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The CfAO's Astronomy Course in COSMOS: Curriculum Design, Rationale, and Application

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Abstract. From 2001 to 2007, COSMOS provided a teaching and outreach venue for the Center for Adaptive Optics Professional Development Program (CfAO PDP). COSMOS is a four-week residential mathematics and science summer program for high-school students organized by the University of California on four of its campuses. Two topical science courses comprised each COSMOS cluster. An astronomy course has always formed a basis for the CfAO PDP-affiliated cluster. The course included a variety of pedagogical techniques to address a diversity of learners and goals. We outline the astronomy course—lectures, activities, etc.—and provide the rationale for what was taught, how it was taught, and when it was taught.

1. Introducing COSMOS and the CfAO's Course Cluster

The California State Summer School for Mathematics and Science (COSMOS) is a month-long residential academic and enrichment experience for high school students. The University of California, Santa Cruz (UCSC) is one of the four UC campuses that host a program.[1] For four weeks, COSMOS students divide their time between program-wide events, both academic and recreational, and their course "clusters." A cluster is a pairing of two math or science-based courses, such as astronomy and vision

[1]`http://epc.ucsc.edu/cosmos/`

science. While there are COSMOS program-wide academic activities (lectures on current science research, career panels, etc.), the majority of academic time is dedicated to the cluster. Typically students spend about six hours per day in cluster activities. For a wider perspective on COSMOS at UCSC, see **?**.

Each cluster has a teacher fellow (TF), two or more instructors (at least one lead instructor per course), and a similar number of teaching assistants. In addition, the students' social and other activities are chaperoned and organized by COSMOS resident assistants. The teacher fellow is a local high-school teacher and is the one instructor who attends all academic events with the students. The TF forms a bridge between the two courses by helping the students synthesize the content from the courses and the COSMOS-wide lectures as well as communicating with the instructors about the mood of the students. The TF also teaches an approximately six-hour-per-week section on "Transferable Skills," where the students learn about, e.g., spreadsheets and preparing presentations, which are beneficial to both courses. Key to a successful cluster is the TF's experience with high school students—a valuable resource for the other instructors. The instructors are often UCSC faculty or doctoral students, and they are in charge of teaching lectures, labs, etc., to the whole cluster.

The Cluster 7[2] teaching assistants were more than aides to the instructors. They were leaders of small-group research projects; therefore, we refer to them as project advisors. All COSMOS students participate in a research project in their cluster, and the last academic day of the four weeks is Presentation Day, when the students share the results of their research. Each cluster handles the research projects in its own way. In Cluster 7, there were a variety of pre-designed research projects. A project advisor worked in collaboration with two to three students to collect, analyze, and interpret data on a specific topic. Cluster 7 had typically allotted the majority of the last two weeks to project time, totaling 20 to 30 hours. Our emphasis and devotion to the small-group research projects was one of the most unique and successful aspects of Cluster 7. The high staff-to-student ratio of Cluster 7, and all that it enabled, was largely made possible through our relationship with the Center for Adaptive Optics Professional Development Program (CfAO PDP).

Cluster 7 developed alongside and over about the same time period as the education programs of the CfAO, a National Science Foundation science and technology center. The CfAO's extensive education and outreach program is largely driven by its PDP (**?**, also see Hunter et al., this volume). Through the PDP, scientists, engineers, and/or educators learn inquiry-based teaching techniques and issues of diversity and equity in the sciences. PDP participants practice teaching in a range of venues; COSMOS Cluster 7 has often served as a teaching laboratory for PDP participants. All of the lead instructors and developers of this course have been participants, and in addition, we recruited teaching assistants (a.k.a. project advisors) and facilitators for hands-on and/or inquiry activities (see §2) from the PDP community.

Cluster 7 provided an opportunity to reach out to students lower on the "leaky science pipeline" (**??**) and encourage and prepare them for college. With this aim in mind, we recruited and selected students as follows. During the school year, Cluster 7 instructors and/or PDP staff did targeted recruitment, giving presentations at partner high schools. The partner schools typically had large numbers of: minorities under-

[2]The CfAO's cluster was initially Cluster 10 but has been Cluster 7 for most of the time. Hence, we consider Cluster 7 synonymous with the CfAO's cluster.

represented in science; English-language learners; free/reduced lunch recipients; and/or (potential) first-generation college-bound students. COSMOS then provided our cluster with approximately 40 applications of students who passed initial selection criteria and ranked our cluster as their first or second choice and/or applied as a result of our targeted recruitment. Typically, Cluster 7 instructors performed a holistic review but gave weight to teacher recommendations and achievement potential despite lesser opportunities or economic disadvantage. We aimed to give opportunities to students who may not have attended such a program previously. In addition, while applicants ranged over four grades, we prioritized the students entering 10^{th} and 11^{th} grades, the age where we were best able to affect their college application pathways. We ranked the applications, which may also have been highly ranked by another cluster, and then the campus COSMOS office placed the highest-ranked students into their preferred cluster until all clusters had 15 to 18 students.

The astronomy course partnered with a vision science course from 2001 to 2006 and a mixed biology course in 2007. This paper focuses only on the astronomy course. In §2, we will briefly describe the various lectures, hands-on activities, and inquiries used over the years. We will refer to these components as we outline and explain the four-week schedule from 2007 in §3. How this specific schedule can be rearranged to accommodate other considerations will be described in §4. Final thoughts will be discussed in §5. Other documentation, e.g., presentations, handouts, etc., from Cluster 7 (2005–2007) can be found online.[3]

2. Curriculum Components

Before we can discuss the rationale behind the astronomy course as a whole, we need to briefly describe all the lectures, hands-on activities, and inquiries used in the course over the years. In Table 1, we give the title, approximate duration, and basic purpose of the curriculum components used over the years. They are listed, roughly, in the order historically used. In the tables, the components are described only in terms of their content and methodology. The motivation for why the components were designed as such will be explained in §3 and §4.

Three overarching themes of the course were: (i) all astronomers have to study is light; (ii) scientific investigation is an iterative, multi-step process; and (iii) the students are capable of scientific thinking and inquiry. The first theme drove the content taught, namely: telescopes and instrumentation; physical properties of light; and current understanding of the Universe. We designed activities that allowed the students to practice scientific processes (second theme). By engaging them in doing science, we aimed to have the students prove to themselves that they could think analytically and pursue scientific careers if they chose (third theme).

Lectures, hands-on activities, and inquiries were the tools that we used for any given pedagogical need. In general, the lectures were slide presentations. This mode of teaching was the one to which the students were most accustomed. We would engage the students by soliciting questions and answers, taking breaks, and integrating the hands-on activities. In all lectures, there was a minimum of content that needed to be covered and getting "side-tracked" by the students' interests was completely acceptable.

[3]`http://space.mit.edu/~kcooksey/teaching.html`.

Table 1. Curriculum Components

Title	Length hrs	Length mins	Brief Description
Lectures			
Overview & Introduction	–	45	History of cluster and affiliation with CfAO; course topics, schedule, and expectations.
Our Place in the Universe	2	45	Taxonomy of Universe—solar system to super-clusters of galaxies; astronomy jargon.
Telescopes	1	–	Refracting and reflecting telescopes; telescope size, sensitivity, and resolution.
CCDs	1	–	How charge-coupled devices (CCDs) work and are used in astronomical observing.
Astrophysics I: Cosmology	1	45	Formation, evolution, and projected future of Universe.
Adaptive Optics	1	–	How adaptive optics (AO) systems work and are used in observing.
Astrobiology	1	30	Short video about variety of life on Earth; discussion on definition of life and habitability of planets.
Astrophysics II: Stars	1	45	Formation and evolution of stars of different mass.
Hands-on Activities			
Telescopes	–	20	Explore properties of refracting telescopes with hand-built cardboard telescopes.
Telescopes & Optics	3	–	Explore telescope optics with cardboard telescopes, lenses, mirrors, and ray boxes.
Human CCD	–	30	Mimic CCD functions (from receiving data to reading it out) with students with buckets as pixels and confetti as photons/electrons.
Lick Observatory Field Trip	9	–	Tour astronomical observatory, attend history lecture, and observe with 36” refractor.
Color, Light, & Spectra (CLS)	1	30	Learn about continuous, absorption, and emission spectra with spectrographs and continuous and emission sources.
Night-Sky Observing	2	–	Observe objects with small telescopes and naked eye at UCSC.
Remote Observing (each group)	1	–	Observe objects with Lick Observatory 1-m telescope from UCSC, for small-group research projects.
Inquiries			
Optics Inquiry	5	45	Investigate properties of light and simple optics (see Raschke et al., this volume).
Color, Light, & Spectra (CLS) Inquiry	5	45	Learn about continuous, absorption, and emission spectra with spectrographs and continuous and emission sources.

While potentially open-ended, the hands-on activities were typically structured around clear instructions and represented another comfortable endeavor for the students. On the other hand, each inquiry activity was designed to subtly guide the students through a full, self-motivated scientific investigation, from defining a question to sharing results. Raschke et al. (this volume) describes in detail an inquiry used by Cluster 7. Students were least likely to be previously familiar with the inquiry style of learning, and this was taken into account in designing, scheduling, and implementing the inquiry.

3. Example Schedule: 2007

In 2007, "Cluster 7: Stars and Cells" featured our astronomy course and a partner biology course. In this section, we detail the astronomy course curriculum and explain the rationale. The four-week schedule is outlined schematically in Figure 1.

There were two perspectives on the goals of the astronomy course: the students' and the instructors'. The students chose Cluster 7 to learn about astronomy and/or biology; their goal was content-oriented. The astronomy instructors wanted to develop the students' abilities to think scientifically, which would benefit them in any career, though we emphasized science careers; our goals were process- and motivation-oriented. We engaged the students in the processes of doing science in the content area(s) in which they were interested; they had to learn specific content in order to successfully advance throughout the course and to succeed in their small-group research project. As mentioned in §1, all COSMOS students undertake a research project, and Cluster 7 has emphasized this (by devoting time and resources—essentially the last two weeks of the program) more than other clusters. In 2007, the projects included Variable Stars,[4] Galaxy Morphologies, and Astrobiology.[5] These projects drew heavily on previous course content. (Other projects developed for other years of Cluster 7 include Globular and Open Star Clusters[6] and Planetary Nebulae.) The research projects were a synthesis of content and processes from the astronomy course.

Since part of the students' final success was giving an outstanding presentation on their research projects, we wove into the course opportunities for the students to practice giving talks. They gave short presentations on a recent Astronomy Picture of the Day.[7] Then their peers gave specific compliments and critiques. Also, our inquiry investigations required short presentations; the transferable skills course and partner biology course also incorporated practice presentations.

In 2007, we had 17 students from 13 different schools. The importance of icebreakers, bonding, setting the right initial tone, etc., cannot be overstated. On Opening Day, the whole cluster—instructors, project advisors, teacher fellow, resident assistants, and students—gathered and began getting to know each other.

The first astronomy "lecture" was a simple introduction to Cluster 7 and an overview of the next four weeks. This was the first formal opportunity to influence how the students *should* participate in class. We introduced one of the main course themes: all astronomers have to study is light; we used this as a vehicle to encourage questioning,

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[4]Documentation for the 2004 version of the Variable Stars project can be found at `http://space.mit.edu/~kcooksey/COSMOS/varstars04.html`.

[5]For details about the 2007 Astrobiology project, see Quan et al., (this volume).

[6]More details about the 2005 versions of the Globular and Open Clusters projects can be found at `http://www.ucolick.org/~kirsten/COSMOS05/index.html`.

[7]`http://apod.nasa.gov/apod/`

Time	Monday	Tuesday	Wednesday	Thursday	Friday
Week 1					
09:00–10:00	COSMOS Lecture		COSMOS Lecture		Transferable Skills
10:00–11:00	Overview & Intro.	Our Place in the Universe		Biodiversity & Natural History Museum Tour	
11:00–12:00	Overview & Intro.		Transferable Skills		Telescopes
13:00–14:00					CCDs
14:00–15:00	Transferable Skills	Geologic Time & Mass Extinction	Evolution & Natural Selection	Telescope & Optics	Astrophysics I: Cosmology
15:00–16:00	COSMOS Session		COSMOS Session		
Week 2					
09:00–10:00	COSMOS Lecture	AO	COSMOS Lecture		
10:00–11:00					CLS Inquiry
11:00–12:00	Transferable Skills	Astrobiology	Transferable Skills		
13:00–14:00				Fossil Hunt Field Trip	
14:00–15:00	Population Dynamics	Lick Observatory Field Trip	Fossil Marine Mammals		CLS Inquiry (cont.)
15:00–16:00	COSMOS Session		COSMOS Session		
Week 3					
09:00–10:00	COSMOS Lecture		COSMOS Lecture		Project Time
10:00–11:00	Transferable Skills & ***Project Selection***		Transferable Skills	Project Time	Transferable Skills
11:00–12:00					
13:00–14:00		Pelagic Field Trip			
14:00–15:00	Marine Life of Monterey Bay		Astrophysics II: Stars	Project Time	Project Time
15:00–16:00	COSMOS Session		COSMOS Session		
21:00–23:00	Sky Observing	Remote Observing			
Week 4					
09:00–10:00	COSMOS Lecture		COSMOS Lecture		
10:00–11:00	Transferable Skills	Project Time & ***College Counseling***	Transferable Skills	Project Time	Presentation Day
11:00–12:00					
13:00–14:00		College/Grad. School/Life			
14:00–15:00	Project Time		Project Time	Project Time	Presentation Day (cont.)
15:00–16:00	COSMOS Session	Reunion Picnic	COSMOS Session		

Figure 1. Schematic of "Cluster 7: Stars and Cells" 2007 schedule. The astronomy course components (*blue*) are described in Table 1; the "Remote Observing" activity on the third Tuesday is shaded as small-group research project time (*red*). Research time blocks are labeled generically except for when there was college counseling (fourth Tuesday). Similarly, Transferable Skills sessions are not described (*yellow*) except for the project selection event (third Monday). The partner course was ecology and evolutionary biology and paleontology (*green*). COSMOS-wide activities are shown (*gray*) though the lunch hours and evening break are just thick (*gray*) lines. Events that extended beyond the time shown are indicated by dashed lines. In the last week, part of an afternoon was for the whole Cluster 7 (*tan*). Presentation Day (*not shaded*) included Cluster 7 and two partner clusters.

participation, and risk-taking. In this case, we showed a full-color astronomical image and had students make observations and ask questions about the image. We shared what astronomers observed and how they interpreted the image. The "Overview and

Introduction" lecture thus introduced content and processes and set expectations for the class: be curious, ask questions, and be respectful of others.

The first content-full lecture was "Our Place in the Universe," where we explored the taxonomy of the Universe from the solar system to super-clusters of galaxies. This was the only lecture where galaxies were discussed, and we set the seed of interest for the Galaxy Morphologies project here.

To address the overarching theme that "all astronomers have to study is light," the course placed importance on the tools of astronomy: telescopes, charge-coupled devices (CCDs), and adaptive optics. Since it was early in the course, we designed a guided activity ("Telescopes & Optics") where the students introduced themselves to simple refracting telescopes and how optics work. We emphasized that the students were to explore what interested them with the materials given. The process of understanding a multi-component, multi-property system (refracting telescope) was divided into a few steps, within which there was freedom to come to one's own understanding. After about an hour of small-group investigation, the students informally shared with the class their understanding of lenses, light, and telescopes.

The day after, there was a short traditional lecture,"Telescopes." We reviewed what the students taught themselves and each other the previous day. Then we built upon that to teach how reflecting telescopes work. The formal presentation of ray tracing was intended to codify the students' understanding of how lenses and mirrors bend light and form images. Some students preferred the lecture format, so addressing this material in two different ways helped assure that expertise was distributed equitably.

Once the students learned how astronomers collect light with telescopes, the next step was to teach how data are collected. The next lecture was "CCDs," which included the "Human CCD" activity. Since verbally explaining how CCDs function was difficult, we had the students work as a group to mimic a CCD receiving photons and reading it out ("bucket brigade" style) to reconstruct the image. The bucket and confetti "Human CCD" was a robust analogy that allowed us to run through a variety of properties of CCDs. It is also a very fun activity!

The "Astrophysics I: Cosmology" lecture/discussion followed. It was an ideal topic to break the flow. This was about the end of the first week, and the students were generally tired, but the topic of the formation and evolution of the Universe was very enticing. The "lecture" followed their questions to the topics that interested them.

The two most important events of the astronomy course occurred in the second week: the observatory field trip and the inquiry activity. Since an adaptive optics (AO) system is part of the observatory tour, prior to the field trip was the "Adaptive Optics" lecture. After this lecture, the astrobiology project advisors led the "Astrobiology" class discussion, beginning with a compelling video on the diversity of life on Earth, including organisms that live in extreme environments (see Quan et al., this volume). From this starter, the class together defined life and tied extremophiles to the possibility of life on other planets. The students had read an article explicitly on extremophiles to bolster their knowledge of the topic. This lecture planted the seeds for students' interest in the Astrobiology project, similar to what "Our Place in the Universe" did for the Galaxy Morphologies project.

The field trip to Lick Observatory on Mt. Hamilton consisted of: a long, winding drive, which has always proven to be valuable unstructured time between instructors and students; a tour of the many telescopes on the mountain; a picnic dinner; a history talk about the Observatory; and observing the sky by eye and with a telescope. On the field trip, a hint was planted for the Variable Stars project.[4] Extrasolar planets are a main research theme at Lick; one detection method is the decrease in the brightness of the host star when the planet eclipses it. The beginning of the Variable Stars project relies on the students remembering this (or the project advisor facilitating the students remembering). On the field trip the students also visited and learned about the 1-m telescope that the astronomy research projects used to collect data.

In 2007, the showcase inquiry was the "Color, Light, & Spectra (CLS) Inquiry." This inquiry, originally created for undergraduates, was re-designed for high school students by four CfAO PDP participants; three facilitated the inquiry. The main content goals were: light is composed of all colors, and there are three kinds of spectra. The facilitators (instructors) intertwined this content with scientific reasoning skills in the inquiry, because the students would utilize both during research project time. All of the projects relied on the students using the different colors of their astronomical objects to gain understanding of the underlying physics. We also wanted the students to complete an investigation before they moved into project time. Here again was an opportunity to practice giving a presentation.

The first day of the third week was project selection day, when the research projects were presented and students ranked their selections. The instructors sorted the students into groups largely based on the students' rankings but also with consideration for the small-group dynamics, an easily-overlooked point that was very important. Since the instructors handled the sorting, they ultimately decided who might make good groups without openly exposing this to the students. This was in contrast to an earlier lottery-style assignment process, wherein instructors must either abide by the students' choices or make an obvious (and potentially regrettable) intervention on-the-fly.

We scheduled an optional night-sky observing excursion for that evening. On the following evening, the astronomy research project groups, Variable Stars and Galaxy Morphologies, met for "Remote Observing" using the 1-m telescope on Mt. Hamilton, from the CfAO conference room. The students were in communication with the astronomer (their Lick tour guide) at the Observatory, who assisted in the observations. The remote observing capabilities gave students the identical experience of any astronomer, a point which we emphasized to reinforce the students-as-scientists theme.

The last astronomy lecture was "Astrophysics II: Stars," which built heavily on the CLS Inquiry content. The main points were: short-lived massive stars are hot, bright, and blue, and less massive stars are the opposite (cool, faint, and red). The Galaxy Morphologies project relied and expanded on these principles.

For the last week and a half, the students focused largely on their research projects. However, our cluster also planned several bigger-picture elements to break up this research time and address extremely important topics. Early in the last week, we organized a UCSC admissions counselor to review and discuss the students' transcripts. The counselor suggested what classes to take and grades to aim for, in order for the student to qualify for acceptance to UC. This individual attention and analysis was not necessarily the sort that our students had received or could receive at their schools (see §1 for details on student selection). The students met with the counselor in groups of two to three, by grade. This divided the research groups, so the project advisors had to account for this. Any students who felt reserved about their transcripts met with the counselor individually.

The same day Cluster 7 met for a "college/graduate school/life" overview and panel discussion. The overview part was a summary of the steps from high school to graduate school and suggestions for along the way (e.g., where to find scholarships). Then, we made four groups of students and staff and spent one and a half hours fielding questions and sharing experiences. We mixed up the students in the groups half way through to increase the interactions. Since many of our students would be the first college students in their families, they had many questions, worries, and uncertainties about pathways to, through, and from college. After all the talk about the future, the students had a chance to "meet the future" via the annual Cluster 7 reunion picnic on the beach. We invited all previous Cluster 7 students and staff to share how the COSMOS experience played out afterward.

The last academic day was Presentation Day. Cluster 7 has always performed exceptionally well on Presentation Day because the project advisors devoted significant time to working on the presentations with the students. As the students developed and practiced their group presentations, we were assessing what they understood in order to teach any final points and to evaluate our success as teachers.

4. Motivating Alternative Schedules

From 2001 to 2006, Cluster 7 was known as "Stars, Sight, and Science" and was a pairing of astronomy and vision science courses. The original astronomy course was designed in conjunction with the vision science course, and we made choices about the astronomy components in light of what would also be beneficial for both. The 2007 schedule largely contained the same astronomy components in the same order. Changes were made to accommodate the new partner course and incorporate newly designed activities. Here we rationalize some of the key differences in the schedules.

The main differences in the "Stars, Sight, and Science" schedule were as follows: there were no "Cosmology" or "Astrobiology" lectures/discussions; we had an "Optics Inquiry;" we used the "Telescopes" activity in the "Telescopes" lecture; and CLS was a hands-on activity instead of an inquiry (see Figure 2).

There was more time for astronomy lectures in the 2007 schedule since there was one less field trip and less research project time. There have always been three main field trips; in 2007, they were Lick Observatory, a pelagic boat tour, and a fossil hunt. In the years of "Stars, Sight, and Science," the last two trips were to the Berkeley School of Optometry and a science museum, the Exploratorium. A fourth field trip, to the Mystery Spot, tied in with the visual illusions taught. During the field trips, students were introduced to professionals who were using and/or doing what the students were learning and/or doing. They also provided important unstructured time for student-staff interactions, but the loss of one trip was necessary due to budget constraints. To compensate, we had a picnic on campus and a short tour of the UCSC Lab for Adaptive Optics. We learned that the picnic was not a good choice, since the students preferred eating in the dining hall where they caught up with their friends from other clusters. This was a lesson in coordinating with the larger program. The Lab tour had the benefit of allowing the students to see a simple AO system (Harrington et al., this volume).

There was less project time in 2007 because the other course elected to cover more material than the previous vision science course. Supporting the needs of the research projects was a priority and affected the final schedule, including an entirely new "Astrobiology" lecture in 2007. That year there were five students participating in the Astrobiology project. This project was designed specifically for the 2007 Cluster 7 (Quan et al., this volume); it acted as unifying topic to the two courses.

Time	Monday	Tuesday	Wednesday	Thursday	Friday
Week 1					
09:00–10:00	COSMOS Lecture	Our Place in the Universe	COSMOS Lecture	Telescopes	Cluster Sleep In / Structure of Eye
10:00–11:00	Overview & Intro.		Optics Inquiry (cont.)		
11:00–12:00	Overview & Intro.			CCDs	Bovine Eye Dissection
13:00–14:00	Transferable Skills	Optics Inquiry	Optics Inquiry (cont.)	AO for Astronomy	Transferable Skills
14:00–15:00	COSMOS Session		COSMOS Session	Lick Observatory Field Trip	Color, Light, & Spectra
15:00–16:00					
Week 2					
09:00–10:00	Holiday	Astrophysics: Stars	COSMOS Lecture	Project Time	AO for Vision
10:00–11:00		Optics of Eye I	Visual Illusions	Berkeley School of Optometry Field Trip	
11:00–12:00					
13:00–14:00	Holiday (cont.)	Optics of Eye II / Diseases of Eye	Color Vision		Transferable Skills
14:00–15:00					
15:00–16:00		Transferable Skills & ***Project Selection***	COSMOS Session		Project Time
21:00–23:00			Remote Observing		
Week 4					
09:00–10:00	COSMOS Lecture	Project Time & ***College Counseling***	COSMOS Lecture	Project Time	Project Time
10:00–11:00	Visual Illusions Inquiry		Project Time	Transferable Skills	
11:00–12:00					
13:00–14:00	Transferable Skills	Project Time	Transferable Skills	Exploratorium Field Trip	Transferable Skills
14:00–15:00	Project Time	College/Grad. School/Life	COSMOS Session		Project Time
15:00–16:00		Reunion Picnic			
21:00–23:00	Remote Observing				
Week 4					
09:00–10:00	COSMOS Lecture	Project Time	COSMOS Lecture	Project Time	Presentation Day
10:00–11:00	Project Time		Project Time		
11:00–12:00					
13:00–14:00	Project Time	Laboratory for Adaptive Optics Tour	Transferable Skills	Project Time	Presentation Day (cont.)
14:00–15:00	COSMOS Session	Being a Scientist Discussion	COSMOS Session		
15:00–16:00					

Figure 2. Schematic of "Cluster 7: Stars, Sight, and Science" 2005 schedule. The color coding is the same as used in the 2007 schematic (Figure 1), except the 2005 partner course was vision science (*green*). Though this schedule had a fairly distinct "astronomy course week" (first) and "vision science course week" (second), the whole Cluster was more cohesive due to the extensive collaboration between the astronomy and vision science instructors, all from the PDP community, during the curriculum design. In addition, there was more topical cohesion since both courses taught about optics, color, and adaptive optics.

When paired with vision science, we used the "Optics Inquiry" instead of the CLS Inquiry since a good understanding of optics would support the astronomy and vision science content. For 2007, we modified the Optics Inquiry into the "Telescope & Optics" activity to convey similar content and to retain elements of the students investigating on their own. The color, light, and spectra content was more fundamental to all of the astronomy research projects, so when we were not paired with vision science in 2007, we chose the CLS Inquiry as the only inquiry activity. With even more astronomy projects (the two Star Clusters projects[6] and Planetary Nebulae), the CLS content would be even more fundamental and drawn upon in project time.

Another substantial difference between the 2007 schedule and prior years' was the distribution of the astronomy and other courses' time blocks. Setting the schedule was an iterative process. Important scheduling constraints came from the COSMOS-wide office, the staff's availability, the field trips, and time-sensitive observing (i.e., Variable Stars project[4]). But the observing had to come after the students learned about astronomical observing. The astronomy project groups also needed the data early in their projects, so observing could not be arbitrarily late in the four weeks. When paired with vision science, the astronomy course was scheduled to fit mostly in the first week, leaving a vision science block for its non-UCSC instructor to schedule travel around.

There were down-sides to isolating the astronomy course to the first week and the vision science course to the second. By project selection time, the students had more vision science on their minds. We also taught the astronomy content at an accelerated rate to make a basis for the Lick Observatory field trip. The more interwoven schedule described in §3 was useful in preventing burn out. The switching between instructors and topics gave the students more times to let what they learned settle. The trend in scheduling Cluster 7 from 2005 to 2007 was to compact project time in order to minimize the time the project advisors were involved because they were typically busy graduate students.

However, with the partnership of astronomy and vision science came significant benefits: extensive collaboration during curriculum design; cohesive teaching practices; and shared content. As mentioned previously, Cluster 7 was originally developed by astronomers and vision scientists, educated and trained by the CfAO PDP. In addition, optics and properties of light (e.g., color) are fundamental content for both sciences, and adaptive optics is a cutting-edge research field in astronomy and vision science, which is why the two fall under the purview of the CfAO.

The overall flow of Cluster 7 was similar to an inquiry. Dividing into small research groups for the last two weeks of the program had everyone focusing on their own investigations. In 2006, we designed a cluster "synthesis" for astronomy. We facilitated small groups in organizing their astronomy content into a concept map. We wanted the students to think about the big picture and place what they had learned in it. This activity also allowed us to assess what the students had retained from different aspects of the course and how they prioritized the information.

5. Discussion

The curriculum components were a mix of slide-based lectures, hands-on activities, and inquiries. The content taught with any given component could be conveyed, at least in part, by another format. Indeed, the topic of telescopes was taught through a combination of lecture, hands-on activity, and inquiry over the years, as needed to meet changing goals.

Mental and physical fatigue is a concern for a long, intensive program like COSMOS. We tried to build in breaks by switching between formats. We also scheduled less intensive, student-driven lectures amidst the more formal, content-driven lectures. Field trips are partially mental breaks but they are physically draining. Also, the students do not necessarily like missing meal times when they could visit with their friends from other clusters. In the earlier years of the cluster, under the umbrella of the CfAO, the astronomy and vision science courses cooperated more on content, process, and motivation themes. Due to scheduling constraints, the two courses were separated, and this made the cluster more intense and fatiguing. The scheduling of “Stars and Cells” was less fatiguing, and learning benefited from spreading ideas apart.

The curriculum components of the astronomy course are readily integrable into other astronomy courses. The hands-on and inquiry activities are especially useful tools that motivate the students to learn on their own and gain their own understanding. As was done with the optics inquiry and the telescope and optics activities, the longer activities can be scaled down in time, at the expense of some goals.

In talking with previous Cluster 7 students, via email or when they end up attending UCSC for college, all emphasize the companionship of COSMOS (residential life) common to all clusters. Our cluster’s extensive field trips (more than other clusters), and the small-group research projects—each of which benefit enormously from excellent student-to-instructor ratios— come up next. The course’s connection with the PDP community has been an integral part of its success.

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