

**CHANDRA ASTROPHYSICS INSTITUTE**  
**Cycle 3, 2007-2008**  
**End of Summer Session Evaluation Report**

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*This document is a preliminary form, given that the CAI will not conclude until May 2008. This document is not intended for wide circulation.*

## EXECUTIVE SUMMARY

NOTE: The Chandra Astrophysics Institute has been funded for 3 years through the Chandra EPO grant program, and we refer to these programs as given in the following table:

	CAI Cycle 1	CAI Cycle 2	CAI Cycle 3
Chandra EPO funding cycle	Cycle 6	Cycle 7	Cycle 8
Summer session	June-July 2005	June – July 2006	June – July 2007
School year session	August 2005- May 2006	August 2006 – May 2007	August 2007 – May 2008

### **Program summary (p. 4)**

The goal of the Chandra Astrophysics Institute (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.

The three phases of CAI include (1) school and student recruitment: talking directly with students to give them an idea of the program, (2) 5 week summer session: MKI staff and research mentors guide 6 astronomical investigations to develop content and analysis knowledge, and (3) school year investigations: monthly meetings at MIT and online interaction as mentors guide students to answer their own questions for a final symposium paper and presentation.

### **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). Several changes in instruments suggested in the original grant proposal were implemented due to time and effort constraints.

### **Educational approach (p. 9)**

During the summer session, physics, astrophysics and data analysis tools are explored using a modified method of science teaching that mirrors the development of scientific knowledge and viewpoints by a working science community. The goal here is that students will then easily be able to engage in the same process of research science in their self-driven investigations. In addition to this “model building” approach of teaching science, we give several examples of how our program design emphasizes the group skills necessary to actively take part in a scientific community: communication, collaboration and argumentation. Additionally, 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. 15)**

### *Concept inventory:*

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. Individual results normalized to original performance show a median Hake gain factor of 0.27.

### *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 few statistically significant changes in the group's sophistication, but a significant drop in the idea that science is a continually evolving body of knowledge. However, compared to a control group, our group shows statistically more sophisticated attitudes about science coming into the program.

### *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 (81% to 23%) toward understanding and appreciating the personal skills--including communication, collaboration, argumentation and model building--that are useful beyond science (25% to 77%). To us, this is a vital indicator that CAI appeals to those students interested in science, but seeking applicable skills from this program.

### *Comparison to previous cycles of CAI:*

A comparison of student demographics, retention rates, feedback ratings and performance on common content and attitude evaluations supports the idea that several changes made over the course of the 3 cycles of CAI have allowed us to recruit and retain our intended target audience. Number of applicants doubled from cycle 2 to cycle 3, and we have 94% retention of those students enrolled in CAI in June 2007.

## **Answering our evaluation questions (p. 28)**

We phrase the outcomes of the CAI program as three questions related to our definition of the process of research science:

- (1) Do participants understand the process of research science?

Students have some prerequisites necessary to do science and understand that it is collaborative, but may not be comfortable seeing themselves in the role of scientist.

- (2) Are they better at this process?

Concept inventories show gains in knowledge, and anecdotal statements of their knowledge and questions shift toward the more natural language of students, and show a regard for the connection between ideas.

- (3) Do they value this process as part of their careers/life?

Overall, the participants value the personal skills (that we think are applicable to different fields besides science) above all else in the program, but it is not as clear that participants see those skills as valuable and applicable in the much larger context.

**Conclusions and Implications (p. 38)**

Thus far, students seem to be well-prepared for their school-year investigations, as a result of spending significant time during the summer repeatedly practicing a few methods of data analysis, communication and collaboration, and developing a stronger working relationship with their mentor. However, more must be done to help them understand the process of research science by helping them engage directly in the roles of a scientist they may not see themselves in just yet.

## **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.

We feel it is most important for students to be comfortable with and confident of their basic astronomy background and a small set of tools *as a result of repeated practice*. In this way, they can interpret what they observe about a piece of data that interests them, develop their own connections and ideas, and communicate them to others, *regardless of whether others have come to similar conclusions*.

The approach to CAI has remained the same over the past three 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:

*School and Student Recruitment (September 2006 – April 2007):*

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 (June 2007 – July 2007):*

Investigations of 6 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. Students repeatedly use 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 (CIAO for spectral fitting, etc.). Expertise from the research scientists at MIT and collaboration with the software developers at the Chandra X-ray Center 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 investigations (August 2007 – May 2008):*

During the last 3 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 at a level of 10 hours per month,

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 course management system.

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 will be held in May 2008 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 a 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 3 proposal for the CAI 2007-2008 program, associated indicators in parentheses):

### **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.

\*Notes: Due to significant changes in the writing of student participants in the CAI from year to year, the applicability of the self-reflection and questioning rubrics above may not be appropriate for this year’s participants. Alteration of these rubrics is not possible within the time and effort constraints for this program.

In addition, appropriate probing questions for the TEAL room polling system were not generated, given the time and effort put into updating the activities themselves.

Although the development of a peer review “scoresheet” has been achieved, ensuring that it is a robust and reliable measuring device both from the developer side and training from the student user side has also proved to be beyond the scope of this project.

However, we still plan to use it as a guide to spark discussion of both student written and oral presentations as the occasion to review them by peer groups arises.

#### **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.

As of this writing, the school year portion of the CAI Cycle 3 program has just begun, so very limited evaluation information can be reported.

We frame the outcomes of the CAI program for the purposes of this evaluation report as a series of 3 questions. These are listed at the end of the next section, once we have outlined our teaching approach.

## **Educational approach/guiding principals**

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

### **Investigations based on the Interactive Science Learning Environment**

The underlying principles of the science instruction for the CAI were originally 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. However, some additions and changes have been made to this method, which are detailed in the sections below.

As an example of this 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 brainstormed and described several models in a public writing exercise. Each group examined all models, and chose one to “adopt” as their own to use and interpret. Models including the following:

- The star is moving toward and away from us
- The star is getting bigger and smaller
- A cloud of dark material moves in front of the object on a circular orbit.
- Clouds of dark material move in front of the object, but not in a repetitive orbit.

- The process of nuclear fusion in the core of the star is somehow sped up / slowed down, resulting in higher and lower luminosity with no other physical changes in the star.
- There is a bright or dark spot on a rotating star. (Similar to the idea of a pulsar that some students had previously encountered.)

*Predictions:*

These models were examined to see if their predictions were consistent with a set of realistic (although hypothetical, due to time constraints) light curves with different periods and relative drops in flux. (They would soon use their understanding of these models and light curves to interpret a real x-ray light curve.)

Each group had to decide how their model, if applied to this observation, could make a reasonable prediction for the behavior of the system. Student groups had difficulty with changing a property of their model (i.e. speed of orbiting cloud, opaqueness of cloud, etc.) in order to have that model's predictions match up with the observation. Eventually, though some groups' models had to be ruled out absolutely as impossible. For example, a light curve with a flux dropping to zero can not be explained by a star with a varying radius—stars cannot change to zero size! In this way, we see that the group interaction brings students to a deeper engagement with a model they had suggested on their own.

*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. The light curve from a second object (4U 1822) was also examined (two dips in flux with different relative depths). Students then had to suggest which of the models developed by the class would be plausible in each situation. Each group then built a physical model of a binary system (suggested as a plausible model for 4U 1822) and adjust this model until the predictions made with their physical system (i.e. detecting flux with a solar cell) matched the observation of the light curve of 4U 1822.

**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 (as we have said, this is based on the ISLE teaching environment mentioned above)

- 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 variable star analysis:

*Communication:*

Each small group develops and presents several models of flux variability by drawing models at their own whiteboard along with a written description. After they have chosen one model, a spokesperson from each group has a chance to explain how their model could plausibly explain each of the hypothetical light curves.

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 their ideas in a collaborative webpage (wiki) which can be modified and commented on with ease. Each of these wikis follows a “standard” format (Introduction/Background, Data/Methods, Results, Analysis/Discussion, Questions, Conclusion) so students become familiar with communicating their ideas in a clear, standard, scientific way. (This format is also used for the oral project presentations.)

At the end of each day of the summer session, there is a short review of what was done 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 models of flux variability. They then talk with other groups to compare/discuss similar ideas and gain insight into new ideas.

The groups must come to a consensus about one model to “adopt” and be clear about their collective understanding in order to understand what predictions this model may make. 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.

Finally, the repeated practice of summarizing the results of a particular investigation in a freely available wiki with a standard format allows small groups to examine the thought processes of another group, even at a later time. Additionally, at the end of each investigation, students collaboratively put up their “state of knowledge” which was then captured in a wiki. Each student was required to put up one statement about “what they know” and one question about “what they STILL want to know” about the topic of the investigation. We hope these wikis will serve as concrete reminders of what students understand (after all, they are written in their own words), as well as a starting point for investigating their own research projects and interpreting those of others in the program.

*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.

After having built their physical models for the 4U 1822 system, each of the small groups presents their ideas to another small group. Because they have all been a part of a collaborative effort to come up with the initial ideas for the models, each student has the background necessary to make intelligent, valid comments about what should and shouldn't be included in an accurate, convincing argument supporting the idea that the presenting groups' model is plausible. This is in contrast to making judgments merely on surface qualities of the argument, which would be the case if groups worked on different models or situations in isolation. Thus, the activities themselves are a way to promote the idea that collaboration is valuable in science and elsewhere.

**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](http://www.afterschoolforall.org/pdf/teen_study.pdf)). The design of the CAI aims to include both of these elements.

*Repeated practice:*

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 writing up the 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. Although the wikis all had the same format, the guiding questions that told students what to put in each section were slowly made more generic, which shows the removal of the supporting scaffolding as students gain a better understanding of what is being asked of them. This is characteristic of an apprenticeship model.

When small groups (3—4 students) would share ideas and models, we minimized sharing with the large group, which we found to be stifling to student contributions. Possibly this is because the large group was not considered a safe, comfortable arena in which to be wrong. Instead, small groups would share ideas with only another small group, which allowed time for each person to share the main idea his or her group came up with. This gives several benefits: each person gets a chance to speak about his/her understanding, and by hearing the same information from several different viewpoints, gets a repeated chance to absorb it.

One large change from CAI 06-07 to CAI 07-08 was the inclusion of fewer research tools and skills, which allowed more practice with the same software and techniques: using the ds9 analysis software to make 3-color images, extract spectra in graph form, and examine images taken in other wavebands. This allows students to be comfortable enough with tools to be able to use them to answer their own questions, developed for the research project.

*Importance of student voice/input:*

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.

Each of the summer investigations began with observations of astronomical data that then gave the students something upon which to form their own questions about the system. Questions were then shared with the group in written form and recorded for posterity. Although the investigations were designed to lead students to an understanding of particular topics and techniques, usually the questions they asked required the development of those ideas. Also, those questions were used directly in (or as the basis for) some of the written investigation summaries. Thus, the students experience the development of ideas during the investigations as a way to fill the vacuum they are aware is stopping their pursuit of the answers of their own questions, instead of simply “the next

thing the teacher wants to present.” In other words, the purpose of the investigations was cast as answering the students’ own questions.

At the beginning of the summer institute, each student chooses a topic area (normal stars, 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. Also, with practice of asking questions, as well as being able to refer back to them in concrete wikis, the students were better able to develop their own research questions during the start of the school year research project at the end of the summer, with which students from CAI 06-07 struggled.

## Instruments

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

### **Concept inventory**

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-2, named for historical reasons). 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-2 (Day 1)	3	3	3	3	4			16
CI-2 (Day 24)	3	3	3	3	4	10	21*	50

\*In the post test version of CI-2, 20 additional items were added with statements that students had to identify as a model or an observation.

Results for group performance on concept inventories:

	Mean score, CI-2, Day 1 N=14**	Mean score, CI-2, Day 24 N=14**	Effect Size, CI-2, Day 1 -> Day 23**	Median gain (ignoring undefined gain for students who scored perfectly on Day 1)
Motion/Forces	21%	31%	0.32	
Gravitation	48%	50%	0.09	
EM Waves	36%	77%	1.23 *	
Spectroscopy	29%	64%	1.01 *	
Astronomy	41%	48%	0.30	
Overall	35%	54%	0.92 *	

\* 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 the post-test on the final day, their results are not included in the following analysis, leaving 14 students

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. However, the change is not statistically significant in the motion and forces, gravitation and astronomy categories. Statistically significant differences show an effect size around one standard deviation of the entire combined sample.

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:

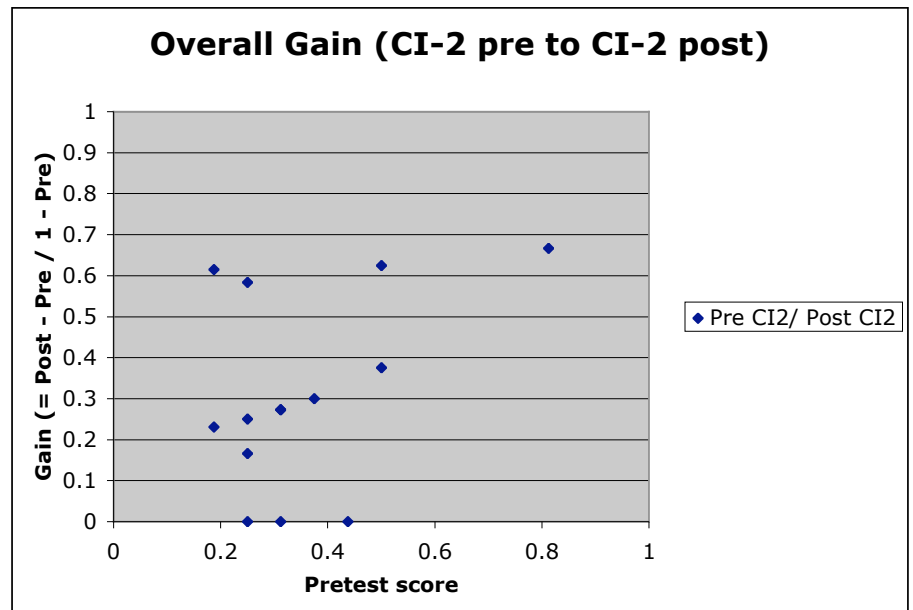
$$G = (\text{post-test fraction correct} - \text{pretest fraction correct}) / (1 - \text{pretest fraction correct})$$

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 median gain in each subsection and the overall gain for each student on the entire instrument:

	Median gain N=14 students
Motion/Forces N=3 items	0.33
Gravitation N=3 items	0
EM Waves N=3 items	1
Spectroscopy N=3 items	0.42
Astronomy N=4 items	0
Overall N= 16 items	0.27

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, but only one student has a pretest score greater than 50%.

We see that there are three seemingly distinct populations: the 4 students with gain 0.6 or greater, the 6 students with positive gain < 0.4, and 3 students with no gain at all.



### **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. 12 of 16 students completed both the pre- and post-testing with EBAPS, with the following results:

	Measure of group results			Measure of individual results	
EBAPS Category (Number of items probing this dimension)	Average sophistication (out of 4) Day 1 N=12	Average sophistication (out of 4) Day 24 N=12 (matched pairs)	Effect size Day 1 -> Day 24	Plot of gain vs. pretest sophistication	Median gain (ignoring undefined gain for students who scored perfectly on the pre-test)
Structure of Knowledge (N= 10)	2.41	2.30	-0.19		-0.04
Nature of Knowing and Learning (N=8)	2.59	2.57	-0.04		0.03
Real-life Applicability (N= 4)	2.54	2.41	-0.22		-0.11
Evolving Knowledge (N=3)	3.08	2.61	-0.65 *		-0.5

Source of Ability to Learn (N=5)	2.97	3.10	0.21		0.56
Overall EBAPS (N= 30)	2.61	2.54	-0.18		-0.01

\* 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.

In all cases, we see a wide range of gain values. In most categories, with the exception of “Nature of Ability to Learn” we see a trend that higher scoring students tend to have a more negative gain, meaning students who are more sophisticated are likely to change their ideas. However, these large negative gains can be the result of a change in just one or two questions, because the student has a small denominator in the gain relationship.

Two trends should be highlighted. Given that the nature of the way we are teaching in the CAI is intended to be based on the idea that students construct their own knowledge, it is disappointing to see no change in sophistication in the “Nature of Knowing and Learning axis.” As an example, the Likert-style (agree/disagree) question

“Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn’t think about her own experiences, she should just focus on what the book says.”

shows a drop in average sophistication from 3.0 (pre) to 2.3 (post), one of the largest drops on the instrument. This may indicate that students don’t see that interacting with science ideas themselves is particularly useful. One possible explanation for this drop is that the material students worked with over the summer was significantly harder or more complex than science material they had previously worked with, and thus they felt less comfortable engaging with it.

The second trend to notice is the large overall drop in the “Evolving Knowledge” category. The largest drop in average sophistication (2.7 -> 1.8) 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.

The most sophisticated answer in this case is agreeing equally with both participants. It is interesting to note that the groups’ average score in this category is larger than all the other categories.

### **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 4 months prior to Day 1): “Why are you interested in participating in the CAI?”
2. (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 (i.e. transferable science skills)
- Nature of science: wanting to learn how to do research, to be involved in a research project, or understanding the real process of asking questions and finding out answers in the way scientists do.
- Knowledge: Gaining knowledge about space / astronomy, including specific content areas (i.e. black holes, supernovae)
- Career exploration: explicitly mentioning career exploration, learning what kinds of things scientists do day to day, understanding what it takes to do a career in science/astronomy
- Access to resources: Having access to resources/ people they normally wouldn’t (i.e. telescopes, software, mentors, as well as practical considerations: “letter of recommendation”, “this looks good on my resume”, “it’s a good opportunity”, etc.)

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 for all three cycles of the CAI:

What’s the most valuable thing you’ve gotten (or hope to get) from CAI?	<b>Cycle 1 Pre-summer N=13</b>	<b>Cycle 2 Pre-summer N= 15</b>	<b>Cycle 2 Post-summer N= 15</b>	<b>Cycle 3 Pre-summer N= 16</b>	<b>Cycle 3 Post-summer N= 13</b>
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Practical, transferrable skills	23%	7%	73%	25%	77%
Nature of science	31%	7%	7%	13%	23%
Science Knowledge	85%	67%	40%	81%	23%
Career exploration	31%	40%	0%	13%	0%
Access to resources	23%	7%	20%	31%	0%

Please note that on the application many students referenced more than one of these areas, while in the anonymous feedback, fewer referred to multiple categories.

**Results:**

In cycle 3, student responses showed a shift away from simply learning more about astronomy (81% to 23%) toward understanding and appreciating the personal skills--including communication, collaboration, argumentation--that are useful beyond science (25% to 77%). In addition, we see a decrease in the number of students who considered career exploration and access to resources/people as 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 3 CAI students had the opportunity to ask the researchers involved in the program about their career paths in an informal setting, but very few actually took that opportunity. We hope that activities to be completed during the school year can give students a chance to explore science careers more in a way that may be less intimidating for students.

**Comparison to past years of CAI:**

It is useful to compare some of the same indicators for all three years of the 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 students who completed the CAI summer session. Numbers are individuals.

<b>Gender?</b>	<b>Cycle 1 (N=14)</b>	<b>Cycle 2 (N=15)</b>	<b>Cycle 3 (N=16)</b>
Female	3	4	9
Male	11	11	7

<b>Race?</b>	<b>Cycle 1</b>	<b>Cycle 2</b>	<b>Cycle 3</b>
American Indian/Alaskan Native	1	0	0
Asian	2	11	1
Black	0	0	2
White (includes Hispanic origin)	3	2	2
Hispanic	5	1	4
Multi – racial	3	1	5
Omit			2

<b>Conversations among adults at home?</b>	<b>Cycle 1</b>	<b>Cycle 2</b>	<b>Cycle 3</b>
Only in English	5	2	6
Sometimes in English	4	8	7
Never in English	4	5	1
Omit	1		2

<b>Grade at time of CAI application?</b>	<b>Cycle 1</b>	<b>Cycle 2</b>	<b>Cycle 3</b>
9		3	6
10	3	3	5
11	10	9	3
12	1		

<b>Years of physical science? (Chem/Physics/Earth Science)</b>	<b>Cycle 1</b>	<b>Cycle 2</b>	<b>Cycle 3</b>
0			6
1	6	4	3
2	6	8	6
3	2	3	
4			1

<b>Taken formal physics?</b>	<b>Cycle 1</b>	<b>Cycle 2</b>	<b>Cycle 3</b>
Yes	6	12	5
No	8	3	11

<b>Taken AP physics?</b>	<b>Cycle 1</b>	<b>Cycle 2</b>	<b>Cycle 3</b>
Yes	0	4	1
No	13	11	15

School District	Cycle 1	Cycle 2	Cycle 3
Lynn	10	4	8
Lawrence	2		
Boston	2	7	7
Cambridge		2	
Other		2	1

As is evident from the table, there is a shift between the students successfully recruited between the three years of the program. From the second to third year, there is a definite shift away from students of Asian (Chinese, Japanese and Indonesian) background to a more diverse group of students. Also, there is a shift toward younger students with less 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 high school level science.)

Student retention rates:

CAI year	# applicants	# accepted	# enrolled	# completed summer session	# completed school year project
05-06	16 (25% female)	16 (25%)	14 (21%)	14 (21%)	4 (75%)
06-07	16 (31%)	16 (31%)	16 (31%)	15 (27%)	14 (29%)
07-08	30 (33%)	23 (43%)	17 (59%)	16 (63%)	

Retention of students is also an indicator of their involvement and enthusiasm for the program. Although we had a very low return rate on an exit survey for students, we believe that most students in the CAI 05-06 program didn't feel they had the time that the research project would take during the school year, or were frustrated by lack of convenient access to software tools and felt that other activities kept their interest more.

End-of-summer feedback questionnaire:

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 1 CAI and the remaining 15 student participants in cycle 2 CAI. The sections of the feedback form addressed several topics (see Appendix for complete listing), but there are several interesting comparisons.

(Note: Cycle 2 CAI values included the following choices: strongly disagree, disagree, agree and strongly agree, or a similar ranges of 4 values. In addition, cycle 1 and cycle 3 CAI ratings also included a "neutral" choice. To compare results, half of all indications of "neutral" in cycle 1 and 8 results were changed to "agree" and half to "disagree." A numerical value of 1, 2, 4 or 5 was then assigned to each response, and 4 and 5 were

converted to 3 and 4. In summary, the data below is on a 4 point scale.) All results are median values of the responses:

Category	Cycle 1 (N=12)	Cycle 2 (N=15)	Cycle 3 (N=12)
Overall difficulty	2.0	2.0	2.5
Pace of course	3.0	2.0	3.0
Intellectually engaging/interesting?	3.0	4.0	3.0
Effective teaching approach?	3.0	3.0	3.0
<i>Teaching approaches from which you learned best:</i>			
Short lectures	4.0	3.0	3.0
Small group observation/model development	3.5	4.0	3.0
Small group presentations	3.0	3.0	3.5
Daily written reflections	2.5	3.0	3.0
Reading selections	2.5	3.0	3.0
Math problem solving, roaming instructor help	4.0	3.0	3.5
Math problem solving, on the board	2.5	3.0	3.0
Solving Problems in Science worksheet/method	3.0	3.0	3.0
Peer review process/worksheet	2.5	3.0	N/A

We see that a majority of cycle 3 students felt less inclined to agree that making observations and brainstorming models was a useful teaching technique than the two preceding groups. However, they felt that presenting their ideas once they were developed was more valuable than last year's participants. They also felt the course was slightly more difficult and slightly faster than last year's participants.

Finally, we see that this year's participants still felt better served by the written reflections and were less dependent on short lectures from the CAI instructors than cycle 1 students. We interpreted this last year (and this year) as 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, post-summer:

Although the concept inventory instrument used in cycle 1 CAI consisted of many different items than that used in cycle 2 and 8 CAI, there were 19 questions (taken from the RAI evaluation or developed by CAI instructors) which were asked of all groups at

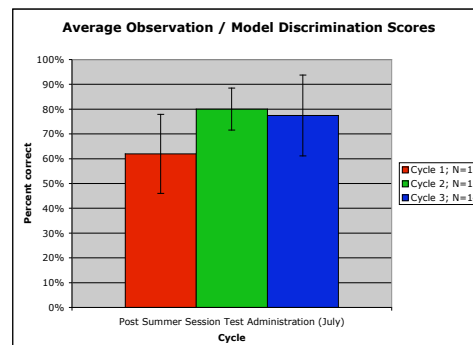
the end of the summer session. In these items, students had to characterize a statement as being either an observation or a model. This distinction has particular significance given that our teaching approach depends vitally on learning to do science using these constructs. (See appendix for a listing of these test items.)

Year	N	Median score	Average score	Standard deviation of scores	Effect size of difference in mean from 05-06 results	Effect size of difference in mean from 06-07 results
05-06	13	58%	62%	16%		
06-07	15	79%	80%	8%	1.2 *	
07-08	14	82%	77%	16%	0.9 *	-0.2

\* indicates a statistically-significant change in mean. In other words, a 2-tailed, independent (i.e. not paired) t-test for samples with unequal variances indicates less than 5% probability that this difference could have arisen at random. We assume that individual student results are normally distributed in order to apply this test.

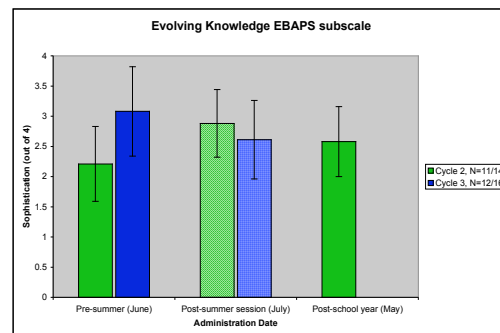
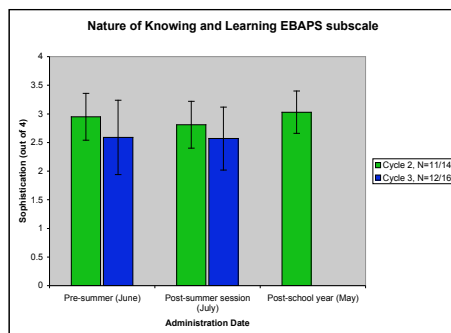
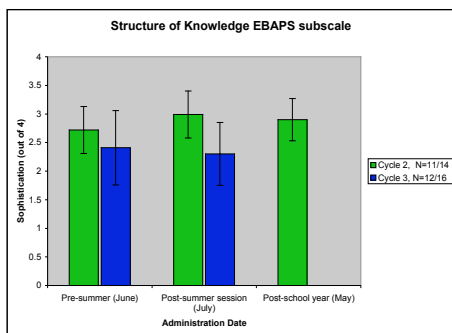
Note: Recall that effect size is difference in mean score of the 2 distributions divided by the standard deviation of the combined distribution.

We take this as evidence that the cycle 2 and 3 participants ended the summer with a better ability to distinguish observations from models than their cycle 1 counterparts. However, whether this is a result of their experiences during the summer session or previous exposure to these ideas is not clear.



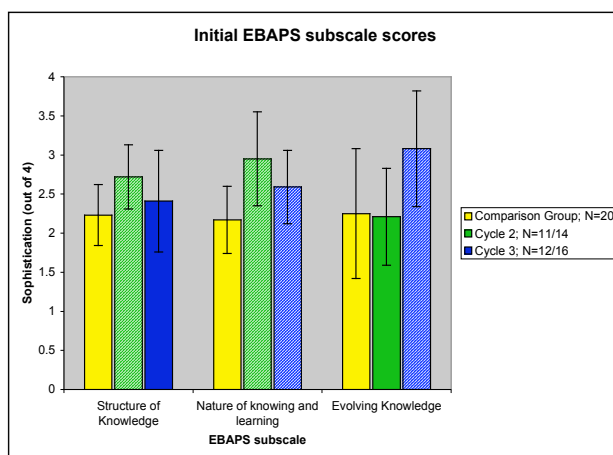
Attitudes and content inventory comparison:

Although the overall EBAPS average score did not change significantly for either Cycle 2 or 3 (not shown), 3 of 5 subscales are particularly interesting, given the goals of the CAI program: “structure of knowledge”, “nature of knowing and learning”, and “evolving knowledge.” These are shown in the plots below. Crosshatching indicates statistically significant difference in mean from pre-summer result ( $P < 0.05$  for 2-tailed, paired t-test) Error bars indicate +/- 1 standard deviation in scores.



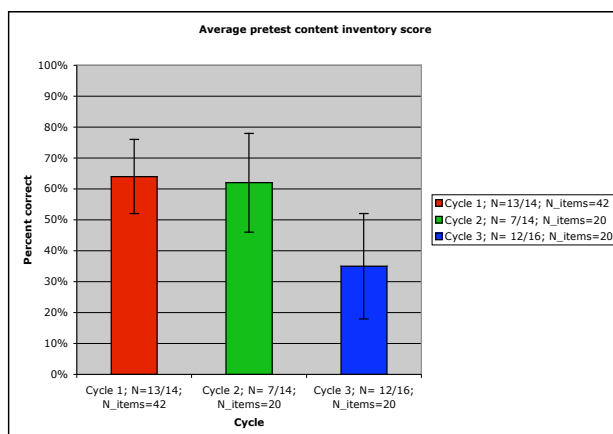
We see statistically significant changes for only the evolving knowledge subscale, but in opposite directions for Cycle 2 and 3. To investigate this further, we examine a comparison group of one honors chemistry course, composed of mostly 11th grade students at the school attended by about half of cycle 3 CAI participants.

We see that cycle 2 and cycle 3 students initially have significantly different scores from the comparison group, but not always in the same categories.



A simple comparison to incoming content knowledge (plot below) shows us that even though cycle 3 students may have lower incoming content knowledge, they still seem to be self-selected for a more sophisticated attitude toward science than their peers at school NOT in the CAI.

(Note: Not all content inventories across the 3 cycles were identical, but generally probed similar content standards, relying heavily on the MOSART Project from the Harvard-Smithsonian Center for Astrophysics, Science Education Department.)



## **Answering our evaluation questions:**

Listed below are the outcomes for the summer session of the CAI.

1. Students have learned enough astrophysics and data analysis skills to undertake a research project.
2. 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.
3. Students become better at practicing and recognizing good implementation of the skills involved in doing research science.

We phrase the outcomes of the CAI program as questions in order to address them using the material we have gathered from the participants, but first we must be clear about our definition of “research science.”

We define the process of science as essentially what we refer to as “model building” above. Observing preliminary data helps students generate questions in which they are genuinely interested. Using tools to make further observations about the system and discovering patterns helps students then make and/or apply models about that system which allow them to make predictions or gain a deeper understanding. Finally, students get the chance to present their own new insights either orally or in writing.

Our questions are cast in terms of how students interact with this process above.

1. Do participants understand that this process is how progress is made in scientific work? In other words, do they understand the nature of science as question-driven, evidence-based, predictive, and a collaborative effort? This is mostly based on outcome 2 above.
2. Are participants better at this process? In other words, do they have the requisite knowledge to ask better questions, make their own connections, and communicate the results? This is based on both outcome 1, science knowledge skills, and outcome 3, science process skills.
3. Do participants VALUE this process? In other words, do they see the skills involved in this process as relevant and valuable to their lives/careers, and to society in general? This is based on outcomes 2 and 3 above.

We deal with each question in turn below.

**1. Do participants understand that this process is how progress is made in scientific work? In other words, do they understand the nature of science as evidence-based, predictive, and a collaborative effort?**

Being able to distinguish between observations and models is a vital precursor to be able to understand the scientific research process. As presented in the observation/ model discrimination task summarized above, this year's participants show an ability to do so with the same level of discrimination as last year's participants and a greater ability to do so than the students from 2005-2006. Cycle 2 / 3 have statistically significant ( $P < 0.05$ ) higher mean than Cycle 1, *regardless of their difference in previous science background*. Thus, although we see that cycle 3 students have a lower *content* knowledge coming in, they are still able to perform at the same level as their cycle 2 (stronger science background) counterparts on the observation/model discrimination task by the end of the summer.

Several questions about the students reactions to the summer were asked anonymously in written form on the last day (day 24) of the summer session. One of them was "What is similar and what is different about your experience learning science in the CAI versus your previous experiences learning science in school?" Our motivation here is to see if students understand that the methods of research science are different from those commonly used in the classroom. Of 13 students responding to this question, responses fell into 3 categories.

The subject (astronomy / astrophysics) was different (2 responses) Example:

- "i never learned astrophysics before ... it was just about the same as school except for switching classes and rooms and lockers "

We as instructors presented things in a different, more hands-on way (9 responses)

Examples:

- "In CAI I liked the models we used on the PC as opposed to in school where we looked in books ...you watch what we're doing more and help us if we need... I like working in groups because you can work stuff out with other people instead of doing it yourself"
- "In CAI, however, there was less lecture and much more group work..."
- "...allowed more independence and brought up more questions to investigate..."
- "the way it's set up. In school we don't observe models and come up with observations the way we do it at CAI."
- "I didn't do much math in my previous science class, but I had a lot of practice here though."

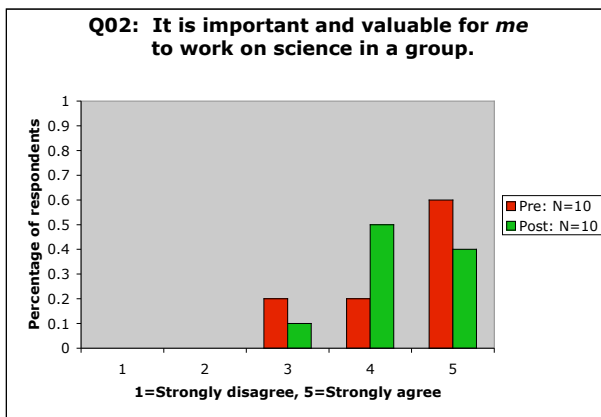
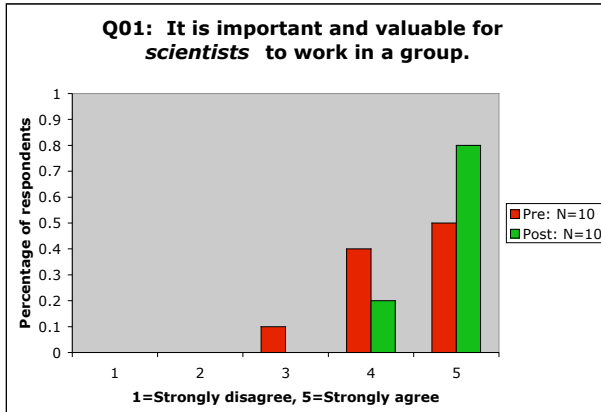
The students were asked to do things in a fundamentally different way, and they recognize this (3 responses). Examples:

- “Having the liberty to try to come up with an explanation for a set of data that we don't really know that much about was quite refreshing...”
- “In CAI we were also told to make connections ourselves before answers were given to us.”
- Learning in CAI is one of the best ways i have learned...we were given a set of instructions to view the data in the correct way, and asked "what do you see here and why?". For me this forced me to reformat all of my problem solving techniques and methods for sorting what is useful and not useful information.”

In general, students seem to realize that we are at least trying a different teaching technique, but whether they are explicitly recognizing that they are being asked to approach things in a fundamentally different way is questionable. Although we go through the process of asking questions to motivate the learning of required basic concepts during the summer session, the real insight into doing science will most likely be from answering their own research questions during their investigation. Indeed one student in the last category responded with an example of a discovery that she made during the first day of her research project. Hopefully this message will come through more clearly at the end of the school year portion of the CAI.

Results from the EBAPS survey also support this idea: we do not see a significant gain in their ideas about how they are involved in creating their own knowledge (Axis 2, “Nature of Knowing and Learning”). Also, the summer experience seems to have decreased their sophistication in knowing that evidence can possibly support several theories, and scientists are still responsible for interpreting those possibilities. (See drop in sophistication on “Axis 4: Evolving Knowledge.”)

Several questions about how scientists work and the importance of communication and peer review were asked at the beginning and end of the summer session. Two stand out with respect to this question.



Although this data is incomplete (10 of 16 possible respondents), question 1 shows a shift to stronger agreement and question 2 shows no significant shift. Thus, we see that students are more likely to see that group work is important for scientists to make progress, but they still have trouble seeing themselves in the role of scientist, or that things a scientist should do are applicable to their work, as well. Again, the experience of acting in a scientist role over the course of the coming school year may affect these attitudes.

## **2. Are participants better at this process? In other words, do they have the requisite knowledge to ask better questions, make their own connections, and communicate the results?**

The most easily measured indicator here is the participants' performance on the concept inventory. From the results above, we see a significant increase in their knowledge of the electromagnetic spectrum and spectroscopy, while the increases in astronomy, gravity and motion knowledge is not statistically significant. Although the last two results are understandable, as we put less emphasis on the general applications of these concepts as compared to previous years, it also shows the difficulty with which students change their ideas about astronomy. Further testing will be performed to see if these gains are permanent or if students will learn more content knowledge from being involved in their projects throughout the school year.

Although it is possible to examine the writing of students individually for trends, the feedback given to students based on this writing was mostly intended to help students become clearer in their writing and correct wrong ideas as they came up in writing. However, at several points during the summer session at the end of each investigation, students were asked to put up summaries of what they knew and still wanted to know about the topic of that investigation. This gives us an insight into the "state of knowledge" of the entire group. (Only after the first two investigations were completed did the instructors put into action the creation of a "group wiki" at the close of each investigation.)

In a preliminary examination of the responses to "What do we know?", participants mostly wrote down "facts" that they had either been told or read about in reading materials. For instance, "In a universe with a typical temperature of 63K, the center of a star is 15 million K." or "The matter in accretion disks of black holes spins around at speeds approaching the speed of light." However, as time progresses, some students begin to phrase some of this knowledge in at least their own language if not based on their own insights from data: "The core of a supernova before the blow up is made of iron.", "Wavelengths don't appear to the observer the way they are emitted if the source is moving."

Questions asked in the "what do we STILL want to know section" show some progression from asking about specific systems or ideas they have heard about to questions which ask about the connection between different times, systems or ideas.

Early question examples:

- "Where does a neutron star get its energy from?"
- "Do all stars turn into red giants?"
- What is the temperature of the matter around a black hole?
- Do we have a close star that will become a supernova?
- How do we detect neutron stars?
- How often does a supernova occur?
- Are all galaxies about the same size and distance from each other?
- How can you tell if a black hole is spinning?

Later question examples:

- Would an accretion disk (knowing that it gives off x-rays) look like a disk or a star?
- Why does x-ray light only detect the remnants of exploding stars (or other remnants of something else), but not stars?
- Is it better using x-ray flux and time for a light curve or just regular (visible) high / low flux and time? Why?
- How does a black hole accretion disk's composition evolve over time?
- Does a supernova remnant stop expanding?
- Do supernovae emit light other than x-rays?
- If a star explodes and the core turns into a black hole, would the SNR be "eaten" by the black hole?

### **3. Do participants VALUE this process? In other words, do they see the skills involved in this process as relevant and valuable to their lives/careers, and to society in general?**

#### *Student-Reported Value of CAI*

The most direct indication of what the students value about being in the program is indicated by what they themselves said, as outlined in the above section “Probes of student-perceived value of the CAI.” The strong shift toward personal skills that have value beyond the scientific field is a strong indicator of two things. (1) Participants realize that these skills are being actively pursued during the CAI, and (2) the summer session experience of students has shown them that at least part of the skills and knowledge necessary for scientific progress are valuable beyond the confines of CAI.

The first point is important also because of the smaller but still significant number of students (25%) who quoted the development of these personal skills as part of their application, as compared to only 7% of CAI 06-07 student applicants. This shows us that the changes in emphasis during the recruitment phase of the CAI (namely to emphasize the development of these skills as a major goal of the CAI program) have had their intended effect of drawing students with an interest in science, but whose sole motivation is not simply to learn more content.

Examining the responses to “What has been the most valuable thing you’ve gotten out of participating in the CAI so far?” question on the final day of the summer session reveals at least two students who mention confidence as a valuable skill, even though it was never explicitly mentioned during the summer session.

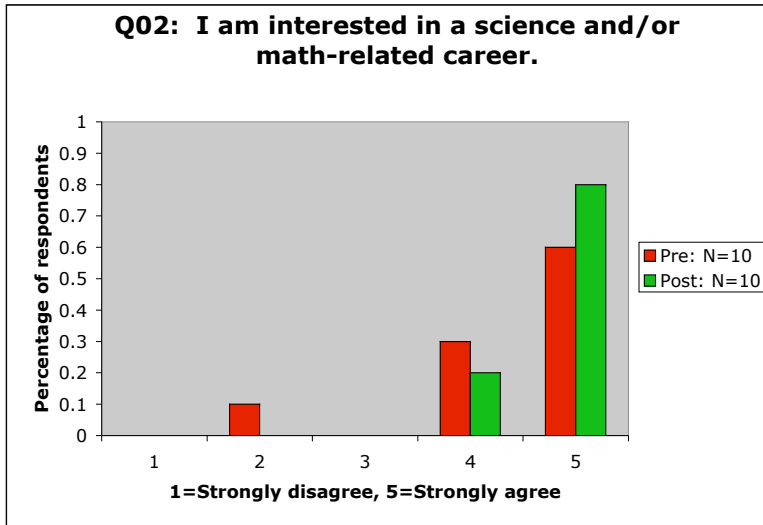
- “the most valuable thing ive gotten out of CAI is being confident enough to work on my own. i agree that the summer sesion is like a training sessin and it works”
- “The most valuable thing i have got out of the CAI program is confidence. In my opinion i think this class help want to put my thoughts and ideas out there for everyone to hear.”

#### *Anonymous Numerical Feedback Ratings*

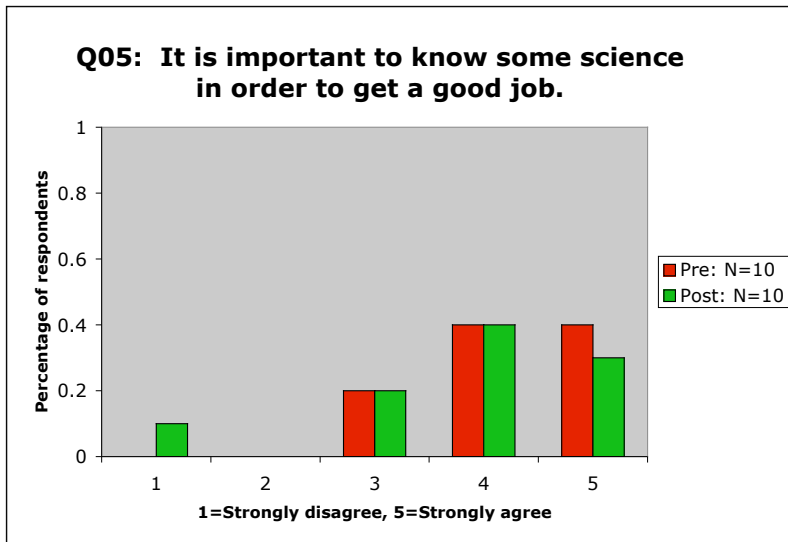
In examining the “End of Summer feedback questionnaire” results, we see that “Math problem solving, roaming instructor help” and “Small group presentations” had slightly higher ratings than other approaches under the “Teaching approaches from which you learned best” category. Unlike the previous year’s students, there was not a higher than average rating on the “Small group observation/model development” tasks. Also, recall from the section above that students shifted toward thinking it is valuable for scientists to work in a group, but did not shift their thinking about how valuable it was for THEM to work on science in a group. Thus, the idea that group work is important for science is there (i.e. they understand how science works), but the extent to which group work is valuable for them beyond a place to practice their presenting skills is less clear.

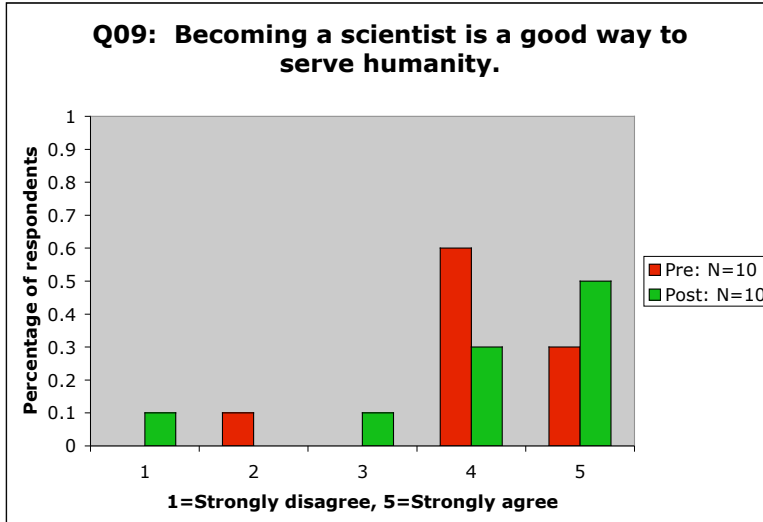
*Questions about attitudes toward science and careers in science*

We see this trend again in other results that probe the degree of real world applicability of science. Several questions about attitudes toward careers in science were asked at the beginning and end of the summer session, with results below for matched pairs of students only:



There seems to be a positive shift in this question.





In these last two questions, there was not an easily discernible shift. Although we see a desired shift toward an interest in a science career, we don't see a shift toward thinking that science is valuable in situations beyond those considered explicitly scientific.

*Anonymous written feedback questions:*

When asked anonymously on the last day of the summer session, "How will this experience affect your approach to any and all classes in school next year and beyond?", the level of perceived ability to transfer ideas/techniques and skills was mixed. Only 2 of 13 respondents say their CAI experience won't affect their approach, and 3 say they don't know.

- "I doubt it will affect my approach to any class that is not in this format, as most of the skills and techniques I learned this summer would be best applied in this type of class setting."

Of the remainders, 5 mention some of the skills they feel they developed, and 4 explicitly mention their better ability to organize their thoughts and ideas. Excerpts below:

- Being forced to construct scientific papers and arguments clearly and concisely in limited amounts of time has really helped me to become a much more proficient worker.
- now I will try harder to make connections on my own and to learn the concepts more than just the facts. I'll also be more organized in school.
- to push myself harder and seeing why i got the answer i got how i got the answer i got and can i explain clear to my peers my i believe i am right.
- writing out what I know and do not know

7 of 13 respondents would recommend the CAI program to a friend, and 6 would "maybe" recommend a friend, depending on whether he/she was interested in astronomy (4) or match with the teaching style (2). 11 of 13 respondents would do this program

again. However, 2 responses to “Would you do CAI over?” and “Was it worth it to be here over other things you could be doing?” are worth examining:

Student 5:

I'm not sure if i would just because i honestly didnt realize the whole prgram was all astronomy but other than that i think i would do the program again. Im not thrilled about astronomy its not in my area of comfort but i think that this program made me a little more flexible and i think thats really good i think that the program is good for you so i dont regret doing.

It was worth being here because i learned valuable skills but its not exactly summer fun. I know i probably dont appreciate this program right now as much as i will in the futute but i do appreciate it right now. Im very big on doing good in my future and that is all im concentrating on and if this prgram brings me one step closer to doing better in the future than it was worth my time.

Student 6:

I think I would do this program again even though astronomy isn't the kind of science I like because it's a good experience. It's going to help me alot in the future and I met some great people. It is worth the hard work and committment.

It was worth it to be here because I learned alot and it's going to help me alot in the future.

Both students may not have the strongest interest in astronomy, but they both believe that being here allowed them to somehow contribute something useful to their futures.

One last interesting point from these anonymous feedback questions comes from the responses to “What else could you have been doing this summer? Was it worth it to be here instead? Give specific reasons.” 6 of 13 respondents specifically mention that they would have had a job. This indicates two things. The students who responded this way valued the opportunity they saw in the CAI program at least as much as the money they could have made. Also, the other 7 students (who mostly cited that they could have been doing “fun” things) are not “held back” from participating in an out-of-school-time program such as this because they need to have a job, as is cited as a common reason why high school level OST programs would not be successful.

Thus, overall, the participants value the personal skills (that we think are applicable to different fields besides science) above all else in the program, but it is not as clear that participants see those skills as valuable and applicable in the much larger context.

## **Conclusions and implications**

Given the results from the CAI cycle 3 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 should be explicitly confronted with alternative possibilities for how to interpret the data from their research projects, and be challenged to present a convincing case for why they interpret them in a particular way. This should help students understand better how scientific work really progresses.
- Although students valued reflections more so than during cycle 1, there should be a mix of different kinds of direct experience with developing and challenging ideas 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 continue to emphasize the practice-based mastery of skills and inclusion of student voice in the CAI.
- The apprenticeship aspect of repeated practicing with reduced guidance must be applied consistently throughout the summer session and in the same format (for written and oral presentations) during the school year.

We have included a chart showing the evolution over the past 3 years of strategies to recruit our target population, engage them in ways they find meaningful, and pursue our desired outcome for them to develop a working understanding of how research science is done.

How CAI has changed	Cycle 1	Cycle 2	Cycle 3
<p><b>Recruitment effort:</b></p> <ul style="list-style-type: none"> <li>Spend more direct contact time with students, after gaining educator input and buy-in.</li> <li>Work directly with as many schools as possible: district-level interaction gives poor results.</li> </ul>	<ul style="list-style-type: none"> <li>1 meeting with educators from 4 schools, who also attend summer session</li> <li>~2 contact hours/educator</li> <li>Active recruitment period: Jan. - May</li> <li>No direct contact with students</li> </ul>	<ul style="list-style-type: none"> <li>1-2 meetings with educators from two schools. (Opened recruitment at last minute to 4 additional schools, due to poor recruitment)</li> <li>~ 3 contact hours with educators from two school; almost none with other educators</li> <li>Active recruitment: Mar. - May</li> <li>1 - 3 direct meetings with students at each of 2 original schools.</li> </ul>	<ul style="list-style-type: none"> <li>Cast broad net to all Boston-area schools</li> <li>4 meetings with educators from 7 schools, including MIT scientist mentors</li> <li>~5 contact hours with educators</li> <li>~2 direct meetings (1 hour contact) with students at each of 7 schools.</li> <li>Average recruitment of ~3 students / school.</li> <li>Active recruitment period: August - April</li> <li>TryCAI event at MIT with scientist mentor / educator input as part of application: Students gain a good idea of what CAI is like before they decide to attend.</li> <li>Strong emphasis on the chance to practice and develop skills that are useful in many fields, including communication, collaboration and building arguments.</li> </ul>
<p><b>Opportunities for independence:</b></p> <ul style="list-style-type: none"> <li>Shift toward more time spent on students' own projects, developing their own questions.</li> </ul>	<ul style="list-style-type: none"> <li>Small group "expert projects" (done during summer session on a topic of their choice) in 1-2 days, including oral presentation.</li> <li>Change summer group daily</li> <li>School-year research projects laid out mostly by scientists.</li> </ul>	<ul style="list-style-type: none"> <li>"Expert projects" extend over 2 weeks, including oral presentation.</li> <li>Change summer group daily</li> <li>School-year research projects and initial direction introduced by scientists; development of final questions by students only in March.</li> </ul>	<ul style="list-style-type: none"> <li>Expert projects extend over 3 weeks, including written wiki and oral presentation.</li> <li>Change summer group every 2-3 days, when start a new summer investigation.</li> <li>School-year research project areas suggested by scientists, but students develop and present their own questions to scientist mentors.</li> </ul>
<p><b>Repeated practice of skills:</b></p> <ul style="list-style-type: none"> <li>Shift away from basic facts toward utilitarian knowledge. (I.e. limit the concepts to that which you actually measure: linear size, distance, motion, luminosity, spectra)</li> <li>Cast investigations to be more like research projects with respect to data examined and interactions with group: oral/written communication, use of collaboration tools/wikis.</li> </ul>	<ul style="list-style-type: none"> <li>Use 3-4 image processing tools, practice somewhat segregated from content investigations.</li> <li>1/2 summer session day to start year-long research project.</li> </ul>	<ul style="list-style-type: none"> <li>Use 2 image processing tools; practice integrated with summer astronomical system investigations.</li> <li>2 summer session days to start school-year research project.</li> <li>School-year research project oral presentations follow same outline as summer investigations.</li> </ul>	<ul style="list-style-type: none"> <li>Use single image processing tool; practice of techniques linked directly to summer investigations.</li> <li>3 summer session days, including "group meeting" and informal lunch with mentor to start school-year research project.</li> <li>School-year research project written presentations/wikis follow same outline as summer investigations.</li> <li>Initial analysis for school-year investigation involves repeated application of tools and measurements identical to summer investigations.</li> </ul>
<p><b>Scientist mentor involvement:</b></p> <ul style="list-style-type: none"> <li>Students should work <i>with</i> real adults from the scientific community, and develop a relationship with them.</li> <li>Provide effective scaffolding for the goal setting and clear communication necessary for steady progress on school-year research project.</li> <li>Students should have their own insights/ideas to bring to the table to discuss with mentors, to make the most of limited interaction time.</li> </ul>	<ul style="list-style-type: none"> <li>Worked directly with students during summer investigations, including students' first exposure to some analysis tasks. (3-4 hours student contact/mentor)</li> <li>4 scientist mentors for 3 of 4 project areas; 3 projects finished, only 1 with mentor.</li> </ul>	<ul style="list-style-type: none"> <li>Advised EPO instructor on how to introduce investigation, what data to use. (~1 hour EPO contact/mentor)</li> <li>Informal summer lunches with scientists (~1 hour student contact/mentor)</li> <li>4 scientist mentors for 4 of 4 project areas; 8 projects finished.</li> </ul>	<ul style="list-style-type: none"> <li>More direct role in revising summer astronomical system investigations (~4 hours EPO contact/mentor)</li> <li>3 mentors new to CAI physically present for summer investigation related to the school-year research project they will mentor.</li> <li>Informal summer lunches AND group meetings (~6 hours student contact / mentor)</li> <li>5 scientist mentors for 5 of 5 project areas; 7 projects started.</li> <li>Mentors physically involved in TryCAI and selection process of students.</li> </ul>

Thus far, students seem to be well-prepared for their school-year investigations, as a result of spending significant time during the summer repeatedly practicing a few methods of data analysis, communication and collaboration, and developing a stronger working relationship with their mentor. However, more must be done to help them understand the process of research science by helping them engage directly in the roles of a scientist they may not see themselves in just yet.

## **Appendix**

### **Listing of topics covered during cycle 3 CAI**

#### **Investigation 1: Sun / Moon / Earth system**

##### Observations:

- Images taken by students themselves of objects with differing angular size
- Physical (scale) model of S/M/E system
- Circular motion of a variable mass and diameter
- Online gravitational simulations

##### Models/topics:

- Angular size
- Centripetal force
- Newton's universal law of gravitation

##### Predictions/Applications:

- Size / mass of Earth/Moon/Sun

#### **Investigation 2: Light from the sun**

##### Observations:

- 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
- Blackbody spectrum (shape only)

##### Predictions/Applications

- Luminosity of the sun / light bulbs
- Temperature of the sun

#### **Investigation 3: The sun as a star (structure and lifecycle)**

##### Observations:

- Multiwavelength movies and images of the sun (SOHO, Trace, etc.)
- Stellar spectra at invisible wavelengths
- Multiwavelength Trapezium images (ds9 introduction)

##### Models/topics:

- Fusion processes
- Blackbody spectrum (production)
- Bohr model of the atom
- EM spectrum

- HR Diagram
- Stellar evolution
- Mass-luminosity relation

Predictions/Applications:

- Stellar lifetimes / sizes

#### Investigation 4: GK Persei / 4u 1822

Observations:

- Multiwavelength archive images
- Visible light curves (M3 movie)
- Chandra observation:
  - Image
  - Light curve
  - Spectrum

Models/topics:

- Binary systems
- Light curves, models for varying flux from a star

Predictions/Applications:

- Components of binary system

#### Investigation 5: Cassiopeia A

Observations:

- Multiwavelength archive images
- Chandra observation:
  - Image
  - Light curve
  - Spectrum
- IR spectra

Models/topics:

- Stellar evolution
- 2D vs. 3D models
- Bohr atomic model
- Doppler shift

Predictions/Applications:

- Composition, expansion velocity of SNRs

#### Investigation 6: 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 of hot gas

**CAI 2007 Anonymous Summer session Final Feedback**

**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 whiteboards, 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 summer session 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 out loud to each other... \_\_\_\_\_
- End-of-day reflections..... \_\_\_\_\_
- Articles and other readings..... \_\_\_\_\_
- Doing problem solving (with math) in a small group with roaming instructor help  
..... \_\_\_\_\_
- Following problem solving on the board as a class..... \_\_\_\_\_
- Using our "Problem solving technique" (State question, Want:, Known:, Math  
relationships:, Change Units, Solve) to organize your thinking about quantitative problem  
solving..... \_\_\_\_\_

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.