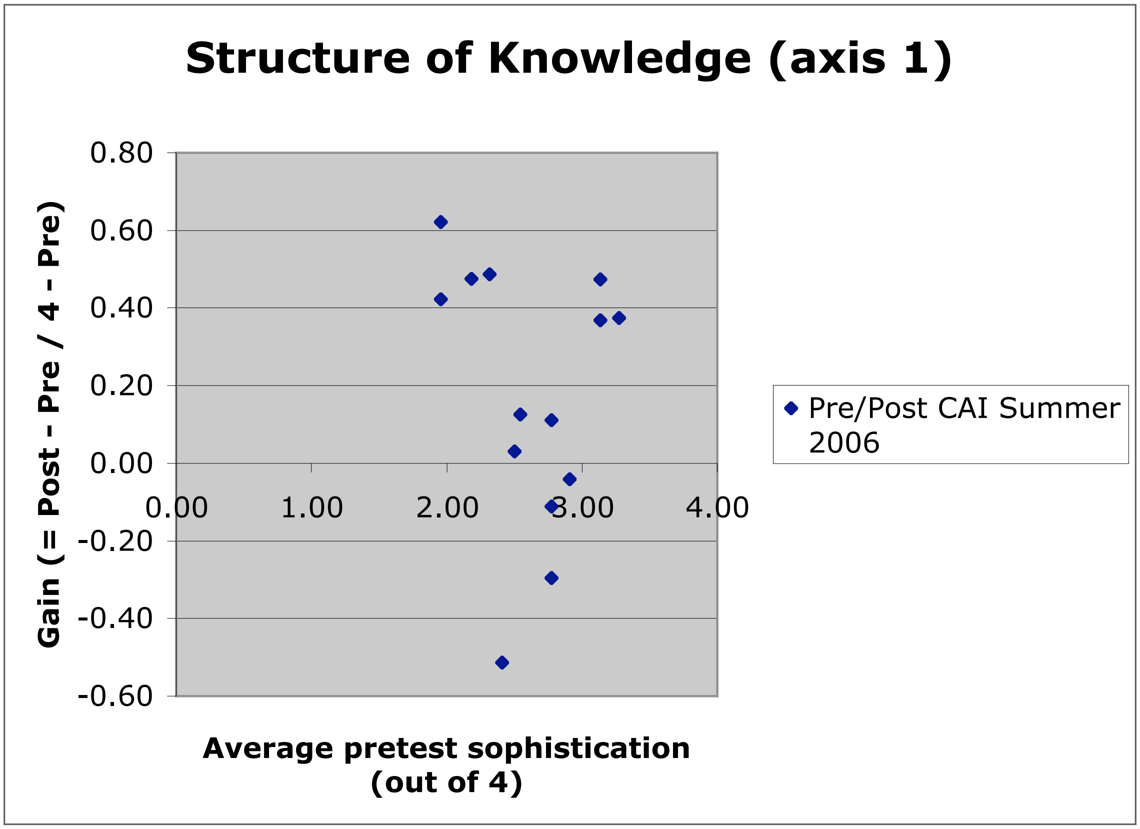
T. _____Galaxies that are farther away from us move away faster.

Complete individual EBAPS results:

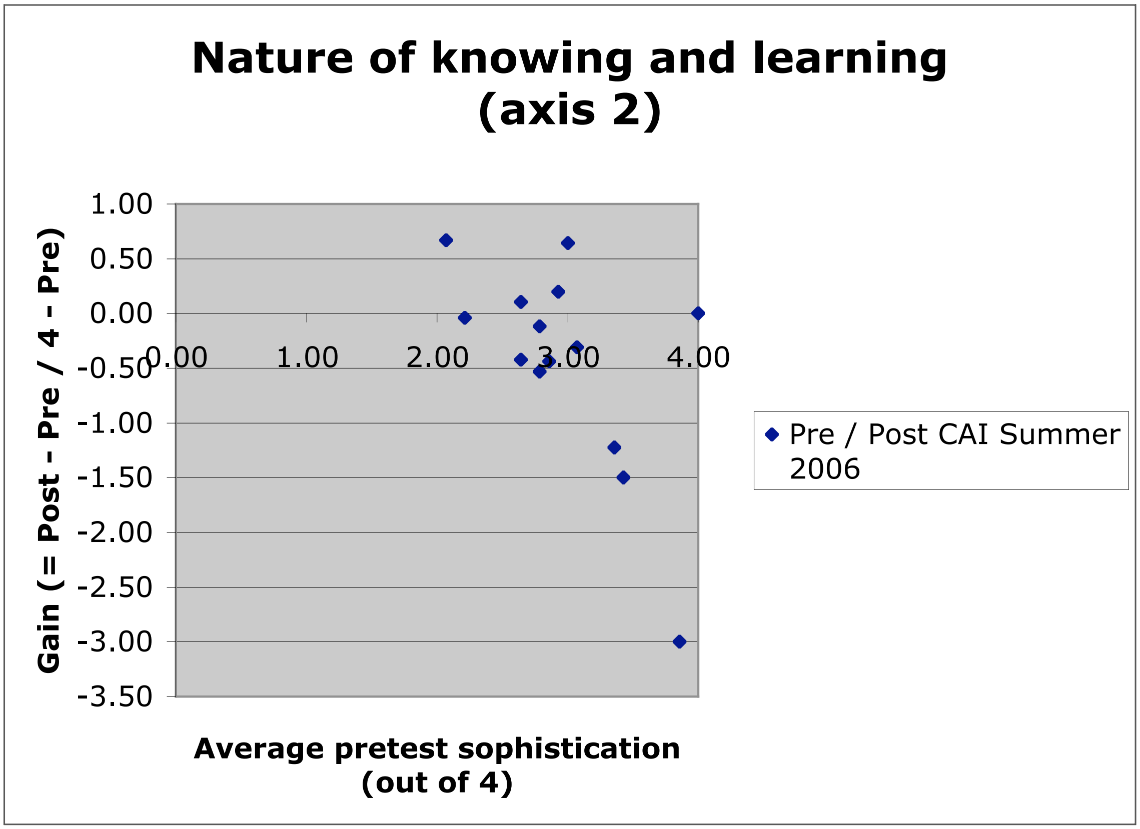
Results by axis:
To compare individual student performance on the pre-and post-tests, we calculate the normalized (Hake) gain factor:

G = (post-test fraction correct – pretest fraction correct) / (1 – pretest fraction correct)

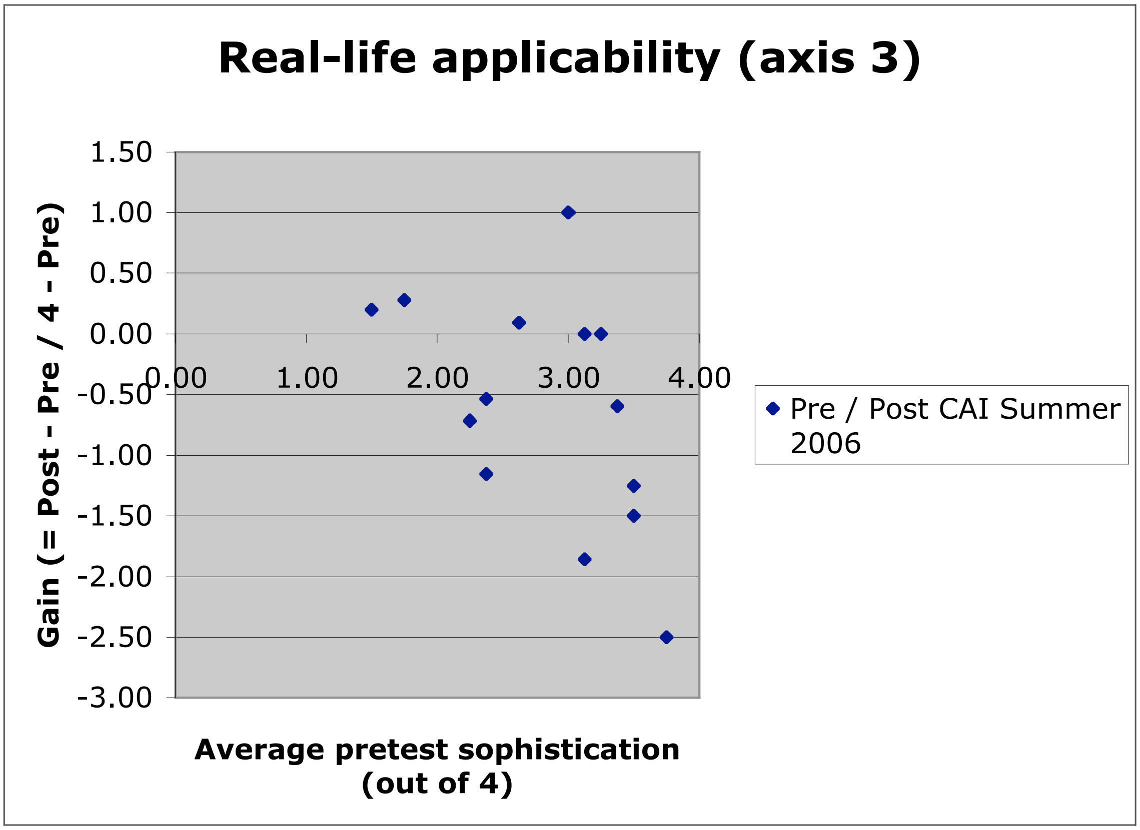
This is a measure of the fraction of the theoretically possible increase in score that a student actually increased.
We give results for each subsection, as well as the overall gain for each student on the entire instrument.



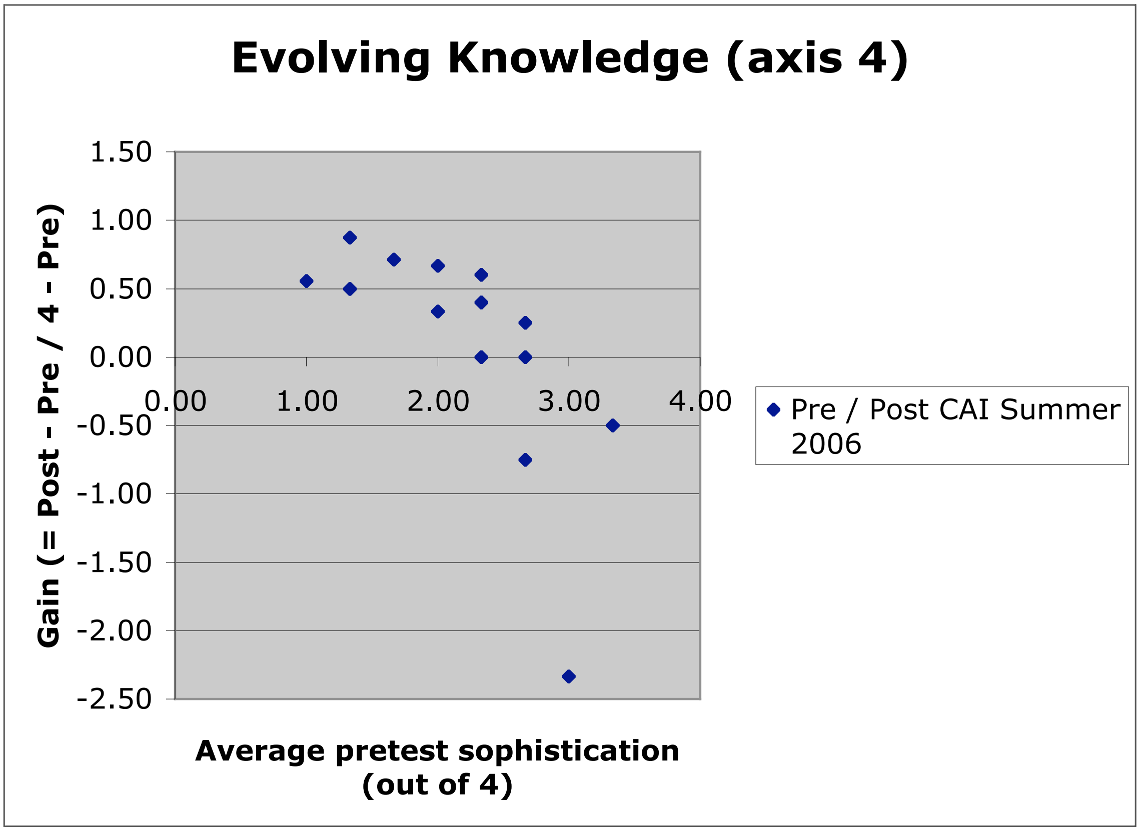
The average gain for these 14 students is 0.18.



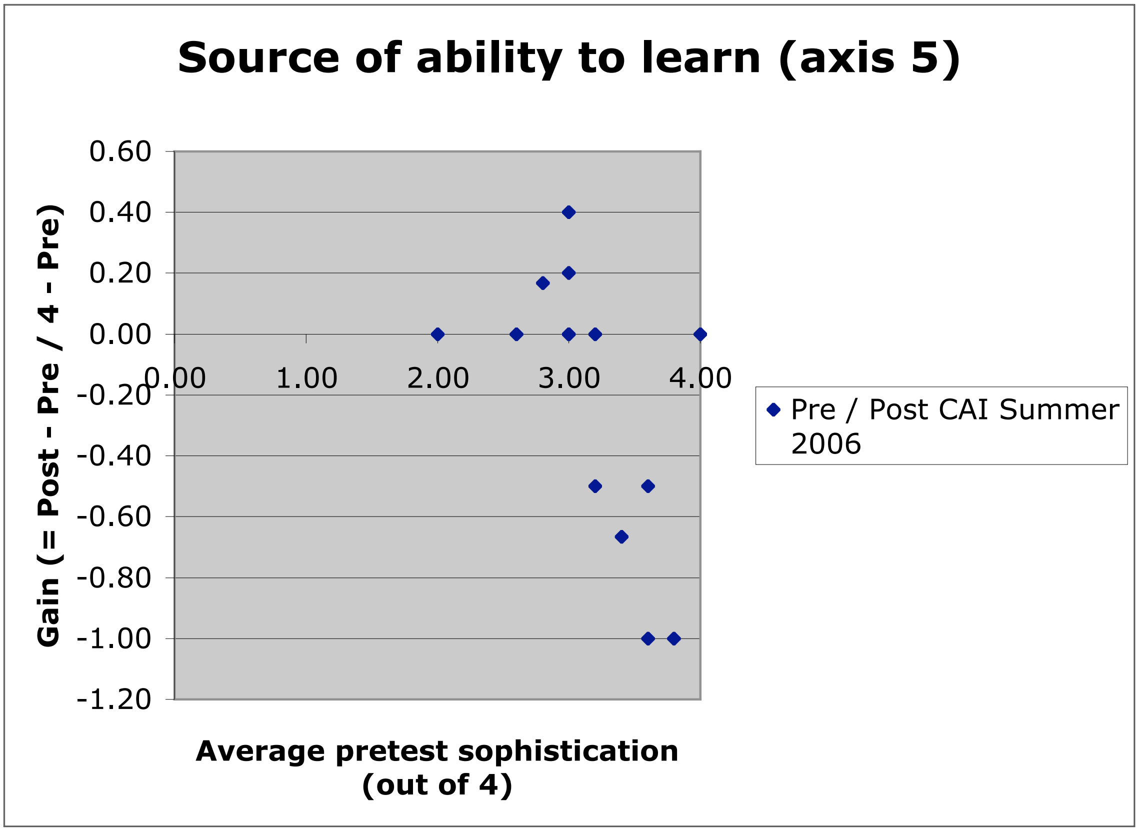
The average gain for these 14 students is –0.46.



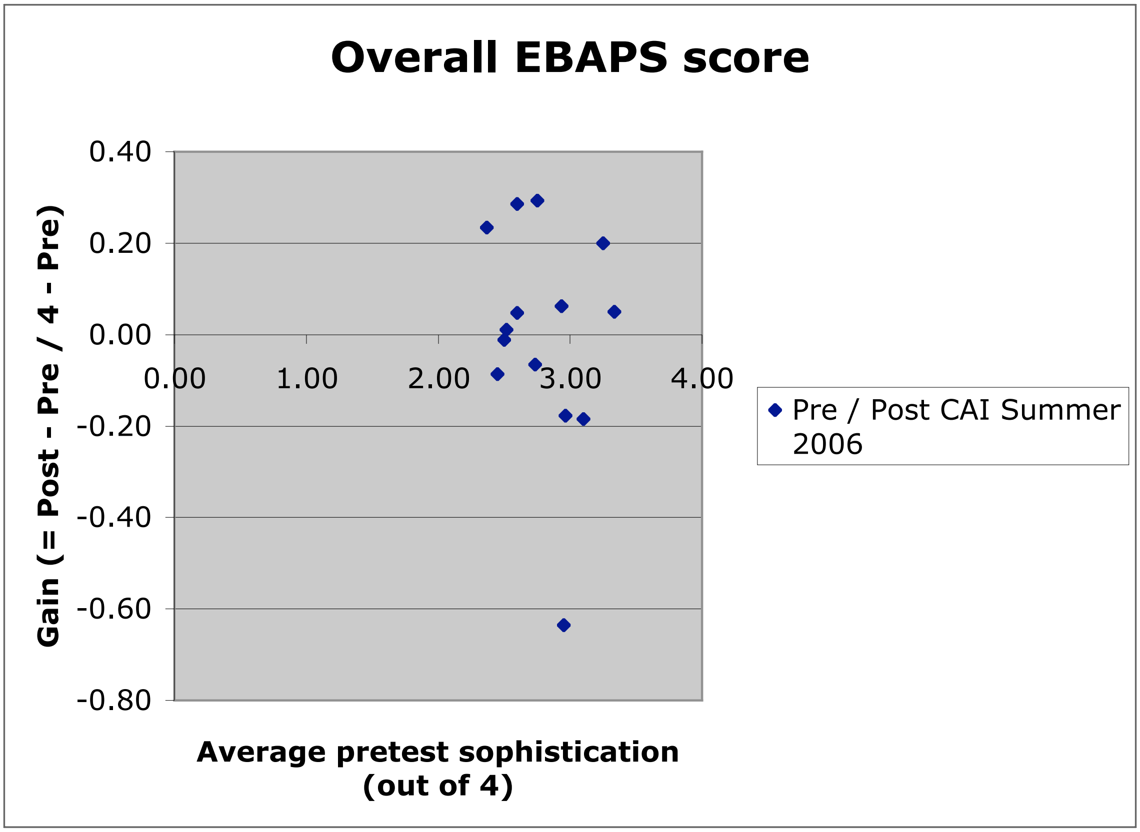
The average gain for these 14 students is –0.61.



The average gain for these 14 students is 0.09.



The average gain for these 14 students is –0.22



The average gain for these 14 students is 0.04.