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Astronomy, Technology, and the Scientific Method: Reflections on the Astronomy Research Seminar at Stanford Online High School, Spring 2018

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Abstract
This article presents lessons learned and reflections on the scientific process from teaching two sections of the Astronomy Research Seminar at Stanford Online High School in Spring of 2018.

Keywords
Scientific Method — Online Learning — High School

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Introduction

Stanford Online High School (SOHS) does not fit the picture that most people have of online education. Unlike large, anonymous, Massive Open Online Courses (MOOC's), SOHS classes are small and synchronous. We meet online twice weekly in seminar groups of no more than 16 students. Students are marked tardy if they are late, and are graded on their participation in the live discussion. We have an active community of intellectually passionate students, many of whom are engaged in significant outside pursuits. In this context, a "significant outside pursuit" has a large associated time commitment that would make participation in a brick-and-mortar school difficult. SOHS is home to dancers, actors, equestrians, musicians, and athletes of every description. Although classes meet online, there are several in-person meetups and activities that take place throughout the year. Figure 1 shows some students getting together to solve puzzles on an astronomy-themed spring break trip that took place in March of 2018.

It is in this context that I initiated the Astronomy Research Seminar in spring of this year. I preceded the official course with two extracurricular pilot projects on double stars and eclipsing binaries, as proof of concept that extended research projects process were possible in this environment with these students.

Course Structure

Like all SOHS science courses, the Astronomy Research Seminar met twice weekly for 70 minutes per meeting. However, the two sections that I taught were very different. One of the sections was taught through the Malone School Open Network (MSON), a consortium of independent schools throughout the United States, of which SOHS is the sole wholly-online school member. The MSON section consisted of only four students, from three different schools. This group decided to take on a double-star research project all together, as a single section, and they completed a compare-contrast study of four different star systems. Because I was in attendance for the entirety of all of their project group meetings, I took an active role in leading and organizing the project. This group finished and submitted their

Figure 1. Stanford Online High School students during a 1 week astronomy-themed spring break trip in March 2018, unlocking a box at the end of a solar system treasure hunt

paper early in the spring, and we spent the remaining weeks of the semester doing small side projects, not for publication.

The second section, from SOHS, had 13 students, split into 5 teams. Three of the teams did double-star projects and two did eclipsing binary projects. Almost all of the section meeting time took place in project breakout rooms, with me popping in on as many breakouts as I could during the 70-minute class meeting. As a consequence, roughly 4/5 of each project's group meeting time was completely self-directed by the students. Only one of the groups from this second section finished early, and at the time of this writing, some of the groups are still completing their projects.

0.1 The Efficiency of Self-Directed Projects

There are several reasons for the decreased efficiency of the self-directed SOHS project groups. First, students do not have enough experience with astronomy research to determine the best way forward in a scientific project. "What should we do next?" was the most common question I heard when I visited their breakouts. Although there is rarely one right answer to this question, the students didn't know any of the possible answers, and often spent significant time discussing ideas that were unworkable for one reason or another, or sending each other off on impossible quests for information or measurements. Additionally, the lack of a clear project lead within each group, and the reluctance of students to hold their peers accountable for contributions to the project, made for a slower pace. Because of the many, known difficulties with group work in educational environments, I made each student's weekly grade dependent on a writeup of their individual project contributions, which was submitted directly to me. (This is something that I'd like to change for next year, because it proved difficult to assess. At the time of this writing, I remain unsure how best to adjust the metric.) In any case, although the SOHS groups made slower progress and spent considerably more time flailing than the MSON group, their learning experience was a more authentic representation of actual science. At least, that's what I'm telling myself.

The Scientific Process in Research vs in Introductory Classes

Over the course of the semester, I found myself reflecting often on the scientific process and the ways in which actual research differs from the picture we paint for students in introductory science classes. A quote from Joe Madeiro, JPL engineer, encapsulates some of these disparities. Dr. Madeiro spoke to our group during the astronomy spring break trip referenced above.

"Anytime you do a new astronomical survey you get new data, and you find new things: things you can't anticipate. . . . When you build a new telescope, you have to have a reason to build it. You can't just build it because it 'feels right'. But you should know that of the reasons you build something, maybe half of them won't be interesting anymore by the time it gets built. However, 10 times as many more things will come along that you could never have anticipated. A survey was done with the Hubble Space Telescope, which was proposed in the 60's and 70's, finally launched in the 80's or 90's, repaired, etc. When Hubble was built there were 10 main goals that they wanted to accomplish. Later they asked themselves, "How have we done with the original goals, and what are the most impactful things that have come out of this?" And three or four of the original goals turned out to be, as expected, some of the main science that has ever come out of Hubble. But, 7 of the top 10 goals were not in the 'most impactful' list." (Madiero, in person talk in Pasadena, March 2018)

My takeaway from this is that in real science, you have to be open to pursuing other paths than the one upon which you originally set out. The experiments that we do in most of our science classes run counter to this, because we grade students on their answers to a specific question. If the lab asks you to cushion the fall of an egg, you will not get credit for investigating the optical properties of the saran wrap you used, even though this might ultimately be more interesting or impactful than the experiment that was assigned. At best, we'll give you a nod and a "hey, that's cool" but as instructors, what we will think hard about and assess and give meaningful feedback on is the efficacy of your egg cushion.

This is how it has to be in an introductory setting because 1) there are not enough hours in the day for instructors to guide 60 students pursuing 60 different experiments, no matter how awesome these might be, 2) students (mostly) don't yet have the knowledge and experience to be able to predict whether the topics they want to investigate have the potential to bear real scientific fruit, and 3) instructors would get complaints about "lack of clarity" for including open-ended goals their lab protocols (ask me how I know). So, it would be impossible to completely replace traditional labs with indiscriminate experimentation for purposes of a normal class, though we can take little steps like encouraging procedural creativity within constraints and encouraging students to keep track of their tangential ideas in sidebars (e.g. requiring a "Notes for Future Research" section).

While the place of student innovation in classroom lab experiments is limited at best, this sort of inventiveness plays a huge role in the scientific enterprise. Real, impactful science depends on scientists' being ready to intentionally study different, more interesting questions than the ones they set out to ask. It would be difficult to train students to "keep their eyes open" the way they would need to do as scientists. But, we do them a disservice in pretending that the cycle of hypothesis - data - conclusion they follow in traditional lab experiments mimics the way science is actually done. Concentrating on cushioning the egg instead of sidetracking into the nuances of how saran wrap interacts with light is what students must do in order to earn an A in our classes, but in "real life", the scientist should find a way to pursue the plastic optics experiment in addition or even instead.

Students who succeed in the artificial environments we create with classroom lab experiments are often not the ones who succeed in real world problem-solving environments, where the questions are less well-defined and the answers are murkier. Indeed, studies have found an inverse relationship between "students' reported GPA and their orientation toward creative or innovative work", which is why Google and other companies no longer ask for transcripts when hiring employees (Gray 2016). As an instructor, I sometimes encounter indignation when I ask students to solve problems creatively. For example, if I set the task of figuring out a way to measure the volume of a system or deciding how to present numerical data graphically, I might be told that my protocol was confusing or that it was not clear "what we were supposed to do." Students who are apprehensive about taking intellectual risks in these sorts of limited-scope situations will be even less willing to be creative about which questions to ask in the first place.

In summer of 2018, I took an astrophysics and fusion teacher workshop at Lawrence Livermore National Laboratories, and on one of the days we toured the Jupiter laser facility. The physicist who took us around explained that research groups come from all over the world to use the lasers there. He said that often the equipment does not function as expected or intended, and groups have to find a way to make productive use of the valuable beam time that they secured for their project. In some cases, they end up doing completely different science, simply because of which lasers are functioning at the time of their run. Groups that can roll with the punches, troubleshooting and fixing things and finding alternatives to their original goals, are (in his words) "the ones we want", because those researchers eventually become the most successful scientists.

This seems to be a common theme, and it calls to mind the many twists and turns of my Astronomy Research Seminar projects this semester. For the eclipsing binary projects, we sidetracked into an exploration of various photometric methods, invented ways of classifying images before analysis, and investigated multiple period-finding algorithms instead of determining the temperature of the system as we had originally set out to do. For the double star projects, we became deeply entangled in coming up with a mathematical technique to infer the proper motion of a secondary star from that of the primary plus the secondary's relative motion. We also sidetracked into understanding how to use an "improvement parameter" (invented by the course TA) to assess trends in the residuals of an orbital solution (Crigler et al. 2019).

Particle physicist Don Lincoln has a video in which he says: "Without transistors, the computer revolution would have never happened. Without particle accelerators, there would be no radiation treatment for cancer. Without the development of large accelerators with superconducting magnets, it would have been a long time before medical MRI magnets would have been available. Even more recently, particle physicists can point to the World Wide Web, which was originally designed to facilitate communication between researchers . . . ". Lincoln cites these examples to make the point that particle physics is worth funding. And it is certainly true that these advances would not have happened without particle physics. But more importantly, they would not have happened if the particle physicists had been constraining themselves to answer only the questions they were asking about the subatomic particles they were studying.

I think it is important to emphasize to students that in our classroom lab experiments, we are teaching them scientific techniques, but we are not "doing science". We are giving them practice with having a guiding question, just as the designers of the HST had clear questions that they hoped to use the telescope to answer when it was launched. But, we are not giving them practice with the fundamental and ultimately more important skills of being creative and being able to decide when to purposefully switch gears, asking different questions and making connections that are tangentially (or not at all) related to the original phenomenon under study. For purposes of the introductory classroom, we must insist that students stay focused on the assignment and answer the original question because we are teaching them to use specific tools. But we should be clear with students that if a chemistry lab involves a titration, the learning goal is “how to do a titration,” not “how to do science”.

Unlike other classes I’ve taught, the learning goal for the Astronomy Research Seminar is “how to do science”. The students who have accumulated the most tools from previous math / science / CS classes often have an advantage; they can make the most connections because they have the biggest reservoir of prior experience to make connections between. But more important is the ability to be self-directed, and this is not a skill that is honed by make-a-measurement, learn-a-skill labs. As a consequence, students become uneasy and frustrated by tasks that are not clearly-defined, setbacks that are unforeseen, and circumstances make the original goals difficult or impossible to achieve. In truth, scientists become frustrated by such things also. The difference is that they do not view the difficulties as inappropriate. The outlook changes everything.

Every single one of my Astronomy Research Seminar projects this semester veered off-course from the direction taken at the outset. The distractions took various forms, but they all had them. We certainly did not made the best possible choice of sidetracks in all or even most cases. Were we to start over, I would advise doing things differently in pretty much every project. That is the nature of the beast. I was fortunate that the 13 students who signed up for my first semester of teaching the Astronomy Research Seminar were (for the most part) students who could handle the uncertainty, though many of them did tell me that it represented a sharp departure from science classes they had taken in the past.

Just to be clear, I’m not suggesting that we completely replace traditional science labs with self-directed experimentation of the Astronomy Research Seminar variety. The skills that are developed by means of traditional labs are important, and students need as many tools as we can give them. For example, they’ll never think to use a titration as a means of probing a system they are studying unless at some point they’ve had the make-a-measurement, learn-a-skill experience of doing one. So, we cannot and should not do away with these sorts of activities in our introductory science classes. We just need to be more explicit about what they are, and incorporate some more open-ended “real science” components into our introductory curricula where possible.

0.2 The “Scientific Method” as Commonly Taught and Practiced in Introductory Classes

In addition to differentiating classroom experiments from actual science, I believe that we should teach the scientific method differently. The scientific method is usually the first unit in a science class, and students snooze through it because they have been hearing about it since elementary school. It prefaces the make-a-measurement, learn-a-skill labs that they will be doing for most of the year and brushes aside the most important and most impactful part of those experiments: the slight adjustments that students end up making to the protocol to “get things working.” As a consequence, students completely omit these from their lab writeups.

For example, in a microbial fuel cell lab, yeast are suspended in a mixture of lime jello in order to test the voltage across the mixture. A student forgot to mix in the yeast, and the jello had set in the fridge before he remembered. He re-melted the jello, monitored the temperature, mixed in the yeast, and let it set a second time in the fridge. None of this was evident from his writeup. To all appearances, he had mixed in the yeast before the jello first set, as per the lab protocol. His voltage results were slightly different from those of other students in the class, but for lack of documentation, a reader would have no reason to suspect that any difference in his procedure might have affected this.

In a DNA extraction lab, a student initially did not have the correct concentration of alcohol, and tried the procedure with the lower concentration that she had in her cabinet. She was unable to see the extracted DNA, so she bought the higher concentration and tried that. At first, that didn’t work either. Eventually, she figured out that the alcohol wasn’t cold enough to crystallize the DNA, so she extended its time in the freezer and tried a third time. Ultimately, this was successful: she was able to see and photograph the strands of crystallized DNA on a toothpick. But once again, none of this appeared in her writeup. Reading her report, a reader would think she had done the experiment only once, using the recommended concentration of alcohol, and would not know how the time the solution spent in the freezer had been adjusted.

These examples represent work done by good students. They knew the "scientific method" and would ace any question about it that might come up on a test. I only know about the differences between their writeups and their actual procedures because they asked me to read drafts of their reports in office hours; in the course of doing so, I asked them questions about what they had done. They were surprised that I would be at all interested in these sorts of details and even more surprised when I insisted on including them in their writeups. And these are only two of many, many more examples of similar omission of "trivialities" that do not conform to the idealized picture of how science is done, which students bring to our classrooms and which we unknowingly reinforce with that first "scientific method" unit.

Students often come to my office hours to ask me to look over their lab writeups before they turn them in. I'll read it out loud to them, asking questions along the way. Every single time, asking questions reveals that their story is incomplete. There was some adjustment that they made due to their particular circumstances that they didn't think was "important" enough to document. Or, their first try "didn't work", and rather than analyzing it or even documenting it at all, they threw it away, did the experiment a second (or third) time, obtained the expected results, and documented that instead. The instances I know about from office hours are only the tip of a much larger iceberg. In passing on the class Skype group, in talking to parents at parent-teacher conferences, and on the last day of class when we share memorable moments from experiments done over the course of the year, I hear many more such stories.

With this mindset, Alexander Fleming would have thrown away his moldy petri dishes instead of looking closer, thinking harder, and ultimately discovering antibiotics. Darwin would have stayed focused on the plants he was studying rather than realizing that the mockingbirds on the islands he visited constituted an important clue to a different puzzle. Penzias and Wilson would have ignored the faint noise in their radio receiver rather than using it to track down the cosmic microwave background. And had they stayed true to "the scientific method," my student project groups would have foregone some of the most interesting science that they ended up doing in the Astronomy Research Seminar this past spring.

Proposal for More Effective Instruction in the Scientific Method

With our curricular focus on the experimental outcomes we anticipate, instructors unintentionally strengthen this tendency to dismiss unexpected results and tangential interesting questions. To counter this, I propose putting the "how science works" parts of the curriculum not as the first unit of a course, but in the middle, or even last, ideally after students have done some sort of self-directed project in which they experienced significant roadblocks or changes in direction. Many students come to our classes with a conception of the scientific process that we simply cannot dispel with citations of history or exhortations to include their missteps in their lab documentation. I've tried all kinds of gimmicks, from insisting that they troubleshoot a non-working circuit (even if their LED did light up the first time they put it together), to refusing to let them discount aberrant measurements without analysis, to assigning a point value to the documentation of an unexpected outcome. They'll do it if it is part of their grade. But, as soon as they are not earning points for it, initial missteps, tangential observations, and unexpected results suddenly and magically stop happening, because these do not fit the picture we have painted of how science is meant to be done. It is only after students have experienced a significant roadblock themselves that they stand to gain a deeper understanding of the importance of such hindrances.

As McDermott et al. write in Preparing Teachers to Teach Physical Science By Inquiry, "The scientific process can only be taught by direct experience." (McDermott et al. 2000) Experience enables one to arrange ideas more hierarchically and into fewer categories, because the connections between seemingly different ideas become more apparent (Knight 2004). We need to give students an authentic experience doing science before an abstraction of the scientific process will be meaningful. Starting with a hands-on experience or a discrepant event instead of the theory and explanation is a recommended approach for science instruction, because this gives students an experience to which to connect the underlying principles, and enables them to learn the explanations more deeply for having developed them themselves (Eisenkraft 2003). But even instructors who subscribe to this pedagogy for purposes of teaching students how springs work tend to start their courses with an abstraction about how science works, not noticing the disconnect.

In summary, I'm advocating moving most of the instruction about "how science works" from the beginning of courses to the middle or end, once students have done some actual science that is self-directed and open-ended enough to be more than a set of measurements. It is then that the stories about the scientific process throughout history will be meaningful, and it is then that students will be able to build a nuanced conception of how science operates, recognizing the often-neglected importance of documenting "mistakes" and changing the project goals. Such instruction might ultimately constitute a better preparation for taking on actual science projects, such as those in the Astronomy Research Seminar.

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A Glass Ceiling in AER?: A preliminary glimpse at the distribution of authors by gender in the iSTAR (istardb.org) database

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Abstract
In this article, we briefly summarise what information we have available about the distribution of authors by gender of articles contained within the international STudies of Astronomy education Research database (istardb.org). These articles represent a nearly, but not totally, complete population sample of published Astronomy Education Research. There are some indications, although lacking statistical power to decide if it is a true effect, that the top ten authors, first authors and authors by h-index have seen a slight increase in the proportion of women in the last 5 years compared to the all-time levels. Women have also submitted the majority of AER dissertations in the last 5 ($\sim 56\%$) and 10 ($\sim 52\%$) years compared to all time ($\sim 41\%$).

Keywords
Gender — Research Database — Astronomy

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Introduction

It was a cold, rainy day, during a lunch break at a conference. Three individuals of much astronomy education research experience were seated around a table in a hotel lobby discussing the pursuit of knowledge in the context of Astronomy Education. One a world-renowned cognitive scientist, the other two astronomers, however, all three with a shared passion for Astronomy Education.

To understand the complexity of the discussions, we must address one key definition "Astronomy Education Research" (AER), which is empirical and theoretical research into the teaching and learning of astronomy content across diverse settings. It is a discipline which traverses the boundaries of other traditional fields, for example: astronomy, education and psychology (Slater et al. (2016). Therefore, the individuals who work in the field of AER, are from a myriad of settings academic, industry, NGO and community organisations, which covers astronomers all the way to policy makers and beyond (Bailey and Lombardi (2015); Slater et al. (2015)).

Back to the hotel lobby, over pints of beer, glasses of red, cups of coffee, nachos and other nibbles, our three protagonists of AER, debated and philosophized, as to the nature of AER and how to accurately map and describe the landscape of the field. Although, they concurred that previous reviews of AER did exist, the actual content which gives life to the landscape, encompassing journal articles, grey literature, working papers, dissertations, resource guides, newsletter articles (like this one!), conference proceedings, books & book chapters, were spread across varying disciplines and a concerted effort would be needed to bring them together into one location A Great Library of AER, inspired by the Great Library of Alexandria, or an Agora of AER.

The cumulative skills of these three individuals, allowed them to instigate what was to be called iSTAR (International STudies of Astronomy education Research) (Slater et al. (2016)). A repository of AER in all its forms, from across the globe, thereby signifying that we live under a shared "sky", on a blue marble, whizzing around a middle-aged star, in a relatively "cool" galaxy.

We presented the current status of iSTAR, at the recent RTSRE & iNATS conference in Hilo, Hawai'i, a recording of the talk is available here. In this paper, we will present a brief overview of some of the pertinent aspects of iSTAR in the context of Women in Astronomy, so as to provide a comparison with the landscape of astronomy research. These are preliminary results that will be more fully expanded on in a future endeavour describing the field as a whole from the perspective of the literature. To keep informed about this article and other iSTAR information, please sign up to the newsletter here, or email the author.

Results

Over the years, iSTAR has grown to contain, or link to where appropriate, more than 1800 publications. These have drawn from major literature searches throughout the mainstream astronomy, astronomy education and science education journals, major conference proceedings and thesis collections. It is very difficult to estimate what percentage of the total real AER literature has been catalogued, especially as new articles and volumes are discovered fortuitously on a weekly basis. It can safely be claimed, though, that for the major publication locations for AER in the English Language, using a similar rationale to that outlined in Fitzgerald et al. (2018), it is largely complete and approximates a total population sample.

Any missing articles in this population sample are very likely to be either in low impact journals, rarer conference proceedings or in the grey literature. This will have minimal effect on the authors considered here who tend to publish in higher impact journals and have no effect on the Scopus h-index analysis as this index rarely includes anything other than long-established and manually vetted peer-reviewed journals, books and some higher-end conference proceedings.

Looking at the distribution of these articles over time, we see an increasing trend in publications over the years, with a major increase occurring in the year 2007 (Figure 1). The spikes in the distribution tend to be years where there are major conference proceedings, particularly those surrounding the IAU (Bretones and Neto (2011)), are released. Nearly 50% of the overall publications are journal articles, the other two major publications are conference proceedings/book sections and dissertations, respectively (Figure 2).

We have pulled out of the database what frequencies we have on publication rates by gender and crossmatched these to h-indices available in the literature or calculable via Publish or Perish (Harzing (2010)) or SciVal. Google Scholar is usually seen as a better indicator of true h-index for education researchers (Harzing and Alakangas (2016), whilst Scopus is more often used in appraisals for promotion at various institutions. Whilst h-index isn't a good indicator of the inherent *quality* or *impact* of the research undertaken by a researcher, especially in education, it is certainly an indicator of whom is citing whom, which, in this short preliminary article, is of more concern.

In our analysis here, we mostly consider all time performance as compared to performance within the last 5 years with a few extra added statistics of interest. This allows a rough glimpse at what direction the statistics are taking over time and which way things seem to be trending. We are prevented from taking a more fine-grained analysis due to small number statistics. There are only 119 authors

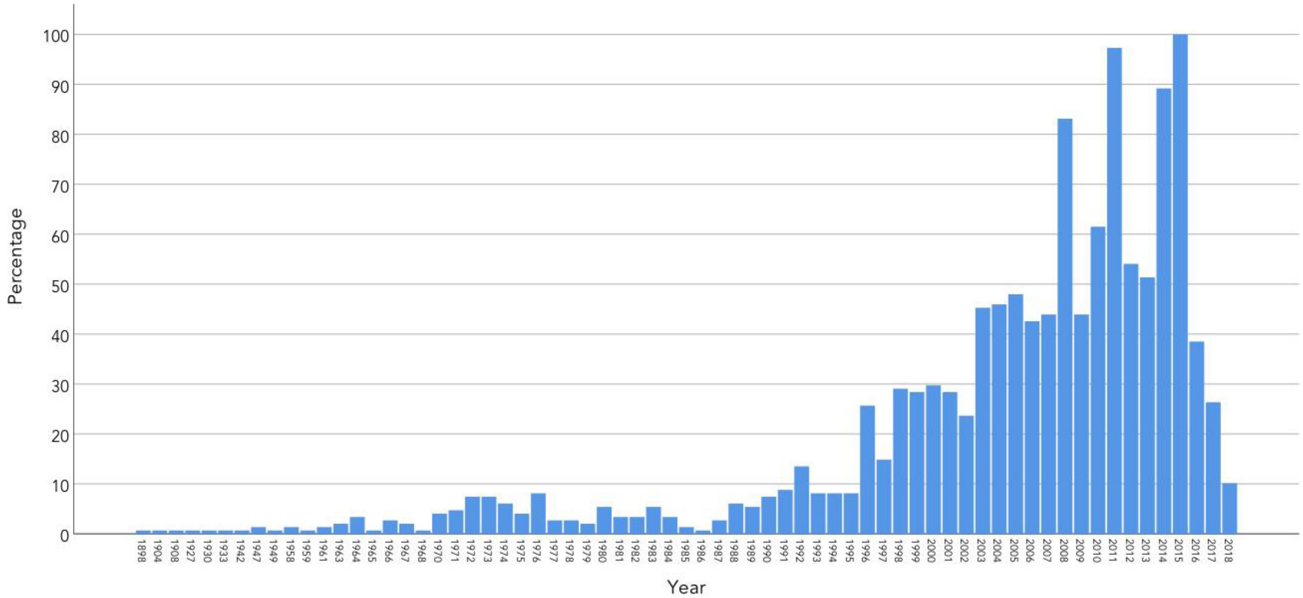

Figure 1. Relative percentage of publications over the years starting at 1898, where 2015 is 100%

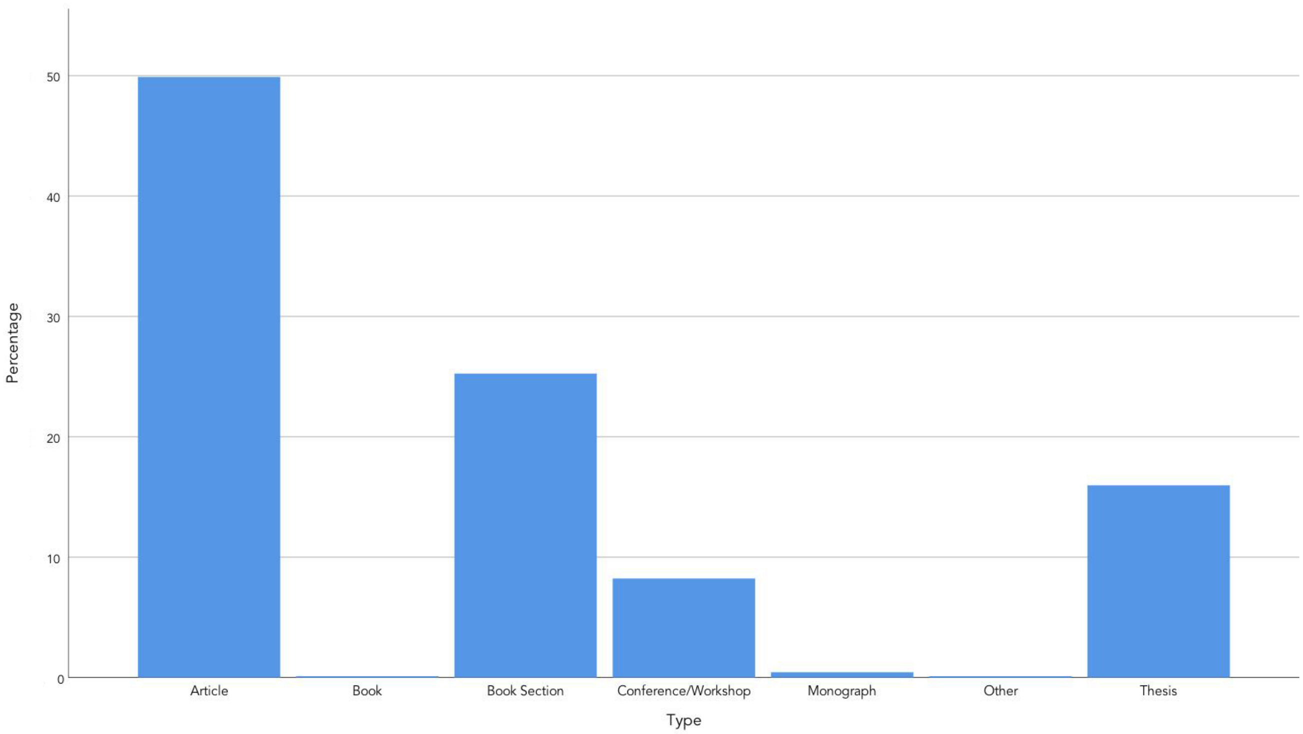

Figure 2. Percentage of publications by type

who have published in the AER literature more than three times with only 30 authors having 6 or more articles in AER. Most authors publish in multiple domains, including Physics Education Research, General Science Education and mainstream Astronomy.

The results for the following discussion are visually represented in Figure 3. In terms of number of articles published by first authors, there were 3 women in the top ten authors in the past 10 years, 4 women in the top ten authors in the last 5 years compared to 3 women in the top top ten over all time. When limit the publications to only peer-reviewed articles, were find that 26.5% of the first authors are women over all time, while in the case of first authors over the past 5 years, this increases to around 57% women. Considering the number of total publications per author, in the top 50 all time, there were 20 women, in the past 10 years there were 21 women, and in the past 5 years, there were 23 women. Comparing this to first authors for any publication, there were 17 women authors all time and in the past 5 years, there were 21 women. In the top 20 authors, all time, there were 6 women authors and in the past 5 years, there were 10 women. Again, both statistically insignificant but also lacking the statistical power needed to see significance.

We found that in the case of the top 10 authors in terms of h5-index using Google Scholar, 3 were women, whilst in the case of Scopus, 4 were women. This is in comparison to all-time h-index, where only 2 women were in the top ten for either database. The discrepancy between the two citation databases indicates that women seem to have published more frequently in recent years than men in the more restricted list of high impact journals in Scopus. However, due to small numbers, we do not have the statistical power to say whether this is a real difference.

The interpretation of h-index also needs to be treated with some caution as this is not the author's h-index based on AER alone, but is based on their publications in all fields. Each field has different average citations rates, so an astronomer crossing over into AER will have a naturally higher h-index then a science education researcher doing the same. A more robust index would be using a field-weighted citation impact metric based purely on AER articles that is beyond the scope of this preliminary exploration.

Dissertations are the third largest contributor to the iStar database. We found that over the past 5 years, nearly 56% of thesis published were by women, whilst over the past 10 years, just over 50% were by women. In 2006, just over 80% were by women. Over all time, we found that just over 40% of all dissertations in the database were by women, with the earliest dissertation by a woman going back to 1942.

Discussion

What do the above stats tell us about gender in the landscape of AER? Like many other landscapes (Barthelemy et al. (2016); Durndell (1991); Seymour (1995); Skibba (2016)), women are still under-represented, or rather there is not an equal distribution. However, it is interesting to note that in the case of dissertations in the past 10 years, we see that nearly 52% of the dissertations published were by women despite lower than parity frequencies in all other considered measures. This distribution coincidentally mirrors the data released by the Department of Education and Training, Higher Education Research Data, 2014 in Australia, which highlights the notion of the "leaky pipeline". Wherein, the distribution of women and men post PhD starts to diverge with the proportion of men holding more senior positions in academia increasing significantly beyond the typical entry level (B) position (Figure 4).

Whilst we have attempted some simple frequency statistical tests on the data to estimate whether the differences are truly significant or could be explained just by statistical fluctuation, this analysis is not enough to draw a complete picture. A truly complete picture would include an analysis of each author with respect to both their AER and their non-AER publications and also each author's relation to each other and through the lens of multiple academic indices. This would require a careful classification of each author's publication into their broad fields and then a recalculation of their publication statistics in each field, segregating and comparing AER publications to non-AER publications Such an exploration of the AER academic network is possible, and is being prepared, but is far outside the scope of the preliminary broad glimpse presented

Figure 3. Key statistics from iSTAR

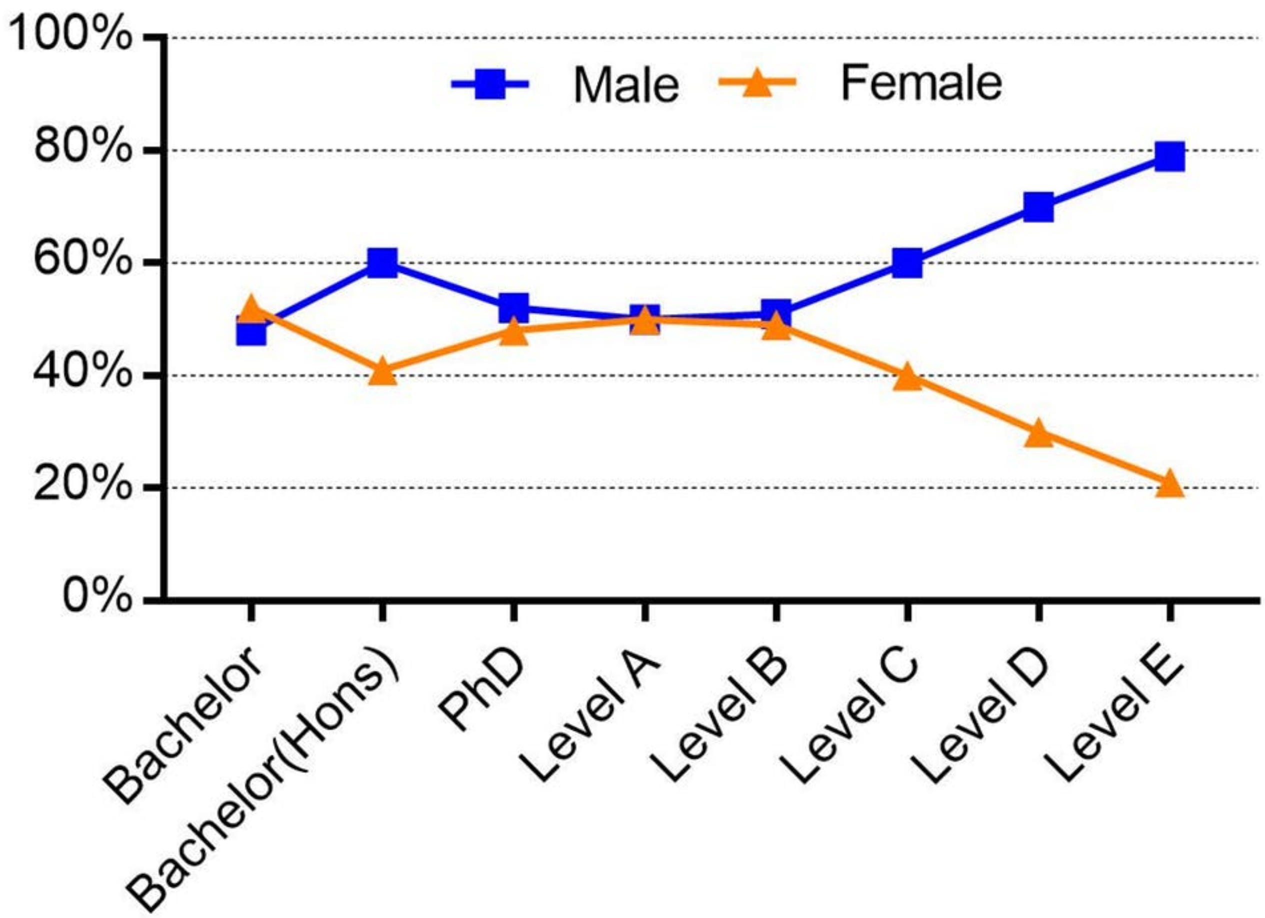

Figure 4. Gender Attrition rates for different levels in academia. Image credit: The Conversation, adapted from Department of Education and Training, Higher Education Research

here.

A recent article in The Conversation (Keenihan (2018)), highlighted that of all the authors who wrote for The Conversation, 72% were men, 28% were women. This gap in gender, is perhaps indicative of another underlying issue. Another statistic highlighted was that, since 2013, only 30% of the pitches for the Science & Technology section were from women. This latter statistic is perhaps innately related to the fact that women are under-represented in Science Technology. However, these statistics have changed and a recent survey by The Conversation showed that in certain fields the distribution is 50:50 (archaeology, communication, innovation, physics, space, sport and veterinary science) or in favour of women (genetics, politics/society).

A recent report by IOP Publishing, reveals that 22% of the authorship in physics is from women. Although they highlight that "papers with female corresponding authors have a slightly lower chance of being accepted", and there is lack of diversity on editorial boards from older journals. Furthermore, the report found that corresponding authors who were women had a 40% chance of their paper being accepted compared to 43%, if they were men.

The challenges relating to gender in science have been discussed in various articles spanning decades, including the most recent special issue on gender in the Physical Review Physics Education Research (Brewe and Sawtelle (2016), which had 17 articles and an editorial on gender. Therefore, it is not just to confine those discussions within the limited context of the this article. Rather, the aim of this article is to highlight the landscape of gender distribution in the context of AER, and provide it as a comparison point to the STEM landscape.

This is potentially the first analysis of gender in the context of AER and as such there are no explicit theories known by the authors for the discord between women and men in AER. Furthermore, to our knowledge, most of the studies that focus on the gender equity are from the perspective of practicing scientists or students rather than science education practitioners or researchers. Despite this, the reasons for the discrepancies could be similar to those identified by studies of gender equity in science (Brumfiel (2008); Ivie and Tesfaye (2012); Ivie et al. (2013, 2016); Sax et al. (2016); Skibba (2016)). However, within the scope of this paper, we do not posit a explanation for these differences but rather present the data as a point of comparison to other similar fields.

Conclusion

The challenges associated with gender equity and equality have been the topic of much research over many decades. In the context of science, the issue of gender is even more pronounced, this is marked by efforts to engage more girls in science, or more specifically STEM. However, the research has mostly centred around scientists and science research. This preliminary study explored the issue of gender in the context of Astronomy Education Research, which is a rapidly growing field of research drawing in, not just astronomers, but also researchers from different fields, e.g., education, psychology, evaluation. The aim of this exploration was to utilise the iSTAR database to provide a snapshot of the distribution in gender in AER. Our results indicate that although there seems to be a growing proportion of women actively publishing in the field, which has potentially increased in the past five years, the distribution is not yet an even match.

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Rationale for a New Journal: the Astronomy Theory, Observations and Methods (ATOM) Journal

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Abstract

In this article, the rationale behind the creation of a new journal, Astronomy Theory, Observations and Methods (ATOM) journal, currently hosted at rtsre.org is provided. It aims to fill a niche in the community for papers on any general topic in astronomy that may not find their place in top tier astronomical journals. The article outlines the thinking behind why there is a gap to be filled with regards to current scholarly metrics and the nature of other journals of similar scope and impact. The journal aims to be accessible to new and novice scientific authors, as well as those more established, through accessible developmental peer review and an explicit aim to avoid using publication metrics as a barrier to publication selection. The scope, which accepts more broader articles than most, of the journal and considerations on behalf of a potential author are also outlined.

Keywords

Scientific publishing — Amateur Astronomy — Student Research — Scientometrics

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Introduction

Part of the rationale for many astronomy student research projects (e.g. Fitzgerald et al. 2014; Percy 2018; Swift and Vyhnal 2018; Cutts 2018; Gomez and Fitzgerald 2017; Freed 2018) is that the students will be undertaking real research with real data with real scientists. If these projects are particularly ‘real’, then this activity should, by natural extension, be able to be published in a ‘real’ journal. It is also true, that a similar line of argument exists in the pro-amateur (pro-am) community, where the backyard astronomer is seen as someone who is readily capable of contributing important observations to science (Buchheim 2007; Conti 2018). However, it is generally not the case that much of this research from either of these two communities ends up in a mainstream professional astronomy journal, such as MNRAS, ApJ, AJ or AA, PASP or PASA.

The “race to the top” for mainstream astronomy journals means that the journals in the middle to top range of impact factor, such as those mentioned above, tend to reject articles that only have minimal, low or moderate impact. This is normal and, in some places, explicitly stated (e.g. Bertout and Schneider 2004). While it is relatively rare, it is entirely possible that if the research is taken to its natural extent in an area of sufficient interest to the astronomical community then such authentic projects undertaken by students, teachers and pro-ams can be published in middle to top tier astronomical journals. Examples include (Beuermann et al. 2009, 2011; Backhaus et al. 2012; Frew et al. 2011; Fitzgerald et al. 2012, 2015; Guieu et al. 2010; Howell et al. 2006, 2008; Rebull et al. 2011).

It is, however, nearly a truism that most research stemming from pro-am and education endeavours is typically not going to reach such a level. This research would be usually one of the first research experiences the authors may have and hence they likely will not have the depth of experience, skills and knowledge that someone in their post-PhD career might have. Therefore, the research will likely be smaller in scope and less on the cutting edge of science than articles that may end up in a higher end journal. Much of the time, the research may not be accepted in low to medium impact journals either.

In this paper, the rationale is outlined for a new astronomy research journal accepting of all impact levels of articles without an explicit goal of maximising impact factor or citation rates. We first provide an overview of the current state of mainstream astronomical journals and the quantitative ratings that drive them, their authors and the institutional policy that drives the activity of authors. We next present other journals that are at a similar level as the intended new journal that are already accepting such articles. We then provide an overview of the new journal, its scope, requirements and peer review process. We finish up with important considerations that an author should make when deciding to publish in this journal.

Current metrics of astronomy authors and journals

In order to, at least partially, understand why there is a gap to be filled in the suite of astronomy journals available to potential authors, it is necessary to understand the underlying metrics driving publication decisions by both journals and researchers. Here we focus on the primary individual researcher metric, the h-index, and the primary journal metric, the impact factor.

The h-index

The manner in which a researcher is rated and ranked against their peers has been changing over time. In 2004, the h-index did not yet exist. Researchers were generally rated by the total number of publications and the total number of citations. This slowly started changing when Hirsch (2005) presented his idea of quantifying a researcher's scientific output in a single index, h. The simplest explanation is that a researcher has a h-index of value h, where h is the nth paper sorted by citation that has n citations. In 2018, this index has become ubiquitous where various versions of the h-index are presented as an indicative proxy for a researcher's worth. This will likely change in the future as more network modelling and artificial intelligence driven metrics appear but, for the moment, it is currently the central scholarly metric for individual researchers.

The impact factor

Similarly, journals have their own central metric, the "impact factor", which is typically taken as the number of citations over the last two years divided by the number of articles published in the same period of time.

> Impact Factor = Total Citations in last two years / Publications in last two years

This value is used to create leaderboards or ranking tables of journals. One of the most prominent journal ranking systems being Scopus. In turn these leaderboards and rankings are used in a variety of ways by institutions and governments around the world to rate the research capacity of institutions (and hence distribute research funding). To complete the loop, these institutions then put pressure on their researchers to only publish in journals that exist towards the top of the leaderboard. This means that for journals to attract the best papers and to score highly on the leaderboard, they need to reject as many low-moderate level papers as possible.

Some journal articles, however, may never be intended to get more than a couple of citations. The results from these papers may be intended to be amalgamated into larger databases and review papers, leading quickly to the situation where their citation links are lost or undercited, especially for updates of single objects or papers with null results. The article may be read broadly by the community and inform much scholarly activity and conversation but not be of a nature that it gathers many citations. It may also be the case that a paper takes many years to be cited significantly and hence does not contribute to the journal impact factor in the two year period where this is calculated. This does not make these papers not valuable. It is also the case that just because a paper gets a citation, that is not necessarily an indicator of quality - the citing paper can easily be saying the cited paper was incorrect.

All that is metric is not gold?

These two metrics, the h-index and the impact factor, do not necessarily describe how an individual researcher or journal acts. An individual researcher can have a very large h-index and have never given a single thought to their citation rate but there are also individual researchers for whom maximising that value is a core career goal. No judgement is made here either way, but there is significant external pressure from multiple directions (e.g. funding bodies and institutional policies) on both individuals and journals to maximise these metrics that impact on publication behaviour by individuals and, more importantly for this article, policy decisions by journals themselves.

All of these numerical metrics are proxies to the true value of a particular journal, a particular research paper or a particular researcher. Much to the probable chagrin of those who seek to quantify research capacity, the true value of a researcher's work or a scientific journal is not something that is easily boilied down to a small set of numerical indices. There is likely also a strong social communal element not captured by publication statistics. The true value of a publication is likely to be unknown for quite some time (perhaps decades beyond the passing of the researcher).

For those who have been working in the field for a while, it would not be hard to find examples of researchers who have equivalent h-indices and who publish in equivalently impactful journals, but whose work clearly differs in importance, impact and magnitude. It is also the case that peer review itself, particularly in grants, beyond a certain threshold value of any of these metrics, can lose discriminatory meaning. For instance, a reviewer might have some concern over an early-career researcher with a h-index of 5 who might be applying for a relatively large sophisticated grant, but would struggle to make a distinction between competing applicants with a h-index of 15 and 40 solely on the metric alone.

A typical astute researcher in the field may not necessarily trust a journal because it has a high impact factor or a researcher because they have a high h-index. The researcher would certainly take time to flip through the articles in the journal, getting a feel for the topics, examining whether there are fellow trusted colleagues and acquaintances (or competitors) publishing there and make a gut-level decision as to whether it is a predatory or for-profit journal (e.g. Beall 2015). It is unlikely that a researcher would make a decision on a journal's impact factor alone (despite potentially being externally pressured to).

Moreover, having such a focus on accepting only "highly citable" articles prevents the publication of useful articles in high-end journals that are not necessarily meant to be "highly citable" but are still useful. This includes, but is not limited to, such things as null results, "observing lore" which can provide practical methodology, replication studies, historical articles, project outlines, observatory classifications and simple deep case studies. Providing a places for articles such as these, and others, is part of the motivation for the creation of this journal.

Journals that already exist

Subdiscipline-specific journals

There are already avenues for publication in discipline-specific journals. The most notable being the journal of the American Association of Variable Star Observers (JAAVSO, Percy 2017, weblink) which is a peer-reviewed publication open to submissions on various topics surrounding variable star research and observations, both archival and original, as well as educational and historical articles relevant to the field. There has been a long history of undergraduate and high school students publishing in the journal over the last few decades (e.g. Percy 2018) as well as a very active amateur community. For those not wanting to produce a full journal article, the

AAVSO also runs a system allowing the upload of observations and measurements (weblink).

Other journals include the Journal of Double Star Observations (JDSO, Clark 2010; Freed et al. 2017, weblink) which captures the results and research endeavours of the pro-am double star community. The Minor Planet Bulletin (weblink) captures short peer-reviewed papers involving pro-am research on asteroids with a particular emphasis on asteroid rotational lightcurves. Two other journals that publish variable star observations and results are the Open European Journal on Variable Stars (OEJV: weblink) and Peremennye Zvezdy (weblink)

The Informational Bulletin on Variable Stars (IBVS, weblink) was another excellent place for variable star observation papers. Unfortunately, it closed down in 2019 not long after celebrating it's fiftieth year jubilee (Szeidl et al. 2011) citing human and IT resource requirements as being too large to rationalise the necessary resuscitation of the journal.

It can be seen from this list, that most journals at this level, by which is meant that they are not aimed at being the top tier of astronomical research, are focussed on a particular class of objects rather than astronomy in general. It is not known to the author whether a peer reviewed journal of similar nature and impact that has a broad scope on any particular class of objects or any generic topic in the field of astronomy. It is not a goal of ATOM to necessarily compete with already existing, well-established, discipline-specific journals.

Non Subdiscipline-specific journals

There are a number of publication opportunities with a variety of pro-am groups. There is the yearly conference proceedings of the Society for Astronomical Sciences (SAS, weblink) which provides opportunities to publish but isn't a journal in the traditional sense. Other examples are journals tied to astronomical societies, such as the Journal of the British Astronomical Association (JBAA, weblink) or the Journal of the Royal Astronomical Society of Canada (JRASC, weblink), which can occasionally feature research articles, although it is not their prime focus.

Historically, the Research Based Science Education (RBSE) project, published a student/teacher journal called the RBSE Journal, edited by Dr. Katy Garmany, from 1999 to 2010 (Hurst et al. 2008; Buxner 2014). This included the research of students and teachers involved in a variety of projects, including RBSE, ARBSE, TLRBSE, the Kitt Peak Teacher Observation Program and the SPITZER teacher observer program (Spuck et al. 2010), a precursor of the current NITARP (Rebull et al. 2018) program.

There is also the relatively new "Research Notes of the AAS" (RNAAS), which is also an attempt at a solution to the problem of a lack of simple, observational, minimal or null results in the astronomical literature (Vishniac and Lintott 2017). The AAS also publishes the peak Q1 Scopus journals, the Astronomical Journal and the Astrophysical Journal. However, RNAAS is not peer reviewed, accepts only short papers (<1000 words), is not copyedited and only moderated by the editors rather than undergoing a detailed review process. This is intentional, particularly as the submissions are intended to be rapidly available online within 72 hours of receipt of the manuscript.

RNAAS is an exceptionally useful tool for the professional community in that it allows quick publication of results and ideas that may never have made it to print otherwise. However, it is perhaps not as useful for a beginning researcher who may want to publish a fully peer reviewed publication that is substantial in scope and length and whose scientific writing experience requires some scaffolding and support.

There are a variety of non-astronomy journals that accept specifically student work at the high school or undergraduate level (eg. The Journal of Undergraduate Research and The National High School Journal of Science), however it is very unlikely that research published in these journals will easily be discovered by other astronomers given their non-discipline specific nature. It has also been reported that some of these more generic education outlet focussed journals (as opposed to actual research journals) have rejected astronomy articles because they ”don't fit the scientific method” (e.g. Tock 2019), even when the article is about a refined method of pulsar detection.

What is the scope of ATOM?

These publication metrics and the current range of similar journals show that there is a gap needed to be filled by a generic astronomy research journal. The journal is not aimed at publishing cutting edge research but research of use and of interest not necessarily of moderate to high impact. Anything that is a valid, new and useful contribution to the science of astronomy and related fields is acceptable, however small. This is not limited to but includes the following:

- Preliminary or speculative research (especially where the researcher may not continue to pursue the object of interest).
- Unconfirmed but potential discoveries
- Null results (including warnings of probable null results where research was cancelled due to this.)
- Observing lore that has not been published but has usually been 'handed down'
- Replication studies of previous research (within reason)
- Useful contributions from non-optimal instrumentation
- Heavily data-based contributions (as long as there is a good rationale for it being heavily data, rather than interpretive)
- Review articles, small and large, of patches of the sky, patches of the universe, interesting subsets of astronomical objects or discoveries or patches of the scientific literature.
- Historical articles
- Case studies
- Instrumentation design and calibration studies.
- Software design
- Tutorials for observing techniques and data analysis
- Detailed information about new projects, observatories and sites
- Computational astronomy and visualisation
- Theoretical modelling
- Outlines of methodology

The journal is open access. There are no page charges. There are no page limits, figure limits or reference limits. This does not mean “unlimited”, it still needs to be concise, dense and to the point and provide enough information to pass peer review.

The first suspicion that someone may have upon encountering the journal for the first time might be to consider the possibility that it is predatory journal or something nefarious along those lines. This is not the case. If this was a predatory journal, it is a poor predator. There are no page charges, there are no publication charges, all work is voluntary. If the journal was nefarious or criminal at all, then it would be a poorly constructed endeavour of this type. This is a community endeavour to fill a need.

The contrast between ATOM and a mainstream astronomy journal

To illustrate the contrast, A&A (Bertout and Schneider 2004) use an example of where they refused a paper. . . . “ that presented standard photometry for an unremarkable binary eclipsing star together with a standard interpretation of its light curve.”. A&A claim that they did not publish it because there was “insufficient content and scientific interest by today's standards” despite “both observations and interpretation were sound” to justify publication in A&A. As ATOM is not aiming for impact at the cutting edge, this type of paper would be acceptable. The approach A&A takes is typical of most mainstream top quartile journals and makes much sense for that context.

Sometimes research instrumentation of sufficient quality is not accessible to authors with less resources or less background to make measurements as precise as the best in the field. For instance, some measurements may be taken much closer to sea level than might be preferred. As long as the best has been made out of the best instrumentation available and the outcoming results have been made with scientific rigour with no major problems, it is acceptable for publication in ATOM.

The journal does not discriminate between single object studies or multi-object studies. For instance, Kepler found thousands of eclipsing binaries in it's FoV. Following up a single binary from that catalogue is perfectly acceptable. It is preferred, but not required, that this will be undertaken in great detail. Taking the Kepler database of eclipsing binaries and exploring it in a new direction is also acceptable. As is following up 15 of the binaries. What is preferred though is that if only one object is examined, it is done to far greater detail, includes a larger exploration of how the object fits into our general understanding or provides much greater novelty than a multi-object study.

What are the requirements for a paper?

The author requirements can obviously change over time but this particular paper remains static so it is best to check the "Instructions for Authors" at the site. Initially, however, the following requirements will be held:

- The journal requires authors to significantly connect with the literature. Science is not done in a vacuum but is a building upon of previous work and a networking of current work. The primary way that knowledge is linked at this stage in human history is by connecting relevant articles via referencing.

- Original data can be provided so that research can be picked up, re-analysed and forwarded, particularly as it is intended that preliminary studies are valid to accepted.

- The article *must* be written in LaTeX. This is the standard format of a scientific article. It can be quite daunting at first to a new LaTeX user, but online tools have made this a much simpler feat nowadays. An online tutorial will be available on the site for first time LaTeX authors.

- The submission has not been previously published, nor is it before another journal for consideration.

The peer review process

The Chief Editor is always the single person responsible for the publications within the journal. They are helped with the process via peer review as well as an editorial board. Not all publications submitted will automatically be sent to review. The Editor makes a first judgement of whether the research or the writing is of sufficient quality and acceptable topic or nature to go out to review. Ample consideration will be made for writers of English as a second language.

As typical articles may be from early career, student or novice authors, a developmental review may be undertaken before a full peer review if the editor so chooses. This is primarily to give guidance on how to work up the paper into a state where it is appropriately ready for a full peer review. It is likely that this developmental review will be very common as it is a stated goal of the journal to accomodate authors who are not career scientists and for whom writing a paper is a very new and unfamiliar process and whom are not already fluent in scientific writing.

Peer review is a very necessary tool in quality control. No article will be hastened through peer review and no article accepted without adequate and careful response to reviewers. The intended timeframe, while noting that firm deadlines are not possible in academic publishing, would be:

- One week for an initial editor appraisal

- If required, a developmental review will take place over two weeks of frequent feedback and response.

- Once the article is ready for formal review, the intended timeframe to receive first reviews back is 1 month

- The timeframe from this point on is dependant on adequate responses from the author and whether further review rounds are necessary

Referees will be selected from active astronomy researchers who have published in the field on the topic in the past three years. In the tradition of most astronomy research journals, this is initially one blind reviewer. Extra reviewers may be brought in if there is a disagreement between the author and that reviewer or if the paper covers multiple fields.

Considerations for a potential author

Due to the wider scope of the journal and the permissiveness of preliminary and null results, this will likely lead to a lower "impact factor" for the journal. This very raw quantitative measure is used to compare the "performance" of journals within a particular field. It is, of course, very difficult to estimate how often a particular paper may be cited ahead of time. However, it can reasonably be assumed that a journal that is inclusive of more broader, speculative or null-reporting research is invariably going to publish a much higher number of articles with low citation rates. It is explicitly not a goal of this journal to achieve a high impact factor. Setting such a goal would be contrary to the mission of the journal to include valid papers with potentially low citation rates.

Hence this means that all quantitative metrics that measure a researcher's scientific output as a function of journal impact factor will score articles in this journal relatively low (we suspect). On the brighter side is the fact that most current metrics have moved beyond the inclusion of a journal's impact factor as a metric for publications of individual researchers (e.g. San Francisco Declaration on Research Assessment, Cagan 2013, link to DORA website). The h-index (Hirsch 2005), the current main quantitative rough estimate of a researcher's publication worth, does not care about impact factor at all, just numbers of publications and numbers of citations of those publications within the considered database. Many major funding bodies (Forschungsgemeinschaft 2010, press release) having seen people 'game' the system are moving away from using quantitative-based research appraisals entirely. Having said that, it is up to each author to find out what their institution or current or future grant funding body might value and act accordingly.

There can be no guarantee that this journal will be listed in Scopus or Web of Science curated indices. These two indices are the primary tools major institutions use to estimate publication impact. Initially, these indices do not consider "new" publications until they have a few years of track record and a calculable impact factor (which by definition requires at least two years of journal issues). We are aiming to meet the requirements of both Scopus and Web of Science but there is no guarantee of eventual selection, although we are aiming to comply with the requirements. Articles will be indexed via CrossRef and via Google Scholar from day one.

Having said all this, for many potential authors, particularly student researchers and pro-amateurs, considerations about such things as whether it counts for promotion or grant funding are largely irrelevant. For undergraduates, high school students and pro-ams, there is minimal functional difference between the Astronomical Journal, Proceedings of the Society for Astronomical Sciences, Proceedings of the Astronomical Society of the Pacific, RNAAS, JAAVSO and ATOM. What is of most benefit to them is the developmental peer review and the capacity to formally publish their valid scientific results in a scientific journal. In contrast, the extrinsic reward value of a publication is not as significant as the intrinsic personal development value, e.g. broadening perspectives and personal transformation (Beltzer-Sweeney and White 2019), content knowledge and process understanding, developmental of scientific identity and community of practice membership (e.g. Freed 2019), of undertaking the scientific process in it's entirety from initial idea to final publication.

It is also the case that there is a significant time limitation on such authors. For a student or pro-am, typically the research undertaken is a single piece of research at a single epoch of time. In contrast, a professional or graduate student will likely be playing a longer game with perhaps tens of research streams that may formulate (or not) into research papers regularly over time on an indeterminate timescale. As the student or pro-am may be undertaking a research project once in a single restricted timeframe, they do not have the luxury of just letting a project take a backseat while they work on other projects. It is typically the one singular project they are undertaking and perhaps in a limited timeframe, e.g. a year or a semester for a student or when their observatory is not in the cloudy part of the year for a pro-am. These issues make the publication decisions and considerations for these potential authors markedly different than for a professional author. In turn, this influences the policies for journals, like those for ATOM outlined above, that would like to welcome such authors to publish.

Conclusion

This paper outlined the rationale for a new peer reviewed journal that provides a place for minimal to moderate impact papers in astronomy to be published. The journal focusses on the development of the author and the field in the process. It also provides a place for non-traditional outputs, such as observing lore, historical articles and observatory classifications. While there are good journals already that deal with object, or class of object, specific fields of research, this journal aims to capture, with peer review, any generic topic in astronomy.

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Three Decades of Distance Education Astronomy at Athabasca University

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Abstract
The first Astronomy course at Athabasca University was offered in 1989 as a correspondence course, using innovative DOS software on the remote students' home computers. A Science-stream course, it simulated astronomy research and offered laboratory credit at freshman level. The success of this course led to a qualitative astronomy course being offered in the early 1990s, based on a commercially-available course package (including videos) supplemented by practical activities. It also included an essay in which students critique aspects of astronomy in popular culture, based on what they learned in the course. Both courses were popular, but enrollment has plateaued. For more senior students, we developed the possibility to do research projects, which also met a need for senior credit for program students in the B.Sc. We now offer two complementary courses in planetary science, one from an astronomy/physics perspective, and one focusing on planetary geology. Although distance education has come to be more accepted in recent times, and moved to the internet, transitioning our materials to being fully web courses has been challenging. Recent success in transitioning Physics online courses to use of open textbooks suggests that this may be possible in Astronomy as well. We also hope to integrate our online research facilities more into education.

Keywords
Distance Education — Historical Review — University Level

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Introduction

Distance education may be broadly regarded as presentation of an educational curriculum through materials for study by students who do not physically attend the presenting institution. In recent times the term has become essentially synonymous with "online learning" since that is now a preferred mode of presentation. Generally, we will refer to the term as learning for credentials (formal academic credit), while the more general term "online courses" may include noncredential offerings such as "Massively Open Online Courses" or MOOCs.

Athabasca University (AU) was established in 1970, and thus is approaching its fiftieth year. From early on, it specialized in distance education, at that time mainly taking the form of "correspondence courses". A package of printed materials was mailed out, usually consisting of a textbook and a customized study guide prepared in-house to lead students through the course material. In most cases, students mailed in completed exercises for marking throughout the course, and graded coursework was mailed back to them. Credible exam results were guaranteed through use of invigilation centers, which are formal sites set up in AU offices at various locations in Alberta, or in cooperating institutions for exam writing. More creative, but credible, invigilation services can be set up through special arrangement (an often-used example is Royal Canadian Mounted Police, i.e. RCMP or Mountie, outposts in isolated communities). A combination of good quality course materials following curricula similar to those at on-campus institutions, credibility of testing methods, and efforts made to coordinate course credential recognition, led to wide acceptance of AU courses for transfer to other institutions. This is possible not only in Canada, where AU has a large presence in the distant province of Ontario (most populous in Canada), but also in the Unites States, where it is accredited by the Middle States Commission on Higher Education (2018).

A more unique aspect of AU was the use of "telephone tutors", whose task is to keep in touch with students on a continuous basis to assure, and help with, progress through the course materials. The normal period for course completion is six months for a standard three-credit course, with the possibility to buy extended support to prolong this slightly. This model of home study with a deadline, but with the student having the choice of how quickly to progress, is referred to as "unpaced" or "asynchronous" study, and prevails to this day in core academic disciplines. Some professional faculties, such as Business, have had a large degree of independence, and have modified their methodologies to emphasize a model in which home study students form cohorts and proceed on a common schedule, which is referred to as "paced" or "synchronous" study. These faculties have also moved to models involving "call centers" in which there is no direct interaction of students with a dedicated tutor. The implications of such changes will be briefly discussed at the end of this article.

Well into Athabasca University's existence, an expansion of its course offerings led to development of its first astronomy course, SCIE 280 Introduction to Astronomy and Astrophysics (SCIE being a general Science designation) in 1989 (Hube 1998). This course was developed by Tony Willis, a radio astronomer, and featured a DOS program developed in-house to simulate planetary motions and even proper motion of stars. Ironically in light of what is narrated below, the dominance of DOS and simple methods led to ease of use of the laboratory exercises. Measurements in most of them were made using a ruler on a printout from a dot matrix printer. As a historical note, such printouts were on paper, and a dot matrix referred to the printhead, which pushed pins chosen in small rectangular matrix to force an ink ribbon into contact with the paper. By this method, rough characters could be printed, but images could also be composited with relatively high resolution. Having a relatively challenging set of exercises involving measurement of data, SCIE 280 was classified as a "laboratory science" course, able to be used for laboratory credit in the B.Sc. degree also introduced in the late 1980s, and usually transferring to other institutions as equivalent to their Science-stream courses. As will be detailed below, other courses developed after SCIE 280, and astronomy as a discipline at Athabasca University is now in its thirtieth year. Space-related research takes place at AU (Hube 1998) and is concentrated in planetary science (e.g. Hildebrand et al. 1995; Connors et al. 2011; Wiegert et al. 2017 and space physics (e.g. Connors et al. 2016). Primarily for research purposes but widely used in education, Athabasca University hosts a Skynet 0.4 m aperture online telescope at its in-town headquarters campus, and a University of North Carolina 0.45 m telescope at its remote site (Schofield and Connors 2019).

About halfway through the nearly three decades in which AU has offered astronomy courses, a detailed survey was published (Connors et al. 2003), including enrollment analysis. This article will update on progress and challenges to date, and prospects for the future, both at AU and for astronomy distance education in general.

Developments in Courses

As noted by Connors et al. (2003), the original course, SCIE 280, was relabelled ASTR 200, while retaining the same course name, in 1995. At this time, a textbook which went out of print was replaced by the Universe text (now Freedman et al. 2014), and this course continues to use that series of textbooks. Modifications to the lab exercises (Connors 1992) were incorporated into the new course, and then-new exercises based on CLEA (Marschall 2000, 1998) were introduced, as well as other attempts at electronic labs (Connors et al. 2003). Ironically, it was found that new developments in computer technology, while quite powerful in making the student lab experience more meaningful and more congruent with actual observational technique, were challenging to implement due to changes of operating systems and computer output methods. A further irony is that when the new course, ASTR 205, was introduced as a non-science-stream course in 1996, it had a higher course number. Apparently perceiving that lower-numbered courses would be the lowest level, many students enrolled in ASTR 200 who actually should have gone into ASTR 205, with resulting lack of success in a course for which they were not prepared. Explanations on course websites seemed ineffective in combatting this perception, so that finally the step of renumbering ASTR 200 to ASTR 210 took place approximately in 2005. This seemed to solve the student streaming problem. A lesson is that course numbers matter, especially when viewed in relative isolation on syllabus webpages. As of this writing, however, ASTR 210 is closed and under revision, as the development of new laboratory exercises, always a challenge, has been brought to a virtual standstill by technical issues.

ASTR 205, Universe: The Ultimate Frontier, remains open as our only current freshman course. It remains little changed from the description in Connors et al. (2003). A long course closure in 2017 was needed to convert the course to an online textbook (now Seeds and Backman 2013). The course had been converted to the Moodle learning management system several years ago, recently upgraded to the current software release. It features online testing and assignment submission via Moodle, and invigilated online exams (usually taken in a testing center but on a computer screen: exams are 100% multiple choice and autograded). Two unique and useful aspects of the course remain: one of the assignments is an essay, near the end of the course in which students critique popular culture item in terms of science learned in the course; and some easy but meaningful observational exercises. Part of the observation is of spectra with a viewer, a small grating which is now the only piece of course material mailed to students. The large enrollment growth cited in Connors et al. (2003) did not persist, and enrollments leveled out at approximately 150 per year in the mid-2000s. This course has also continuously featured videos related to the course materials, initially broadcast on the former provincial educational TV named ACCESS, now privatized. After a period in which videos were loaned by AU's distance education library as tapes or DVDs, they are now streamed. We are unsure to what extent the video materials are used by students. Some of them clearly do view them and find them useful, as we sometimes get questions or comments about them. In general the videos are supplemental to the course textbook and not essential for course success.

GEOL 415, Earth's Origin and Early Evolution, has continued to be offered, but was modified to no longer use a large selection of textbooks, mostly on meteoritics, but instead Moons and Planets (Hartmann 2005). The complementary new course ASTR 310, Planetary Science, was introduced about five years ago, using the same textbook. The courses differ in emphasis, the Geology course stresses concepts from that field, while the Astronomy course emphasizes physics and astronomy. These differences are also enforced through the in-house developed study guides and exercises, and the pre-requisites. Although the number of annual enrollments is modest, these courses play an important role in meeting the demand for senior science courses both by visiting students and by those in our programs.

The lack of senior science credits has led us to offer "project" courses in fields such as astronomy, physics, mathematics, and geology that are relevant to this discussion. We also have the option to label ASTR projects under the general rubric of Science (SCIE), and in principle we could also use the Computing (COMP) designation. We have had steady although small enrollment in, for example, ASTR

495 and 496, Astronomy and Astrophysics Projects. We have had cases of students doing both of these and then having to choose a further project in another subject area such as physics, with a slight change in emphasis. Some projects are of high enough caliber to merit publication: one led to publication and educational/outreach impact (Noshin et al. 2018, weblink). The general rules that keep project courses of high caliber are that prerequisites are enforced to ensure that incoming students are capable of senior level research work (often relatively independently), and that original research must be done. In the 495 level project courses, it is allowed to mainly do library and online research in original sources, usually as a preparatory study intended to lead to original research work. At the 496 level, completely original work must be done, within the period of the course (although that might include analysis of data taken earlier). In fields such as physics and geology, we often have students presenting research which is related to their full-time careers. In astronomy, this is rare, but sometimes the projects are related to amateur astronomy activities.

Outlook

Connors et al. (2003) was written at a rather optimistic time when it seemed that Athabasca University could go on to be a leader in the transformation of distance education to online learning. The subsequent decade or slightly more was marred by the university losing viable executive guidance, with consequential negative impacts on the ability of faculty to lead in the field. For example, innovations in online astronomy education in 2018 seem to be coming mostly from the nearby University of Alberta, with its ASTRO 101: Black Holes MOOC, despite the fact that this institution has no special mandate to do distance education. On the other hand, some other institutions have introduced astronomy online courses that did not seem to catch on (e.g. Western University), showing that doing distance education is not as easy as it may look.

As a result, Athabasca University offerings may have stagnated into some reflection of the state of astronomy teaching about the time of the previous article (2003). One overall trend since has been that 3-credit courses covering the entire large field of "astronomy and astrophysics" are no longer favored. There is an increasing tendency to offer a total of six credits at freshman level. For example, the "Universe" (Freedman et al. 2014) textbook is now offered as two "splits". Since a home study student getting an 800 page book by mail or courier can be rather intimidated, it likely is better in many ways to offer split courses, especially in the Science stream where there are also lab exercises to be done. As noted, reliance on outside textbooks can also lead to situations where courses must close to make revisions. For this and to assist with lowering cost to students (at least in principle), we have experimented with open textbooks. The initial reaction to this conversion in physics has been favorable (e.g. Daigle, 2018 weblink). We are currently evaluating Openstax Astronomy to see where it may fit in our subject area. Hopefully, a cost advantage could be implemented, effectively lowering our course fees to benefit more students. However, even without this, de facto control of the revision cycle, as given by an open textbook, is important in distance education, since in our experience course modifications are difficult to make, and associated course closures are costly for us and detrimental to students.

Our way forward in distance education likely lies in adoption of open materials, updating of materials to use appropriate web technologies and data sources, and splitting of courses into at minimum 3-credit units (smaller course modules are also possible and being considered). Our courses are now online, and well organized under Moodle. This mechanical aspect being under control, we may be able to explore optimum pedagogy. The use of personalized tutoring was a hallmark of AU, but the old model of telephone support at certain fixed hours no longer meets modern lifestyles. More and more interaction with students is by email. The merits of the tutor system itself are being discussed. Our experience is that some students put heavy demands on tutors while others do not, and some even express a wish to work without such support. The merits of call centers hopefully will be carefully evaluated and weighed versus the tutor system, before possibly irreversible changes to one of the distinguishing characteristics of AU distance education.

Although to some extent it is already happening in project courses, one could also wish for enhanced use of our advanced research facilities in student education at all levels. We are exploring having an M.Sc. degree in Science, although progress has been frustratingly slow.

Final words

It is appropriate to close in paralleling the recent AU experience and new optimism with a quote from Alighieri in 1321, "e quindi uscimmo a revider le stelle", leaving the meaning to be sought as an exercise for the reader (see Figure 1).

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Figure 1. Gustav Doré, 1857. *A riveder le stelle.*

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Astronomy Research Seminar Expansion and Building a Community-of-Practice

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Abstract
The astronomy research seminar has been growing by leaps and bounds over the past several years and is now offered in almost a dozen institutions from middle schools up through community college and undergraduate courses in four-year universities. In its spread it has gone through diversification in how it is taught to fit the needs of the new instructors, students and institutions, whether it's as a three-day intensive workshop, eight-week fully online seminar or semester-long hybrid course. An important part of the growth, success and sustainability of an astronomy research seminar is having student teams working within a Community-of-Practice. Key to this, is building up that Community-of-Practice and helping students understand that they are important partners within the community. This paper presents brief descriptions of many of the seminar offshoot programs in the context of building a Community around student astronomical research.

Keywords
Community of Practice — student research — astronomy education

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Introduction

For several decades it has been recognized that science education and career-readiness in the US are on the decline (National Research Council 2011; Kastberg et al. 2016) and many governmental and educational organizations have tried to determine how to reverse this trend, from improving teacher education programs (National Research Council 2010), increasing STEM motivation in students (Johnson 2012), and completely rewriting national science standards (NGSS Lead States 2013), among other things. Many studies have pointed out that astronomy is the "Gateway Science" (National Research Council 2011), and the author can attest to the intrinsic draw astronomy has on the public imagination and interest based on more than 20 years of public outreach in astronomy. Translating the way that astronomy can capture the attention of people of all ages into a way for them to learn about the nature of science and scientific inquiry may well help direct students into STEM education and career pathways. Keeping the fascination of the subject alive within the educational context is crucial for maximal impact and the Astronomy Research Seminar (ARS), pioneered and taught by Russell Genet for over 10 years (Freed et al. 2017; Freed 2018), may well serve this role.

Astronomy education comes in a tremendous variety of forms, from the large-scale Astro101 college courses, some implementing telescope access remotely and some not, to other large universities and small community colleges with their own telescopes for hands-on use, to MOOCS with or without student access to telescopes, to high school astronomy courses and after-school programs, as well as the myriad of informal astronomy education programs around the globe. Many programs over the years have attempted to implement telescopes into education, as outlined by Gomez and Fitzgerald (2017), with varying amounts of success and longevity. Evaluation of many of these programs has been ongoing for years or may just be beginning and each serves an important role for its population. This evaluation is critical to understanding the true impact of these programs and to help improve them.

The Astronomy Research Seminar appears to be providing critical learning and motivation for those students it serves in its variety of settings and incarnations which will be expanded upon below. It certainly serves a different community of learners from those in a large university or MOOC setting, with the Seminar's emphasis on students working directly with advanced amateur astronomers or experts in their particular field of research. The strong focus on student-led diverse teams and writing for publication, guided by members within the larger Community-of-Practice, also distinguishes this program from most others, and seems to provide an entryway into STEM as a hobby or education or career path for some students who might not otherwise have clear access to these.

It is thought that the ongoing development of a Community-of-Practice around student astronomical research is one of the contributing factors to the success of the program over the past decade, with success being defined as numerous students undergoing at least a small identity change in seeing themselves as scientists or as contributing meaningfully to science. Wenger (1999) states in his seminal work, Communities of Practice: Learning, Meaning, and Identity, that learning "transforms our ability to participate in the world by changing all at once who we are, our practices and our communities" and "Education design must engage learning communities in activities that have consequences beyond their boundaries, so that students may learn what it takes to become effective in the world." It is the case that many students, having gone through the seminar once, then go on to do it again and bring others into the program or build their own programs.

Expansion of the Astronomy Research Seminar

The Astronomy Research Seminar (ARS) has expanded significantly over the past three years. After initially being offered through Cuesta Community College in San Luis Obispo, CA, it is now offered by numerous institutions and organizations throughout the country, either in-person or as a hybrid or totally online course. In its spread it has taken on several different forms over the years as discussed below. As Wenger et al. (2002) points out, one of the seven principles for cultivating communities of practice is to design for evolution: "As the community grows, new members bring new interests and may pull the focus of the community in different directions...Community design is much more like life-long learning than traditional organization design".

As many of the organizations that have embraced the Astronomy Research Seminar have shown, the interests of its members have lead them to develop and promulgate new versions of the seminar with diverse audiences with a far-reaching domino effect helping to keep the Community-of-Practice dynamic and alive. It is important to note that the goal of expansion of the seminar is NOT to make a handful of identical programs at different institutions, but rather to share lessons learned about how to have students do research and publish their results, to share resources created for these purposes, and to provide assistance as needed for new programs to establish themselves in the manner that best suits their local communities.

Figure 1 attempts to show some of the connections between organizations, individuals and schools through which the Astronomy Research Seminar and student astronomical research has recently propagated. It is by no means an exhaustive portrayal of people and institutions involved. The individuals, shown in purple, have helped student teams and instructors at various institutions. A few of the high schools (in blue ovals) and community colleges (in green ovals) which have taken on or created their own version of the Astronomy Research Seminar in the past few years are shown, as are conferences and organizations (in orange) that have supported student research, publication and presentations. This represents a small snapshot in time, between 2016-2018, and could include more community members on the periphery and interwoven amidst the schools and organizations. It would be difficult to capture the full interconnectedness of the community and its expansion, as it is alive, dynamic and growing.

To illustrate the growth and expansion of the seminar, a variety of different implementations at different institutions are outlined below beginning with the original "Astronomy Research Seminar".

Cuesta Community College

The Astronomy Research Seminar originated at Cuesta Community College in San Luis Obispo County, CA. It has been taught there almost continuously since 2008, for the first six years as an in-person course and then with fully online and hybrid versions also available since 2014. The course has often had both undergraduate students and high school students from the local area. Student teams consisted of mixed levels of students with varying skill sets. Whether meeting in-person or online, teams met with their instructor once a week and were required to meet on their own at least once a week in addition, as a major seminar goal is for students to learn to take responsibility and ownership of their research. The students were sometimes recruited from advanced math courses and sometimes from the general school population and had students from a diverse range of majors.

Other Institutions providing the in-person ARS

The Seminar was occasionally taught in the winter as an in-person course at Maui Community College, in Kahului, Hawaii. Between 2010-2012 there were also versions of the seminar at Evergreen State College in Olympia, WA, revolving around a weekend at Pine Mountain Observatory in Deschutes National Forest, near Bend, Oregon. Students would come to the observatory, learn how to use the telescopes, collect their data and then return home to finish writing up their papers. This program continued in the summer of 2018.

Offshoots of the Astronomy Research Seminar

Apple Valley Double Star Workshop (AVDSW)

Mark Brewer took the seminar as a junior in college in 2011, resulting in the first of his 13 publications (Brewer et al. 2012), and loved it so much he immediately started his own version which he provided for students from middle school up to college as well as the general public. He advertised to the local school district and did fundraising at various places such as Walmart and Starbucks, advocating for the research seminar and how it benefited the public. He ran the workshop with assistance from others from 2012-2016, and the tradition was carried on after 2016 by the High Desert Research Initiative (Brewer et al. 2016). Approximately 70 participants participated in the workshops over the five years and most of Brewer's 13 publications include numerous students. He has written about and presented his double star research program at the Society for Astronomical Sciences Annual Symposium (Brewer et al. 2014).

Vanguard Double Star Workshop (VDSW)

Sean Gillette first participated in the Astronomy Research seminar under the guidance of Mark Brewer, a former seminar student, at the Luz Observatory at the Lewis Center for Educational Research in Apple Valley, CA in 2011, co-authoring a paper on visual measurements of several binary star systems (Brewer et al. 2012). He then started the Vanguard Double Star Workshop (VDSW) research program at Vanguard Preparatory Academy where he taught science until mid-2018. Approximately 30 eighth grade students have participated each year, beginning in 2014, with 36 in the program in the Fall of 2018, and culminating in a total of nine published student papers and several more in preparation (Gillette et al. 2017). This program is significantly different than the eight-week or semester-long course taught at most institutions. The students participate in a three-day intensive workshop in which they take measurements at the telescope,

Figure 1. The Expanding Community-of-Practice around the Astronomy Research Seminar - a snapshot in time. Light blue ovals are high schools that provide the Astronomy Research Seminar. Green ovals are community colleges that provide a research seminar. Purple parallelograms are individuals who play a role in disseminating or supporting student astronomical research. Yellow boxes are conferences that support student astronomical research.

analyze the data and write up their results.

Evergreen State College, Olympia, WA

In 2010 and 2011 Rebecca Chamberlain, an instructor at Evergreen State College, worked with Russ Genet to provide the Astronomy Research Seminar to community college students. They went to the Pine Mountain Observatory Summer workshops to collect data and published six papers in 2011 and 2012. Recently, Evergreen State College partnered with the Institute for Student Astronomical Research (InStAR) in the Summer of 2018 to again provide the seminar for ten community college students as well as a high school student from Irvine, CA. This new version had student teams meeting with the Evergreen instructor in person once a week while the InStAR seminar instructor joined the class remotely via Zoom. In addition, the InStAR instructor met with the students via Zoom as needed to answer questions and help solve problems. The student teams also met independently throughout the eight-week seminar and have two papers in preparation for submission for publication (e.g. Pangalos-Scott et al. (2019)). The partnership is continuing in the Fall of 2018 and the Summer course will be offered again in partnership in the summer of 2019.

Figure 2. Group Photo, left to right. Zach Medici, Shannon Pangalos-Scott, Danielle Holden, Micaiah Doughty, Melody Fyre, Rebecca Chamberlain, at The Evergreen State College, Olympia, WA. Rachel Freed, in the background; Jaeho Lee, in the bottom right.

Research, which has been verified in recent interviews with students (Freed 2019), shows that having actual time at the telescopes critically enhances the learning experience in terms of student understanding of how data is collected. In addition, students feel more connected to the research and have a sense of ownership of their work. Recently, Evergreen State College in Olympia, Washington, had seminar students who attended Pine Mountain observatory and were actually able to observe their double stars on a 0.7-meter telescope. They had already collected and analyzed data using the LCO 0.4-meter telescopes and they expressed an incredible sense of connection and pride in seeing these stars they had been studying.

Currently, in the Fall of 2018, four students who took the Evergreen/InStAR seminar have embarked on a new round of research projects on double stars and recruited new students to join them. This has spurred the development of a follow-on seminar by the InStAR team, which has been proposed many times over the past decade. In this course, students will take on mentorship roles in addition to the research roles they had in their first seminar experience. They have a goal of disseminating the seminar to local high school students in 2019 and serving as instructors at that point. Furthermore, they will be presenting their research at the Conference for Undergraduate Women in Physics, helping them build upon and strengthen their own Communities of Practice.

BOYCE-ASTRO and the San Diego Area

In the San Diego CA area the Boyce Research Initiatives and Education Foundation (B.R.I.E.F) has established the BOYCE-ASTRO program which works with three community colleges in the area, Mesa College, Grossmont College and San Diego Miramar College, as well as BE WISE (Better Education for Women in Science and Engineering) and several other organizations to provide astronomy research opportunities to high school and undergraduate students. They have served over 200 students and have produced 33 student publications since the Spring of 2015. Links to these publications can be found on their website at http://boyce-astro.org/library/.

While the BOYCE-ASTRO program initially modelled their courses after the Astronomy Research Seminar taught by Genet, they have expanded significantly, creating their own model for teaching astronomy and having students conduct and publish research, building an impressive collection of educational materials for this purpose. They have incorporated many of the educational technology tools that students are already naturally inclined to use, such as Remind (https://www.remind.com) and Ed Puzzle (https://edpuzzle.com/) to create dynamic and interactive learning materials (Boyce and Boyce 2017). The BOYCE-ASTRO program is now working with TESS (Transiting Exoplanet Survey Satellite; https://tess.gsfc.nasa.gov/) follow-up programs to have students observe candidate exoplanets in collaboration with NASA.

Stanford University Online High School (OHS)

Stanford University Online High School (OHS), is a fully online, accredited high school run out of Stanford University in Palo Alto, CA. Students in the program live at various locations around the world. Kalee Tock, a science instructor at OHS, and one of her 8th grade students participated in the seminar in the Fall of 2016. Tock then provided the seminar as an extracurricular program for one year and has now developed a course at OHS for astronomy research (Tock 2018). By connecting with the larger Community-of-Practice, in particular with significant guidance from Michael Fitzgerald of Our Solar Siblings (Fitzgerald et al. 2018), Tock has provided the opportunities for her students to study eclipsing binaries (EBs), RR Lyrae stars and exoplanet transits in addition to developing computer models to study orbital parameters.

The students also write python code for analyzing large quantities of EB data. (See Badami et al. 2018; Hensley 2018; Hensley et al. 2018; Kith et al. 2018). Several papers are still in preparation and a new cohort of approximately 20 students has begun the seminar this Fall. Several students from OHS presented their research at the second annual conference on Robotic Telescopes, Student Research and Education (RTSRE) in Hilo, Hawaii, in June of 2018, and another presented his research at the InStAR workshop held in June 2018, in Ontario, California (Figure 3). Additionally, Tock now gives workshops on how to provide the Astronomy Research Seminar and how to use Google Collaboratory, for students to work together on these sorts of research projects. Her students are already being scheduled to present their research in New York and Southern California in 2019.

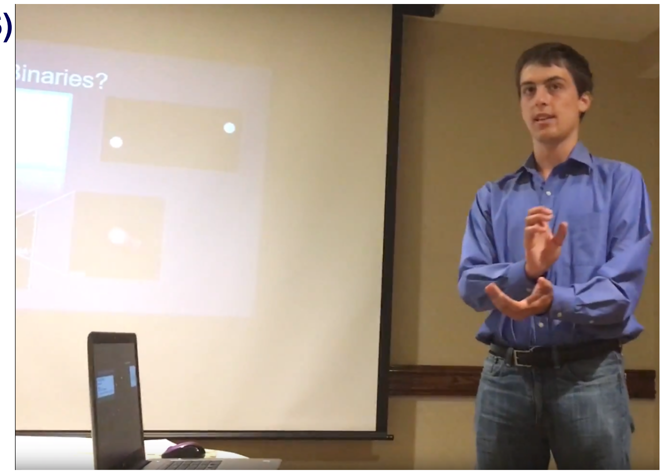

Figure 3. A Student from Stanford University Online High School presents his team's research at the InStAR workshop in Ontario, CA in June 2018.

Paradise Valley Community College, Arizona

In Arizona, the Astronomy Research Seminar is provided at Paradise Valley Community College which had its first student teams in the Spring of 2018. Six students, five girls and one boy, from Paradise Valley and Foothill Academy High School, worked with their team members and used a C-11 with an attached ZWO ASI290MM camera at Brilliant Sky Observatory, owned and operated by Richard Harshaw, to study the double star STF 1427. Harshaw has been studying and publishing double star research for several decades, having published measurements of over 1000 double star pairs (Harshaw 2018; Harshaw and Cave Creek 2017), and over the past five years has helped numerous student teams throughout California and Arizona conduct research. Three of the team members presented their work at an InStAR workshop held in Ontario, CA in June 2018 (Figure 4). The audience of other college professors, astronomy curriculum and lab developers, observatory operators, and advanced amateur astronomers who conduct and publish research provided an authentic audience for these students for whom research and presenting their work was all quite new. Their paper is in preparation for submission to the JDSO.

Paso Robles HS, Paso Robles, CA

In the Spring of 2018 Jon-Paul Ewing, a physics instructor at Paso Robles HS, joined an Astronomy Research Team at Cuesta College to learn how to provide research experiences for his high school students. After submitting a paper for publication in the JDSO (Andersen et al. 2018) Ewing lead a team of nine girls (Figure 5) through the research seminar in the Summer of 2018. Their paper was accepted on September 3rd, 2018, for publication in the Journal of Double Star Observations (JDSO).

Figure 4. Two community college students and 1 high school student from Arizona present their research at the InStAR workshop in Ontario, CA in June 2018.

Included in their seminar was a trip to Mount Wilson where they had time on the 2.5-meter telescope, although their data collection for the research was actually done on one of the Las Cumbres Observatory 0.4-meter telescopes. (Phillips et al. 2019)

Figure 5. Students from Paso Robles High School and their Instructor, Jon-Paul Ewing, at Mount Wilson Observatory, Summer 2018

College of the Desert, Palm Desert, CA

This is a public two-year college, dedicated as a Hispanic Serving Institution, in the ethnically diverse Coachella Valley. It has recently acquired a 1-meter PlaneWave Instruments telescope and is adapting the Astronomy Research Seminar for students enrolled in its Research Experience for Undergraduates program (ElShafie et al. 2018). Their observatory operator has attended several InStAR Workshops over the past year, most recently in June 2018, in preparation for coordinating student research and publication programs at the school.

Mt. San Antonio College (Mt. SAC), Walnut, CA

Over the past year three astronomy instructors from Mt. SAC have attended several different InStAR workshops and one recently sat in on a two hour Zoom meeting with an instructor and students as they worked on refining their research paper for publication. One of the key lessons learned over time is that educators are best able to conduct the Astronomy Research Seminar once they have gone through the Seminar themselves. To that end, immersing new instructors in the course is invaluable to their success and these new seminar instructors will be supported in their development of a research program.

InStAR Courses

The first InStAR Course was taught as a hybrid course in collaboration with Evergreen State College in Olympia, WA. Starting in October of 2018, several new InStAR online courses will be provided, one for studying exoplanets, and one for double star astrometry in conjunction with GAIA DR2 analysis. These can be found at https://www.in4star.org/. Over the past half-decade InStAR has created numerous resources for student research with small telescopes and publications. These include videos about the processes of conducting research, writing papers, and many tutorials about how to use software programs to do data analysis. Additionally, it has produced an online Canvas course and the Small Telescope and Astronomical Research Handbook (Genet et al. 2015) which serves as a text for the courses and a guide to those generally interested in small telescope astronomical research.

Seminar Material Development

Over the past three years many resources have been developed in addition to the InStAR handbook. These include mini tutorial videos on YouTube and they are constantly being added to as new questions arise. For example, in response to student questions, videos have recently been developed to explain how to use AstroImageJ and astrometry.net and how to add new data points to the orbital diagram using measuring tools within PowerPoint. Additionally, a full course has been developed in the Canvas Learning Management System which is available to new instructors and students. The program continues to grow and develop organically in a fashion similar to the way science itself is conducted, with new questions and obstacles leading to new research and experimentation.

Future Directions

The Astronomy Research Seminar's success in influencing student pathways in STEM and helping change their identities as scientists is put in the framework of working within a Community-of-Practice and a requisite goal for sustainability and growth of the program is expanding that Community-of Practice. To that end numerous workshops have been held and more are being scheduled next year. One of the most important meetings/movements to come out of trying to broaden and build a larger Community-of-Practice was the first annual Conference on Robotic Telescopes, Student Research, and Education (RTSRE) that took place in June, 2017. That conference, organized mainly by Michael Fitzgerald from Edith Cowan University, Pat Boyce from San Diego, California, and Russ Genet from Cal Poly San Luis Obispo and Cuesta College, brought together many players in the greater arena of telescopes in education, astronomy curriculum development and evaluation, remote observatory owners and designers and both formal and informal astronomy educators. Likely the most impactful result of that first RTSRE conference was the Call for Proposals from the Las Cumbres Observatory (LCO) Education Partnership (Gomez 2018) which led to about 18 institutions having access to the network of 0.4-meter LCO telescopes for use with students and in informal education environments. That education partnership has expanded with a new call for proposals for partnerships for 2019 and a selection of 21 total partners. According to the LCO Global Director at that time, Todd Boroson, LCO had been trying for a long time to reach out to a large segment of the educational world, and it was really the conversations at the first RTSRE conference in 2017 that led to the expansion of the Education Partners program. The 2nd annual RTSRE conference was held in Hilo, Hawaii in July 2018 and out of that came a Skynet call for collaborators. Skynet (Reichart et al. 2005) is one of the largest global and networked collection of telescopes, along with LCO, and this, combined with the LCO Education partnerships, marks the beginning of a cohesive, global effort to provide telescope access to as many students in as many countries as possible, providing the necessary framework on which to continue to expand the astronomy research seminar. Of course, the community needs not only the telescopes, but the people as well and to this end monthly online meetings have been developed to help build and support this growing Community-of-Practice around student research. While the Skynet call for collaborators is focused more on the study of its Astro101 and higher level curriculum impacts, there are numerous Research Seminar Instructors who are part of the Skynet group and therefore, their student teams have access to these telescopes for research projects. Another avenue to expand the research seminar approach is in providing a continuing education course for pre-service and in-service teachers based on the astronomy research seminar, allowing for more educators in the K-12 arena to bring authentic research experiences to their students in collaboration with language arts and education specialists. This program is under development at Sonoma State University in the School of Education with a goal of providing the course in the Summer of 2019. The Astronomy Research Seminar has begun to expand from the initial domain of double star astrometry to other astronomical arenas available to small telescopes (0.4 - 2-meters), such as Exoplanet transits, asteroid photometry and eclipsing binaries. In addition, a collaboration with several radio astronomy organizations, including GAVRT, (Gladstone Apple Valley Radio Telescope) and Skynet with their 34" meter radio dish at Greenbank Observatory in West Virginia, is in development to incorporate the use of radio telescopes and projects for which they are especially capable of such as the study of intraday variable blazars, solar phenomena recorded over month-long time scales, synchrotron radiation effects on the Juno mission, and other radio observations. It is interesting to note how members within a large Community-of-Practice may flow from one arena to another over time, bringing their experience and expertise to a new domain. Sean Gillette, who ran the Vanguard Academy Double Star Workshop for 8th graders, now works for the GAVRT team at the Lewis Center for Educational Research and can bring his years of experience with the Astronomy Research Seminar to bear on this new collaboration. Finally, in an effort to expand awareness of and participation in the astronomy research seminar, several workshops are being scheduled around the country for 2019, so far in Houston, TX, Suffern, NY, Fort Davis, TX, Provo, UT and Ontario, California, with others potentially being conducted. The goal of these workshops is to bring together local astronomy educators, students, and amateur and professional astronomers, and to give them training on how to conduct a successful research seminar with a student publication at the end, and to connect them all to the larger Community-of-Practice in order to ensure sustainability.

Conclusion

Over the past several years the Astronomy Research Seminar has taken on a life of its own, spreading throughout the country and globally through its various in-person and on-line personas. It has clearly moved on past the "founder effect" and hundreds of students are gaining the experience of participating in true scientific research, publishing their results and working within a Community-of-Practice larger than their school districts and college campuses. Many of the offshoots of the original seminars provided at Cuesta College are still running, even four years after their founding, and new programs are being developed each year. Access to at least two large, global telescope networks, with web-based interfaces, removes one of the biggest obstacles for astronomical research for students, and the expanding community will hopefully provide enough support for it to achieve long-term sustainability. Furthermore, branching out from double star research, into other areas of astronomy that students and the public are excited about, such as exoplanets and asteroids, as well as diversifying to include radio astronomy, will likely help propagate and sustain the research seminar further. Student-led astronomical research, publication and communication, aligns very well with the Next Generation Science Standards as well as Common Core standards, and is therefore perfectly situated to be adopted within high school science courses. Providing workshops for educators and the amateur astronomy community with the expertise to support them will hopefully allow these programs to flourish, and students to become more scientifically literate, as they become the voters and policymakers in the not-too-distant future.

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Recent Evolution and Status of Online Homework Systems for Teaching Introductory Astronomy

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Abstract
Internet-delivered, automatically-graded, online homework systems are becoming ever easier for college science teaching faculty to adopt and integrate into existing learning management systems. In this sense, online homework systems have great potential to extend the amount of time on task students allocate to learning astronomy without overburdening already overextended, busy professors. At the same time, the systematic education research surrounding the use of online homework systems is less conclusive, with both benefits and disadvantages being reported in the literature. Moreover, some student advocates lament the financial burden to students and the negative optics about instructors' commitments to teaching. In the end, an ASTRO101 professor's decisions about whether or not to adopt online homework systems are complex and insufficiently supported by compelling education research data and by and large depend heavily on both a professor's teaching philosophy and the academic context in which the students are learning.

Keywords
astronomy teaching — astronomy education research — assessment — online homework systems

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Introduction

In a concerted effort to enhance the introductory astronomy survey course, well-meaning faculty have long endeavored to engineer student behaviors to increase their students' achievement. Absent special circumstances, the traditional student-based formula for student participation in most general education courses for undergraduates is: (i) go to class and take notes; (ii) skim the textbook; and (iii) review notes or provided study guides before the exam; and then (iv) forget everything temporarily learned. Knowing that a student's attendance record is positively correlated with test performance, some faculty require students to attend class, penalizing those students who skip class. Knowing that a student's performance can be improved by providing detailed exam-review guides, some faculty provide students with a formally written outline of the major topics that are likely to be covered by an upcoming exam. Knowing that students who are actively engaged in thinking about astronomical concepts, some faculty try to move students from a passive-listening posture during class to an intellectually engaged orientation by having students discuss concepts with their peers. These engineered student behaviors, among many others, are firmly grounded in the notion widely advocated by long-time astronomy instructors Slater and Adams (2002, 2016) that, "it isn't what the teacher does that matters—it is what the students do."

For many faculty, the teaching of general education, introductory astronomy survey courses for non-science majoring undergraduates—hereafter referred to simply as ASTRO101—differs in large parts from the typical approach to teaching the undergraduate introductory physics course sequence. Of many differences between the two courses, including that ASTRO101 is typically filled with non-STEM majoring undergraduates as compared to introductory physics which almost exclusively enjoys seats filled with enthusiastic STEM majors, the ASTRO101 instructors by and large do not rely on students devoting many hours each week wrestling with outside of class time homework sets characterized by solving numerical problem after numerical problem. Instead, the majority of ASTRO101 faculty by and large do not assign daily or weekly homework to be graded. Although there are certainly exceptions, ASTRO101 faculty do not assign students homework in the same way as physics instructors because, as but one reason, ASTRO101 faculty often teach large-enrollment courses and lack grading assistance in the form of graduate teaching assistants. Moreover, as ASTRO101 courses are largely conceptual in nature rather than calculation-based mathematically intense courses as is typical for physics courses, ASTRO101 narrative-based homework tasks can be more difficult and time consuming to grade than traditional numerical answer-based physics homework. Because of these challenges, along with other pragmatic reasons far too numerous to describe exhaustively here, the tradition of students submitting pages and pages of hand-written homework solutions in ASTRO101 is not widespread.

At the same time, ASTRO101 faculty generally have some tacit sense that students who spend more time dedicated to studying and thinking about astronomy are usually better positioned to be more successful and to learn more than those students who spend less time thinking about astronomy. Under the broad category of "time on task", education researchers agree, and the research literature has consistently confirmed the idea, that students who spend more time immersed in thinking about a subject simply learn more than those who do not (Chickering and Gamson 1987). Given both a natural sense and a robust research-base that students would benefit from spending time outside of class thinking about astronomy, dedicated ASTRO101 faculty have been searching for solutions ranging from developing flipped astronomy classrooms where students learn new information outside of class and come to class to practice applying their new knowledge (viz., Bishop et al. 2013 and references therein) to coming up with innovative hand-grading systems that dramatically reduce the amount of time needed for faculty to hand-grade ASTRO101 homework (Slater 2005).

The appeal for faculty to assign outside of class homework is obvious. For one, assigning students to complete homework outside of class naturally extends the amount of time—time on task—students spend thinking about astronomy. For another, researchers such as Walberg et al. (1985) have clearly demonstrated in two-group comparison studies that graded homework improves student learning more than ungraded homework. Yet, at the same time, Penner et al. (2016) found that, as experienced faculty have tacitly feared, students all too often approach their homework assignments without reading the book and, even more worrisome, that unlimited attempts when using online homework seems to actually reduce student effort. Speaking of online homework system specifically, Gaffney et al. (2010) report that computer graded homework further impersonalizes a course and rarely enhances student satisfaction.

Nonetheless, a broad swath of the ASTRO101 teaching community has long hoped for an emerging technology-based solution that would simultaneously engineer student behaviors to engage in thinking about astronomy while simultaneously not require an extraordinary amount of effort on the part of busy faculty. In other words, as one solution of many possibilities in the solution space, ASTRO101 faculty have long hoped for easy-to-use, automatically graded homework systems to become widely available to support students' enhanced achievement of astronomy. One naturally wonders, given the rapid evolution of emerging Internet technolo-

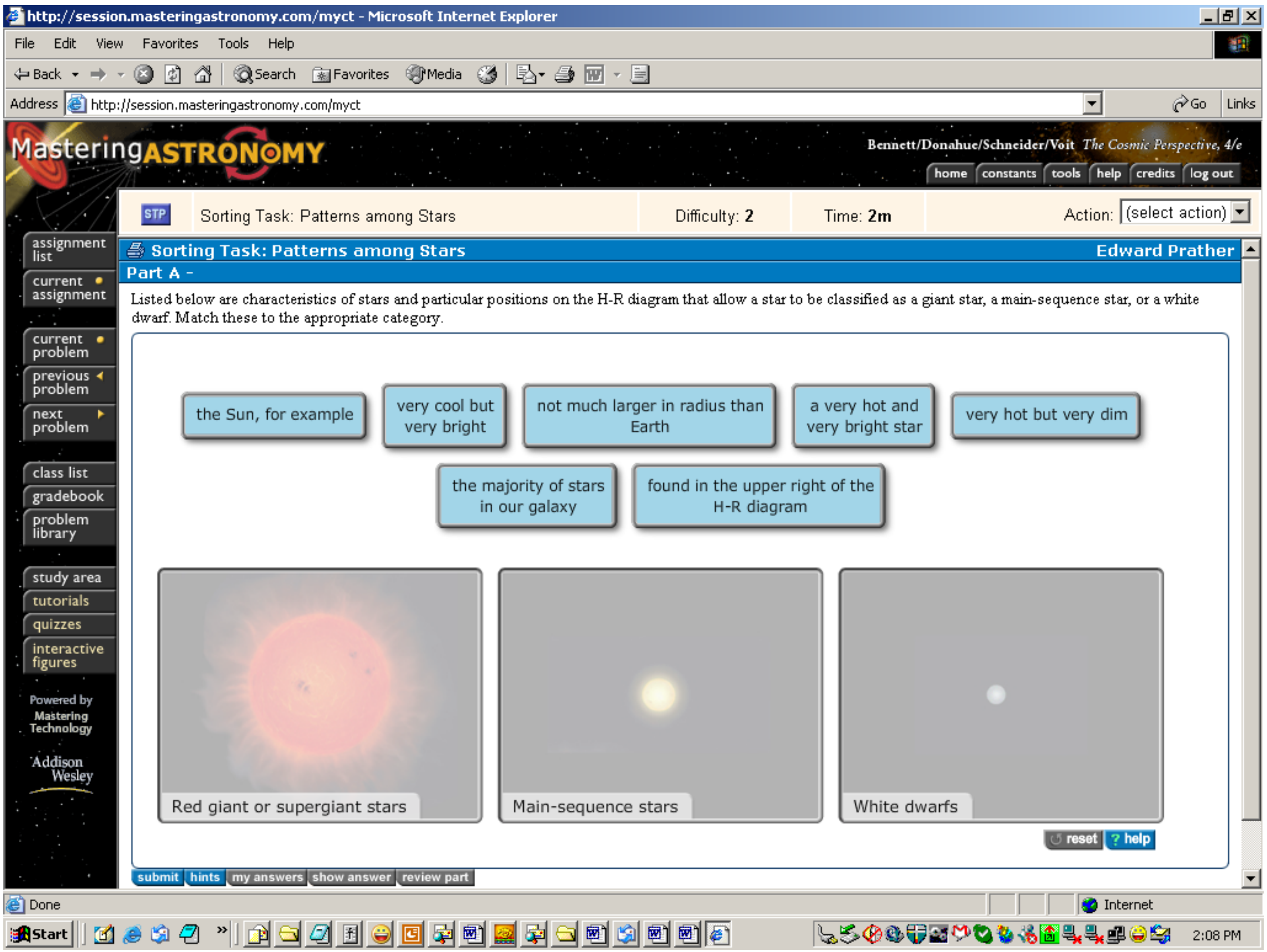

Figure 1. An Illustrative Screenshot Example Of MasteringAstronomy Online Homework System, adapted from Slater (2007).

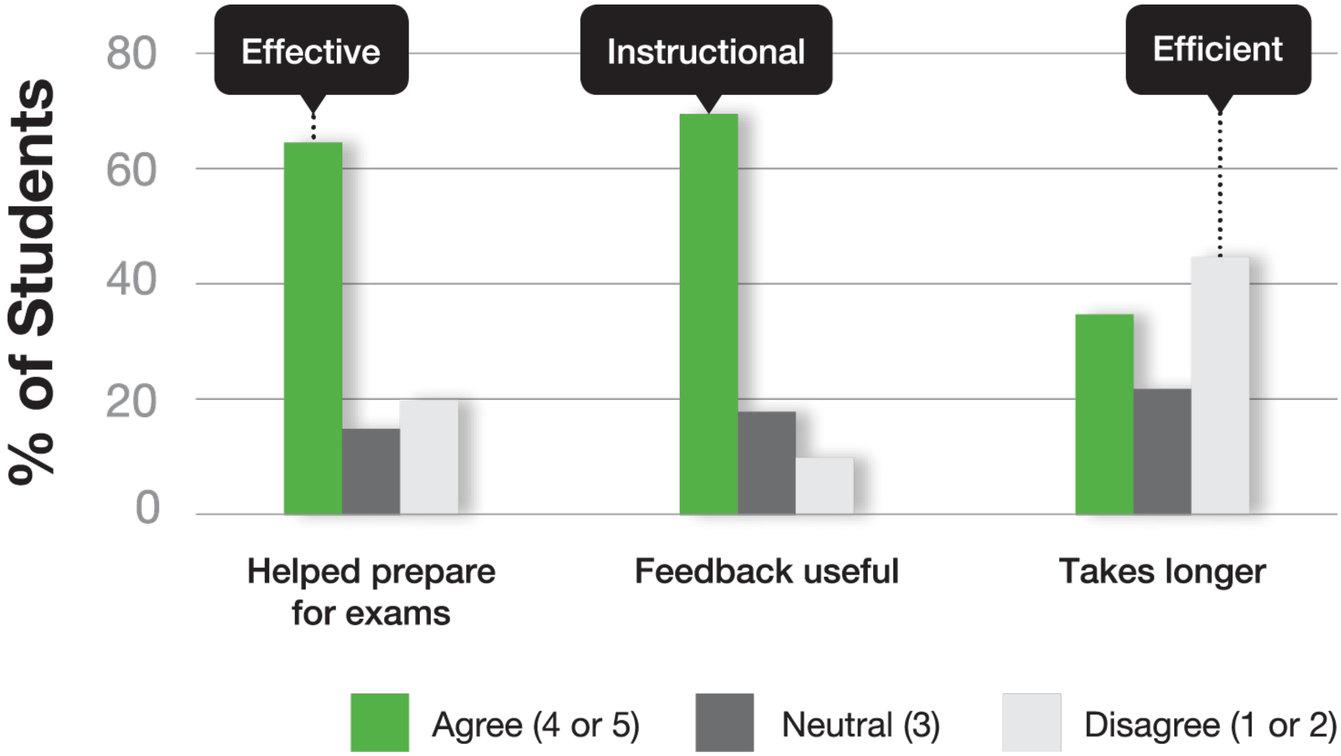

Figure 2. Example of Online Homework Promotional Materials from Macmillan's Sapling Learning System

gies, is the long-awaited time for robust, online homework systems for ASTRO101 finally here?

An Oversimplified History of Online Homework Systems for ASTRO101

One way to conceptualize the motivation for developing online homework systems appropriate for ASTRO101 is the convergence of two seemingly separate teaching problems in desperate need of solutions. The first motivation, as briefly outlined above, was driven in large part by the needs of overworked and overloaded busy ASTRO101 faculty trying to extend learning and students' engagement beyond traditional in class seat-time to provide more out of class learning experiences in the service of enhancing student achievement. The turn of the Century was characterized by US colleges and universities becoming—for better or worse—more client-oriented which, in turn, resulted in college and university faculty becoming forced to be more accountable to their student-clients. Student success in learning astronomy, which is appropriately correlated with students giving professors higher end-of-course-evaluation marks (Clayson 2009), requires faculty to provide accountability measures demonstrating their success in teaching students. Homework scores, in addition to exam grades, naturally provides a reasonable accountability measure and, when done well, seems to increase student achievement and end-of-course satisfaction.

At the same time, the number of colleges and universities starting to teach off-campus, distance-learning courses increased dramatically. A complete discussion of why both college administrators and students themselves hungrily desire online courses compared to traditional face-to-face classroom-based courses extends far beyond the realm of this paper, but suffice it to say that faculty presented with the challenge of teaching courses to students off-campus desperately needed secure, online homework systems and course management systems that could go far beyond students handwriting answers to end-of-chapter textbook questions and submitting those assignments electronically, by

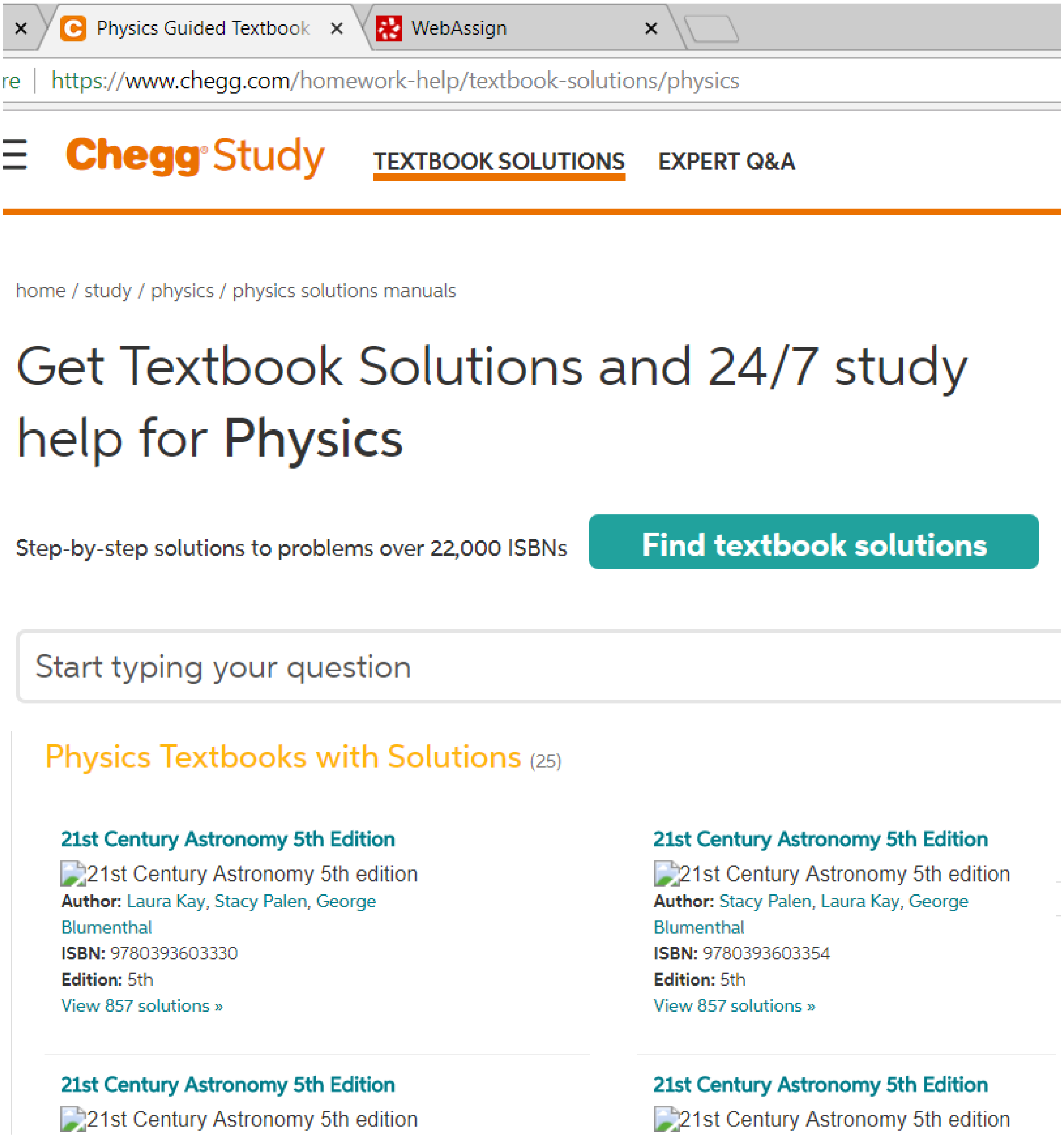

Figure 3. Illustrative Screenshot from Homework Solutions Provider Chegg.com

facsimile FAX machine for example (viz., Keller and Slater 2003; Slater and Jones 2004; Slater and Beaudrie 1998; Slater et al. 2001). Taken together — between the complimentary needs for classroom-based ASTRO101 faculty to extend learning beyond the classroom and the needs for distance learning-based ASTRO101 faculty, the time to develop automatically graded, online homework systems at the turn of the Century was ripe.

One of the first widely used online homework systems for ASTRO101 was created by then Addison-Wesley Publishing (now Pearson Publishing) to ac-company the early editions of The Cosmic Perspective (Bennett et al. 1998) in the late 1990s. In this system, students visited an online webpage using an early-generation web browser, such as Netscape or Mosaic, and answered multiple-choice questions characterized by radio buttons next to possible answers that were then submitted as email to their respective professors by entering the professor's email. Other examples of this sort of first-generation online homework system certainly exist.

The next generation of online homework systems were driven by the notion that students would learn more if the received some sort of feedback beyond "right and wrong" from the Internet-based computer system. Leading the development of such a system was a group from MIT led by Dave Pritchard (Morote and Pritchard 2009) in what eventually became the system that is now known widely as MasteringAstronomy (Slater 2007) with significant financial investment by Pearson Publishing, and illustrated in Figure 1. What characterized this next generation online homework system was that when students submitted an incorrect answer to a multiple-choice question, the system would automatically reply with feedback to the student about why a particular incorrect choice was incorrect and provide a hint as to which choice might be correct. Eventually, these systems, known collectively as MasteringX platforms, along with far too many competitors to name, became able to provide rapid feedback to students for text-based and numerical-based responses, both correct and incorrect. Although these systems still fell far short of an imagined intelligent, smart tutor based on artificial intelligence systems, eventually, under the banner of what is generally known as "adaptive testing" some of these advanced generation online homework systems could alter the sequence and difficulty of homework questions delivered to students dependent on students' individual performances.

Today, most major textbook publishers—and a few single-minded companies outside of traditional publishing, such as TheExpertTA.com, among many others—provide students and faculty with a variety of semester- and year-long subscription options for wide array of online homework systems, all with widely varying levels of interactivity and feedback provided. It is not my intention to exhaustively list all of the companies and their available options. Nonetheless, simply because these systems exist is not sufficient reason enough alone for faculty to blindly adopt these systems and require their students to pay subscriptions to them. Although certainly not all, some authors have presented considerable evidence that students learn more when using online homework systems as compared to not (Cheng et al. 2004; Allain and Williams 2006). The publishing companies themselves also point to evidence that online homework matters, as shown in Figure 2. More to the point, Wooten and Dillard-Eggers (2013) offer powerful evidence that online homework systems seem to help lower ability students more than upper ability students if—and that's a hugely important "if" qualifier—students use the computer-based systems to learn concepts rather than simply complete tasks. Taken together, the broader education research jury is still largely undecided regarding the real impact of online homework systems as there is solid research suggesting that many students learn more by laboriously handwriting their lecture-notes and handwriting answers to their homework (Duhigg 2016). In the end, given the current absence of singularly minded educational research landscape, the decision about whether or not to adopt online homework systems still depends largely on a professor's specific learning goals and teaching philosophy.

Is Now the Right Time for You to Adopt Online Homework?

Much of the future of education is clearly tightly tied to computer delivery. The number of computer-based, online learning modules, seminars, courses and certificate programs is becoming ubiquitous. Even NASA's requirements for all employees and contractors to understand security protocols must be competed annually online. Today, computer-based instruction and assessment falls under the mantra of "we're here; get used to it." As a result, it might seem natural to fall in line with the trend and use computer-based assessment in ASTRO101, despite

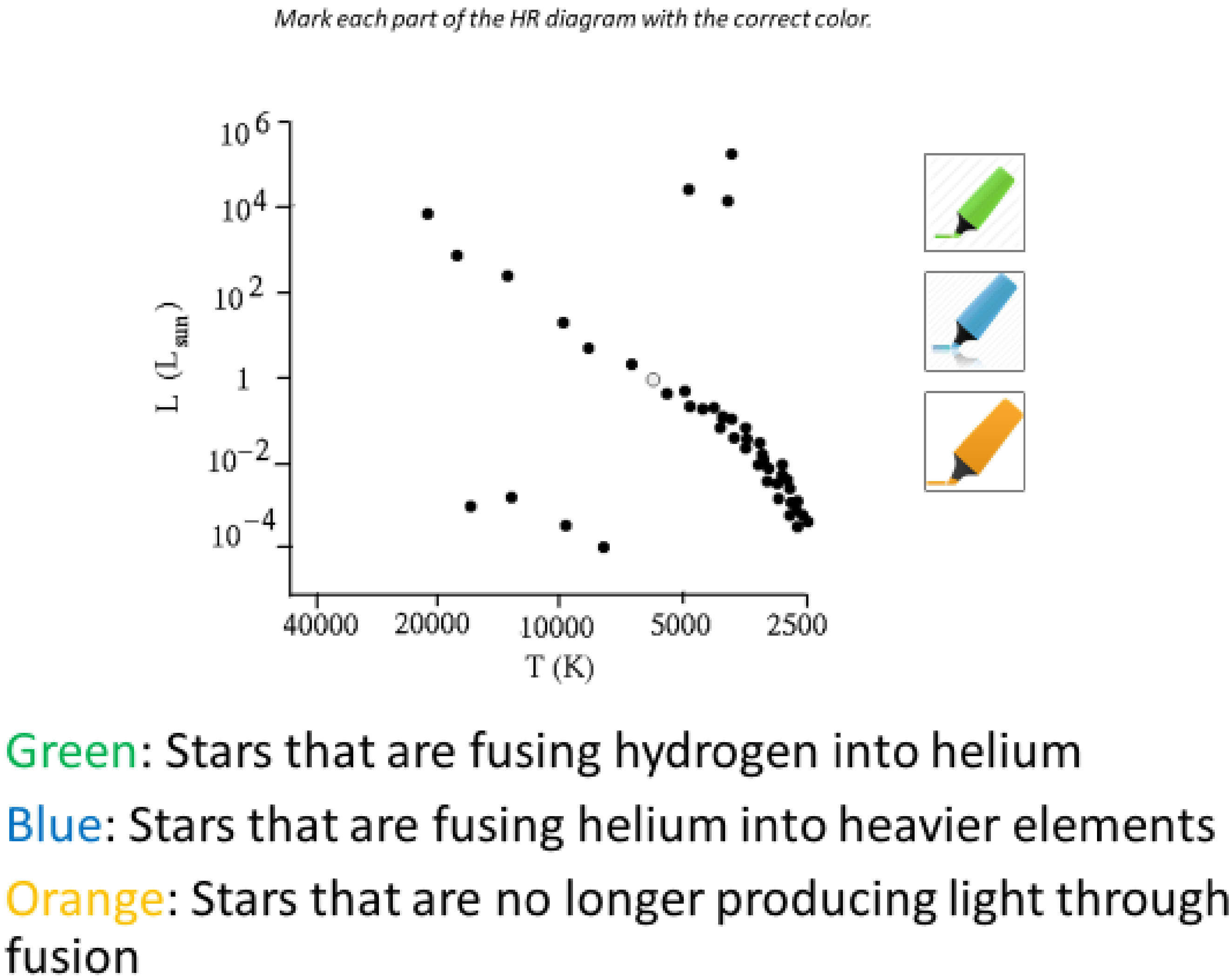

Figure 4. A Next-Generation Online Assessment Question Where Students Color-code a HR Diagram, adapted from work by Stephanie J. Slater, Ph.D.

their being insufficiently compelling evidence that online homework systems work as brilliantly as promised by the providers and as sincerely hoped for by compassionate educators.

At the same time that these systems are becoming ever easier and more convenient for busy faculty to use and integrate into their existing learning management systems, the costs to students are increasing. Online homework systems seem to range from about \$30 USD per semester to as much as \$99 USD per semester. Some schools are instituting policies that ban the required use of such systems because of the burgeoning cost burden to students, not to mention the optics of students paying giant tuition bills for faculty who don't even grade student work themselves. Moreover, as with any technological solution, there are also technological undermines. Chegg.com, as illustrated in Figure 3, are one of many online companies that make money from students selling solution sets to online homework systems. Stated another way, imagine that students pay \$59 USD per semester to subscribe to an online homework system required by a professor and then another \$59 USD per semester to subscribe to the online homework solutions and answers system. With textbooks costing students hundreds of dollars on top of tuition and fees, the burden on students is swelling.

Conclusion

Unquestionably, providing students with rapid, formative feedback on their learning improves achievement and attitudes and is worthy of pursuit (Brissenden et al. 2002; Lee et al. 2006). Nevertheless, the bottom line is that the answer to the question of adopting or not adopting online homework systems falls far short of being clear cut. Personally, I am experimenting with online homework systems and anecdotally find that the benefits are outweighing the risks—as of today. I'm trying to prepare myself for the upcoming next-generation of adaptive and responsive online homework systems that could hold tremendous, but as of yet unrealized, promise for individualizing, pacing, and providing video game-like motivational rewards for a diversity of students to enhance learning. Furthermore, the upcoming generation of online homework systems could be very fun to teach with, such as the assessment task illustrated in Figure 4 where students color code a HR diagram. In the end, I am skeptically enthusiastic about using online homework and feedback technology to help students better understand our place in the universe.

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Astronomy Laboratory Experiences in the FullDome Digistar 5 Planetarium Environment

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Abstract

College level astronomy is typically offered as a laboratory-based introductory level course for non-science majors. In comparison to a typical physics laboratory where there is a large choice of equipment available for physics experiments, there is only a limited number of setups that can be used for nighttime astronomy activities. Furthermore, many astronomy events require time to collect data and this can be challenging in three-hour lab periods. Most instructors use a mix of different mediums like computer software, internet, and workbook style labs mixed with one or two optics experiment and a few stargazing activities with telescopes. These are all good methods to engage students in astronomy learning; however it cannot compare well with the actual process of collecting data by observing the night sky and analyzing that data. Certainly, it is possible to develop one or two such activities but for a variety of reasons it is not practical for a large class environment setting. Fulldome planetariums simulate the night sky and offer the ability to collect data on many astronomical events in a laboratory setting. Unfortunately, astronomy curriculum material that make use of fulldome technology in teaching and laboratory experiences in astronomy is largely lacking. The goal of this talk is to show that fulldome planetarium can be used as a medium for college-level astronomy courses. Several examples will be shown in which students collect and analyze astronomical data as well as activities that are planned for the future.

Keywords

Astronomy Education — Planetarium — Laboratory Activities

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Introduction

When was the last time you visited a planetarium for a show? Today, modern planetarium facilities are fully immersive technologies and offer programming on variety of science subjects Law (2006),Yu (2005),Wyatt (2005). These facilities are equipped with the state-of-the-art fulldome video projections and surround sound audio systems. Some even offer 3D programming. Planetariums are expensive and they do not make profit from ticket sales unlike movie theaters. So how does an educational institute justify the cost of building a planetarium facility and continuous financial support it requires? The answer lies in the educational mission of the institution: to educate the students so that they play a positive role in the development of a country and its preservation through transfer of knowledge from one generations to the other.

At the heart of this mission is for the educational institution to provide an intellectual environment to students to develop their mental skills. Among the highest of mental skills to develop is problem solving. Science subjects allow students to build concrete-problem solving skills. The ability to solve problems starts with the act of observing and categorizing, and culminates in inferring, predicting and communication. Astronomy is an ideal science subject that lends itself to developing problem-solving skills. It is a subject that has been passed on from generations to generations and gets the highest level of interest from students. It appeals to all groups of people regardless of age, gender, or career goals. It is highly accessible in terms of learning concepts and content that are fundamental to everyone's life experiences, like the concept of time, calender, seasons, tides, and others. Further detail discussion on the use of planetarium for education can be found elsewhere (see Smith and Haubold 1992; Reed 1994; Slater and Tatge 2017; Türk and Kalkan 2015; Bishop 1979; Riordan 1991).

Planetariums are ideal laboratories to learn and teach astronomy concepts. The first planetarium came into existence in October 21, 1923 in Deutsches Museum in Munich, Germany (Chartrand 1973, and Hagar 1973. Planetariums mimic the real night sky and offer an environment in which the simulated sky can be manipulated and experienced in real time. This very feature of the planetarium is the key to developing problem solving-skills in young minds. Consider the fact that in a typical laboratory experiment a student makes observations and/or measurements and carries out analysis of the data gathered to prove some known fact or law. For subject like physics and biology, there is a wealth of equipment and instruments available to make this possible in some prescribed, allotted time period. In astronomy, one usually uses a telescope at night for observations and measurements. There are many limitations that can make the learning experience challenging and difficult. For example, the weather is a big uncertainty, then there is the question of waiting till night time to do the activity and finally, many astronomical phenomena like moon phases require long periods of time to allow sufficient data gathering. This is where the planetarium provides the advantage. Activities can be done during the day time and the simulated sky can be manipulated for any time of future or past or changed in a step-wise manner.

The first planetarium at Tarleton State University was installed in 2001 with funding from the US Department of Education. It had Digistar II projection system with slide projectors and stereo sound system. Until 2014, the planetarium offered a variety of programming to the public, school districts and university community. However, like every other equipment, the Digistar II system became obsolete and difficult to maintain due to unavailability of slide projectors and parts and frequent breakdowns. The university administration decided to upgrade the equipment to Digistar 5 in 2015 (see Figure 1). However, that became a reality at the cost of some conditions, that, besides its entertainment value, the planetarium must be used by multidisciplinary classes for instructional activities and in particular, by introductory astronomy classes for instruction and laboratory experience. In this paper, I describe how the Tarleton planetarium is used for laboratory activities for introductory-level astronomy classes.

Current Laboratory Activities in the Planetarium

Eight laboratory activities have been developed that make use of the Digistar 5 projection equipment. Teaching assistants can run the planetarium equipment and so the activities are written in a general fashion and the worksheet contains enough information for teaching assistants such that no specific, separate instructor sheets are required. However, if needed, customized instruction sheet can be developed specific to one's planetarium facility. The activities list is as follows and a brief description of each is given below. Complete PDF files of activity worksheets cannot be provided in this proceeding paper in light of page requirements but can be made available upon email request. Here are only a few sample snapshots of some activities are shown to emphasize the data measurements, calculations, and analysis.

1. Constellations
2. Surface Brightness and Magnitudes
3. Celestial Sphere

Figure 1. Tarleton Planetarium

4. Seasons
5. Lunar Phases
6. Kepler Laws
7. Precession
8. Cross Staff and Angle measurement

Constellations

This laboratory activity focuses on five major objectives: 1) Learning to recognize major constellation of each season; 2) Finding Ursa Major, north pole and Polaris, with orientation in different seasons and the orientation of the Milky Way; 3) Learning some common asterisms with the help of charts; 4) Learning to predict when a certain bright star will rise or set; and 5) Comparing brightness and magnitude of stars in Ursa Maoris.

Surface Brightness and Magnitudes

In this activity students learn about different definitions that relate to brightness and magnitudes. The goals are: 1) To explore different types of twilight and its affects on star visibility, 2) Light pollution between a small city and a large city, and 3) Surface brightness of extended objects like nebulae and galaxies.

Celestial Sphere

This laboratory activity focuses on four major objectives: 1) Learning the names and location of major circles and season markers on the celestial sphere, 2) Learning to draw a celestial sphere and represent these circles and markers, 3) Learning and using the Altitude and Azimuth grid, and 4) Observing and recording the time, Altitude and Azimuth of the Sunrise, noon and Sunset on each equinoxes and solstice day.

Seasons

This activity has four major goals: 1) Learning to recognize the constellation of the Zodiac, 2) Learning the Right Ascension Declination grid system, 3) Recording the position of the Sun on the 21st of each month, more specifically, the azimuthal position at Sunrise and Sunset, the noon time altitude and declination of the Sun, and 4) Learning to plot a graph of altitude and declination as a function of time (21st of each month). From the data and graphs, student are asked a series of 15 questions to do simple calculations and figure out the longest and shortest days and nights, obtain the tilt axis of the Earth, learn the significance of the tropic of Cancer and Capricorn lines on the Earth's map, predict the change in seasons that would occur if the tilt axis were to change. A snapshot of the table for collecting data is shown in Figure 2 and here are some sample questions. Readers who are interested in additional literature related to teaching seasons in the planetarium can refer to Yu et al. (2015).

1. Determine the amplitude of the curve in graph you plotted. Show your calculations.
2. How does the amplitude compare (i.e. is it similar or different in value) to the earth axis tilt of 23.5 degrees?
3. If the amplitude came out to be 90 degrees, what would seasons look like on earth?

Lunar Phases

This activity has four major goals: 1) Understand the orbit of the Moon around Earth and the change it brings to the visibility of the Moon, 2) Learn to identify the phase of the moon by observing it in the sky, 3) Learn the relationship between Moon phase, its rise and setting time and its position in the sky, and 4) Be able to predict future dates of various Moon phases. In the activity, students collect observational data over a full lunar month (see Figure 3). Following a series of example calculations, they complete calculations with their own data and answer a series of questions which are designed to help them learn how to predict the position, phase, and time of a certain lunar phase. All together, there are 15 questions in the activity and here are few example questions:

1. Compare your sketch for two last quarter moons, are they same or different? If so, in what respect they are different? Explain why?
2. Predict the date for the next new moon phase. What is it?
3. The moon rises at 6 pm. What will be its altitude when it is on the meridian? Hint: see example 1.

Kepler's Laws

This activity has four major goals: 1) Learn the Kepler's laws of planetary motion, 2) Collect orbital period data on the four Galilean moons of Jupiter, 3) Learn how to compute the mass of planets by observing its natural satellites, and 4) Learn how astronomers estimate the size of our solar system using Kepler's laws. In a planetarium environment, the best way to identify the four moons of Jupiter is to show their orbital trace around the planet on the dome. Students collect the data for all the moons in their separate tables and then perform calculations to determine the mass of Jupiter with the help of four questions in the data analysis section.

Precession

This activity has three major goals: 1) Study the wobble motion of the Earth's spin axis, 2) Estimate the period of precession, and 3) Learn the observational changes in the sky, particularly as it applies to the north celestial pole. The students are shown the night sky at a present date and time and are asked to document their observations on the declination and altitude of a few properly chosen bright stars. They are then shown the night sky at a future date several thousand years later and asked to record the declination and altitude of the same brights stars again. Through a series of questions, students explore the changes precession brings about to circumpolar constellations, and estimate the period of precession.

Cross Staff and Angle Measurements

The objective of this activity is to measure angles in the sky by making and building a Cross-Staff. The goals are: 1) Design and build a Cross-Staff, 2) Use the Cross-Staff to make altitude and azimuth measurements of the Moon, and 3) Make angular measurements of the stars in the big dipper on a clear night sky and in the planetarium and compare

	A	B	C	D	E	F	G	H
Date -21st day Of Month	Days in Month	Number of Days passed	Sunrise Time	Noon Time	Sunset Time	Altitude at noon	Declination at noon	F-G =X
January - 2016	31	21						
February	29	52						
March	31							
April	30							

Figure 2. Sample Table for collecting data on Sun: Seasons Activity

the results. Figure 4 shows the material required to construct the Cross-Staff. Figure 5 shows the triangle used for trigonometry calculation. Figure 6 shows the table that is used in collecting data for the moon.

Activities Under Development

Among the very best fundamental nighttime astronomy activities are to measure the magnitude of a pulsating and/or eclipsing binary star as a function of time and in comparison to nearby constant stars. However, most variable stars have period of the order of several hours and often one needs to be at a dark site to obtain data viable for plotting the light curve. In addition, weather uncertainty could make this a challenge not to mention the administrative increase in work for the instructor for very large classes. Now imagine if you could scale the period of the variable in the planetarium sky so that the required data could be collected in a couple of hours in a closed environment during night or day time. With Digistar 5, it should now be possible to implement variation of a known variable star against the background of nearby constant stars. While we don't have a working activity at the time of this writing however, efforts are underway to develop the necessary Digistar 5 scripts that can facilitate observation of a variable star in the planetarium.

Discussion

In this paper I have shown that it is possible to use the modern planetarium facility with Digistar 5 equipment to teach introductory astronomy and use it as a medium to offer several laboratory activities. These laboratory activities would be very challenging to do with large classes during night time and with the uncertainty of the weather conditions. Institutions and instructors that do not have Digistar 5 equipment but other systems or smaller mobile inflatable planetariums can easily adopt and modify these activities. Further, those who do not have any kind of planetarium facility can actually modify and adopt it to work with computer-based planetarium software like the freely available Stellarium. In fact, almost all of these activities were first tested with the Stellarium software during the development stage. All of the activities described in this proceeding paper are available to anyone under the Creative Common Attribution-Noncommercial-ShareAlike 4.0 International License. The author requests that people who use these laboratory activities in their astronomy classes provide feedback for improvement and any errors that are found.

Year: 2018

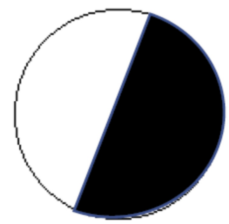
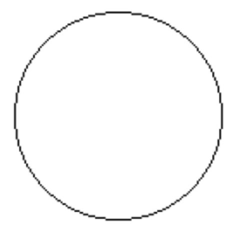
Date	Moon Rise		Moon Set		At Local Time				
	Time	Azimuth in degrees	Time	Azimuth in degrees	Local Time	Lit on side (E, W, new, Full)	Phase	Elongation in degrees	Phase appearance
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Feb. 7	00:47	103	11:50	253	09:54	E	Third quarter	235	
Feb 10					03:00				

Figure 3. Sample Table for collecting lunar data: Lunar Phase Activity

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Thanks are due to Tarleton State University administration for making it possible to upgrade the planetarium equipment to Digistar 5. Thanks are also due to the planetarium staff for allowing me to teach astronomy in the planetarium and carry out the laboratory activities. Thanks are due to the creators of Stellarium, and sponsors and organizations that support the free software, without which it would have been difficult to test the content of the activities. Thanks are also due to Michigan astronomy program, a few of the activities were modeled on the planetarium based labs produced by the Michigan Astronomy and were made available under Creative common License. Finally thanks are also due to the department of Chemistry, Geoscience and Physics to provide teaching assistants to help implement the laboratory activities in my astronomy class.

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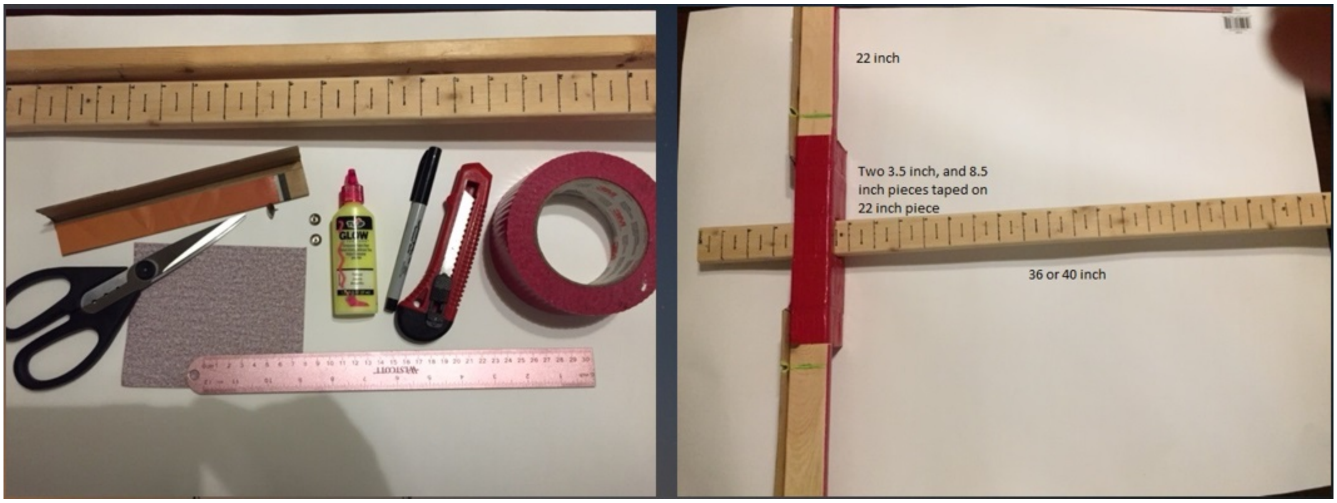

Figure 4. Materials for Cross-Staff

view of the literature. *The Planetarian*, 20(3):18–25.

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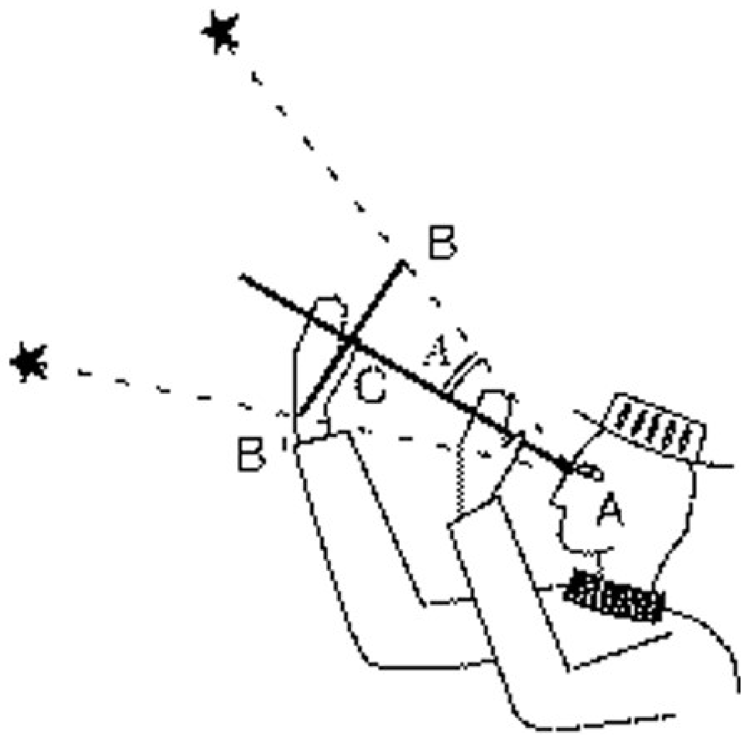

Figure 5. Triangle for Trigonometry calculations: Image source NASA

Part I

Use your cross staff to measure the altitude of the Moon and your smart phone compass to measure the azimuth for the following phases. If it happens to be cloudy or rainy during that day. Use the next day or a day earlier when it's clear the first chance. Also, if you have another engagement at that time, just do the observations couple of hours earlier or later.

A	B	C	D	E	F	G
Moon Phase	**Day Number**	**BC**	**AC**	**A**	**Moon's Altitude**	**Moon's Azimuth**
Waxing Crescent October 26th 2017 @ 22:00	5					
First quarter October 27th 2017 @ 17:00	7					
Waxing Gibbous October 31th 2017 @ 22:00	10.5					
Full Moon November 4th 2017 @ 00:00	14					
Waning Gibbous November 7th 2017 @ 06:00	17.5					

Figure 6. Table for collecting data on Moon using a Cross-Staff

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Scanning the Auroral Skies: The Athabasca University Robotic Telescope

Ian Schofield[1]*, Martin Connors[1,2], Phil Langill[2,3], Stefan Cartledge[4]

Abstract
The Athabasca University Robotic Telescope (AURT) is a moderate aperture (0.36 m) networked robotic telescope that supports teaching and research at Athabasca University, a pioneering and prominent distance learning university in Canada. This paper reviews the establishment and implementation of a robotic, Internet-based astronomical observatory whose development parallels and complements Athabasca University's auroral observatory. We discuss the unique features and challenges of the northern observing environment, give examples of teaching and research activities underway at AURT, and discuss an investigation into dark sky conditions over the AURT site.

Keywords
robotic telescopes — telescope networks — distance education — photometry

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Introduction

The aurora borealis is a fixture over the Canadian prairies, particularly during the long dark winter months given their proximity to the northern auroral zone . This roughly 10 degree wide band encircling the north magnetic pole sweeps across Alaska and the northern half western Canada. Athabasca University, located in the town of Athabasca, Alberta, is situated in a sub-auroral location at 54.6 degrees north, slightly south of the auroral oval. A critical requirement for selecting an auroral observation site suitable for research-quality all-sky observations are exceptionally dark skies (see figure 1). Population density drops off as one goes north in Alberta, so that light pollution could also be expected to diminish. Athabasca University is a distance education institution, unusually among high-enrollment universities (ca. 40,000 students), located in a small town setting. Its campus grounds in the late 1990s and early 2000s were sufficiently dark to support auroral observation, which led to the establishment of the Athabasca University Geophysical Observatory (AUGO) in 2002. The dark sky requirements for auroral all-sky observation are ideal for an astronomical observatory, so three years later, the Athabasca University Robotic Telescope (AURT) was built, co-located on the AUGO site.

Creation of AURT

The primary intended role for AURT was to serve as an automated telescope for performing sky surveys to search for near-earth objects and exoplanets. Ideally, AURT would be linked to a software pipeline that would produce a steady stream of research data to assist researchers in identifying new objects. AURT could carve out a niche role in observing high latitude objects given that there were

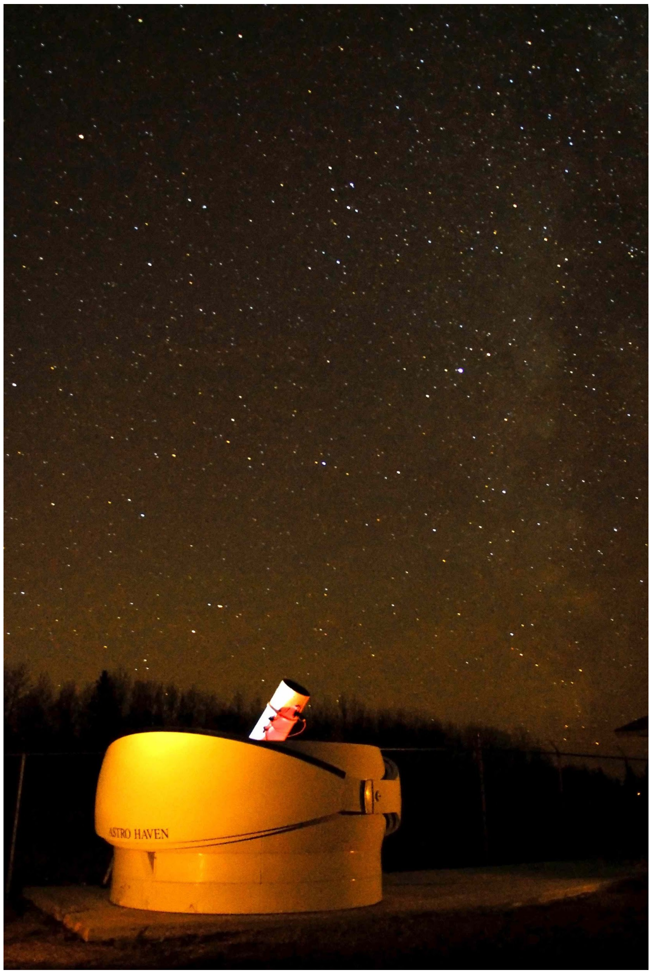

Figure 1. Athabasca University Robotic Telescope (AURT) as it appeared in 2006, set against the southern sky prominently featuring the Milky Way. Pictured is the original custom-built 14-inch Newtonian telescope. At this time, the AURT site was located in a secluded area of the Athabasca University campus, on the edge of the town of Athabasca, Alberta. It was indeed sufficiently dark to support auroral observations at the neighboring Athabasca University Geophysical Observatory (AUGO). Photo by Mathieu Meurant.

few research-oriented telescopes in high latitude areas conducting surveys of the northern skies. Although the density of observable objects is low, in principle there are interesting targets to be observed or discovered at high ecliptic latitudes. Ironically, the Earth Trojan class of objects nominally able to be discovered by such surveys was found by other means (Connors et al. 2011, 2014). Further, by taking advantage of its northerly Alberta location, AURT could become a test center for northern-based, remote, autonomous robotic telescopes, ultimately leading to the laying of the groundwork for meter-class Arctic telescopes in the future (Martin and Connors 2008). Recognizing Athabasca University's role as a leader in distance education and its mandate to deliver science education at a distance, a robotic telescope can also serve as a powerful teaching tool supporting research-based astronomy courses.

AURT reached operational status as a robotic telescope in 2006. It consisted of a f/5.6 14-inch Newtonian reflector, coupled with a German- equatorial fork mount. Both were custom engineered by an advanced amateur telescope builder associated with the Edmonton Centre of the Royal Astronomy Society of Canada (RASC). The telescope was housed in a 12-foot diameter motorized clamshell dome, built by Astrohaven Enterprises. AURT was upgraded in 2013 to address lingering technical problems with the telescope mount that were preventing reliable operation. AURT in its current state is pictured in figure 2.

The most prominent change to AURT after the 2013 upgrade was the switch to a networked, queue-based observation system, made possible by joining the Skynet Robotic Telescope Network. Operated by the University of North Carolina Chapel Hill (UNC), Skynet is a worldwide network of modest-aperture telescopes whose fundamental task is to facilitate rapid target acquisition of gamma ray bursts (GRB) (Reichart 2006). Given the rarity of GRBs, the telescope network can also be put to use serving observing requests using a queue-based observation scheduler via web-based user interface. Skynet offers a networked instrument control and data management infrastructure that allows simple, efficient and secure access to telescope observing time. It serves thousands of users worldwide and includes students, astronomy enthusiasts and professional researchers. Smith and Caton provide a detailed account of their experience adapting their legacy robotic telescope to function as a networked Skynet telescope and provide many details on the design and operation of the Skynet telescope net-

Figure 2. AURT in 2018, picturing the west side of the Astrohaven dome lowered. AURT's Celestron Edge 1400HD 0.36 m f/10 Schmidt-Cassegrain telescope, mounted on a Software Bisque Paramount ME robotic German equatorial mount, forms the core components of the AURT. AURT has been a member of the Skynet telescope network since 2014 and is one of a growing number of Internet-based moderate-aperture telescopes. Photo: Ian Schofield

work (Smith et al. 2016; Caton 2018).

Operating Environment

The observing environment in Athabasca allows for extended observing periods during the winter months due to its high geodetic latitude. For example, in December, astronomical darkness can persist as long as 14 hours. Provided there are clear skies, long periods of darkness are advantageous for performing long photometric observations, such as in collecting light curves. The tradeoff to long wintertime observing is proportionally short dark sky periods during summer months. AURT experiences no astronomical twilight between May 8 and August 4. The Athabasca region occasionally witnesses dramatic auroral activity such as pictured in figure 3. The northern half of Western Canada attracts auroral researchers and tourists as it is an accessible region in the northern hemisphere from which to see the northern lights. Despite the breathtaking beauty of the aurora borealis, it is a form of natural light pollution and does affect astronomical observations.

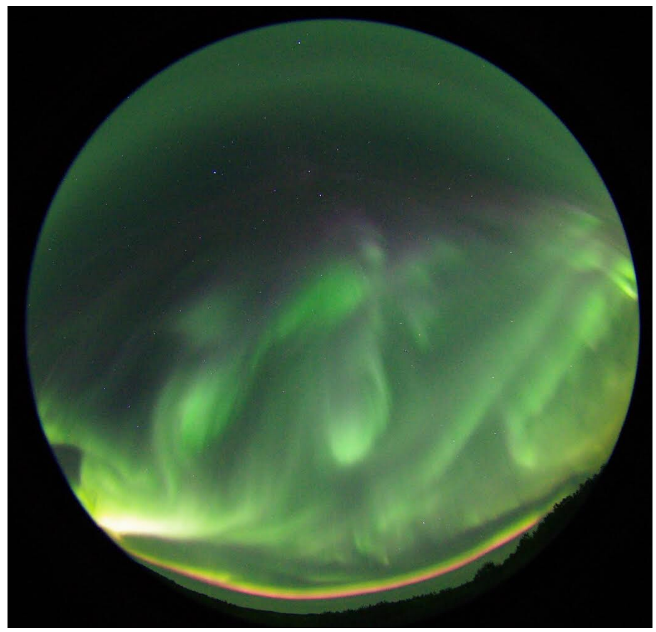

Figure 3. Astronomical observations can be affected by bright auroral displays, such as the one pictured, which occurred on September 16, 2017. This all-sky auroral photograph shows the skies above the Athabasca University Geospace Observatory, situated 25 km southwest of the town of Athabasca. The bottom of the image shows the northern horizon. Photo: Athabasca University Geospace Observatory.

Athabasca's temperate continental climate (Köppen class Dfb), bordering on subartcic, means that in the prime winter season, low temperatures, exacerbated by wind, affect nearly all the components of the observatory. As temperatures dip below -30 degrees C, mechanical systems gradually lose reliability: solenoid switches start to stick, camera filter movement becomes labored or seizes, and the mount begins to generate errors. As recommended by the manufacturer, we swapped out the default worm gear lubricant and replaced it with low temperature grease. As a rule, we halt operations with AURT when temperatures dip below -30 degrees C. However, most affected, from our experience, is the dome.

Snow in northern Alberta is usually relatively light, but it must be swept off the dome after a fresh snowfall. Unlike tracking domes or roll-off roofs, clamshell domes like the Astrohaven have the potential to dump accumulated snow onto the telescope below when opened. When snow resting the dome melts under sunny conditions, water drippings freeze and accumulate on the sides of the domes, which can jam the dome when opening. Furthermore, ice film can develop along the seam between the two outer shells, effectively welding them shut. Damage to the fiberglass dome shells has happened when the frozen or jammed outer shells come apart and come crashing down. We run a heating cord along the seam of one of the outer shells to prevent ice film formation, and keep the dome cleared of snow to prevent snow melt from occurring.

Applications

Teaching

Astronomy distance education courses have been offered at Athabasca University since 1987 and have all contained computer-based instructional content that represented the state of the art at the time (Connors 2003). Presently, Athabasca University has two senior-level project-based astronomy courses (Connors et al. 2019), Astronomy 495 and 496, that offer students the option to collect data using AURT. When the student begins the course, he or she will draft a learning contract that outlines the objectives of the study. The plan, upon approval by the supervising instructor, will detail what kind of data is required and how it will be gathered. This may include telescope observation, but other types of instrumentation, such as tracking digital cameras, have also been used in course laboratory work.

In the case of a telescope-based project, AURT's telescope operator engages with the student by setting up a Skynet account, provide operating instructions, and answering questions through email. Students are responsible to perform their own data reduction using tools recommended by their supervisor. AURT is usually involved in one student research project per observing season that runs from September through March. Although we try to start student projects as early as possible, poor weather and mechanical failures can slow down or derail student lab work. In the event that observations cannot proceed within the confines of the semester, we have worked out telescope time sharing arrangements with our Skynet partners to acquire telescope time.

Collaboration

Skynet has allowed us to enter into collaborative research and teaching arrangements with other universities and organizations. We have shared telescope time via Skynet with the U.S. 4-H Skynet Junior Skynet Scholar program (Childers et al. 2015), a program that engages middle school youth to explore the universe using robotic telescopes and analyze their data. Participating students have published variable star observations using data from AURT.

Starting in 2015, we entered into a teaching collaboration with MacEwan University that has enabled three of MacEwan's junior and senior level astronomy courses to use AURT for conducting course lab work and student-led observing projects. In 2017, MacEwan University's third-year planetary systems course used AURT to perform photometric light curve measurements of exoplanets. Students were asked to confirm attributes of known exoplanets using AURT by observing their transits. Students selected targets of interest, planned the observations, then loaded them into the Skynet observation queue through the classes' Skynet account that was set up for the course. Once the observations were completed and data downloaded, students analyzed the resulting light curves and reported on the observed planetary characteristics, comparing their results to those reported in the literature. Example data appear in figure 4.

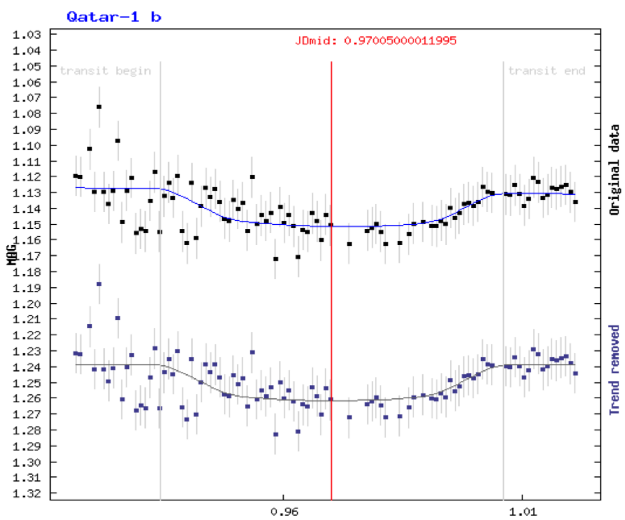

Figure 4. An example exoplanet transit observation of Qatar-1 b, taken from data gathered in the Winter of 2017 by MacEwan University student Jared Fairbanks for the PHYS 324 Origins of Planetary Systems course. This light curve, plotted from data collected by AURT, shows the raw and fitted light curve at the top. Below appears the same photometric data, with linear and quadratic trends arising from sky brightness and airmass removed. In total, 6 students used AURT to generate light curves from multiple exoplanet systems in order to confirm their attributes.

AlgolCam

As an alternative to telescope-based observations, we have had success using robotic tracking digital cameras fitted with consumer-grade zoom lenses to produce photometric light curve measurements. The system, similar in form and function as the Panoptes survey camera (Guyon et al. 2014), is called Algolcam (Connors et al. 2016). Using a 50-200 mm f/4.5 zoom lens, set to 85 mm focal length, Algolcam is capable of imaging a 10 x 15-degree field of view and capturing objects as faint as 12th magnitude with a 30-second exposure under optimal dark sky conditions. The current Algolcam design, shown in figure 5, operates under an auroral observation dome at our current auroral observatory, the Athabasca University Geospace Observatory (AUGSO). A new Algolcam design, currently in development, will be weatherproofed for outdoor operation and not require an enclosing structure. Several of our students have used Algolcam for collecting exoplanet light curves in support of their senior-level astronomy course work and have reduced their data using Muniwin for photometric image analysis, and astrometry.net (Lang et al. 2010) for field cataloging. Once Algolcam moves out of the experimental phase, we anticipate it will be an effective low-cost teaching tool, with applications in automated sky monitoring.

Figure 5. The first version of Algolcam, a tracking DSLR camera fitted with telephoto lens, used for performing photometric measurements on variable stars, with applications in low cost sky surveys, sky monitoring and teaching. Photo: Martin Connors

Dark Sky Assessment

New building development near the Athabasca University campus began to degrade dark sky conditions at the AUGO site as early as the late 2000s. H-beta narrowband optical measurements of proton precipitation aurora (Sakaguchi et al. 2015), which are highly susceptible to light pollution from street and architectural lighting, were becoming increasingly difficult to perform. This set into motion the decision to relocate auroral research outside of the town of Athabasca and establish a new auroral observatory removed from the town's light pollution footprint. The Athabasca University Geospace Observatory (AUGSO) was opened in 2012 in a dark sky location 25 km southwest of Athabasca. AUGSO hosts multispectral auroral optical, radio and magnetic instrumentation operated by Canadian and international partners. In November 2016, University of North Carolina installed a robotic telescope at the AUGSO site. The 16-inch Richey-Chretien telescope, originally used in the UNC PROMPT cluster in Chile, went online in January 2019.

Simultaneous sky brightness measurements at the AUGO and the AUGSO sites were initiated in October 2017 in order determine if development, which has continued unabated since 2010, is affecting our ability to view faint objects with AURT. To quantitatively measure sky brightness, we turned to the Unihedron Sky Quality Meter (SQM), which is commonly used in the amateur astronomy community (Langill and George 2017). The SQM measures sky brightness in terms of visual magnitudes per square arcsecond from a patch of sky spanning 20 degrees. The SQM's peak sensitivity, dictated by the transmittance of its internal filter, spans the visible spectrum from 300 and 700 nm, peaking around 540 nm. Pierantonio Cinzano's technical report on the Unihedron SQM (Cinzano 2005) provides a comprehensive analysis of the SQM device. Simply speaking, an SQM reading tells you the maximum magnitude object (meaning faintest object) you are capable of observing under the given sky conditions: the higher the visual magnitude, the darker the skies are. An exceptionally clear dark sky suitable for astronomical observing is equal to a SQM reading of 21.6, which is equivalent to a Natural Sky Unit (NSU) of 1. This unit, first described by Christopher Kyba in 2015, was based on sky brightness measurements made at Kitt Peak Observatory using a Unihedron SQM (Kyba et al. 2015).

We placed a Unihedron SQM-LE meter at the AUGO observatory, located in Athabasca, and another at the AUGSO, our current auroral observatory and dark sky site. The SQM devices were installed pointing towards zenith under the observatory's auroral observation skylights, which are composed of spectrally transparent (from IR to UV) GS2458 acrylic material acrylic material. Both devices are queried every 60 seconds by software that gathers and archives the data. By examining the SQM measurements over an extended period, we expected to see a gradual increase in the brightness of the sky over the Athabasca site. A similar study was conducted by the University of Calgary's Rothney Astrophysical Observatory (RAO) in 2016 (Langill and George 2017). Like ourselves, RAO faces similar challenges with deteriorating dark sky conditions, since we are both located on the edge of expanding urban development.

Looking for gradual increase in sky brightening in the data has proven to be difficult, due to numerous factors in play: sky cloudiness, phases of the moon, the aurora borealis, and possible darkening due to smoke particulates from summer forest fires. Similar to Langill's study, which saw the overall sky brightness over RAO between 2012 and 2015 remain relatively stable (which they attribute to effective light pollution bylaws), we did not see any detectable increase in sky brightness over the span of the data set. Figure 6 summarizes our SQM measurements taken at both sites from mid October 2017 to November 2018. The red trace shows data from AUGO (Athabasca), while the black trace depicts data from AUGSO (rural Athabasca County).

Some interesting patterns appear in the SQM data. By following the time series month by month, one can pick out the lunar cycle as represented by the monthly rise and fall of the sky brightness. The gradual widening and narrowing of the daily sky brightness curve clearly show the long nights of winter and the short nights of summer. In dark, moonless conditions, the sky brightness curve from AUGSO, being a dark-sky rural location, will appear tall and flat-topped. Similarly, we see a similar curve from AUGO, but a little less tall. In the case of cloudy conditions, however, the sky in town is

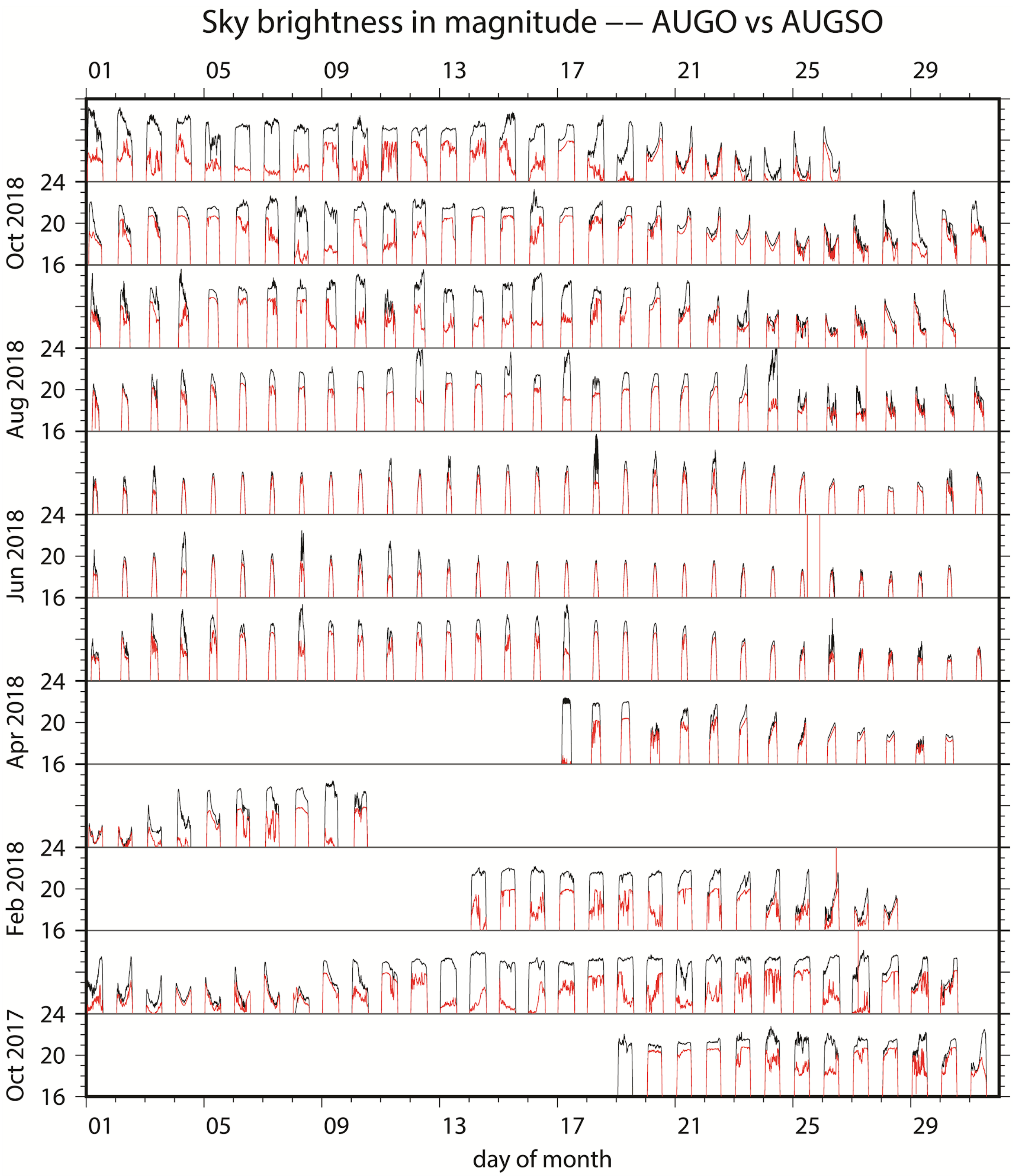

Figure 6. SQM measurements at AUGO / AURT site (in red) overlaid with SQM readings at the AUGSO site (in black). A clear offset between the data point to a difference in sky brightness magnitude between the AURT site in Athabasca, Alberta and the darker AUGSO site, located 25 km southwest of the town of Athabasca.

significantly brighter due to urban lighting reflecting off the clouds. On cloudy nights, skies are extremely dark in the country, while pale gray in the lighted urban areas. The rising and setting of the moon chisels out a rounded bite off the top of the tooth-like sky brightness curve.

It was necessary to identify a handful of nights where the sky was simultaneously dark and clear over AURT and AUGSO. To confirm that the sky was truly dark and clear (which generally should apply to both sites, since they're only 25 km apart), we consulted imagery taken by our Auroral all-sky imager (ASI), a Princeton Scientific ProEM EMCCD camera. A second all-sky camera, a Pentax APS-C format digital SLR, provides back up imagery where gaps exist in the EMCCD record. Additional confirmation on sky conditions was provided by Nagoya University's Canadian-based OMTI imager, based at AUGSO. ASI imagery from May 2018 show some exceptionally dark nights that were cloud free. The darkness may be due to the lack of red auroral emissions (630 nm), which fall within the SQM's range of spectral sensitivity. These emissions can be detected in auroral all-sky imagery, but their study is outside the scope of this paper. When they are not present, or if they do not affect astronomical imaging, the AUGSO site may at times be even darker than our averaging indicates.

There are certainly sources of systematic error, which we glossed over when doing this study. Namely, we did not measure the offset between the two units. We also did not consider the opacity of the domes, and the effect of aging of the SQM's bandpass filters. As the SQM's internal filter ages it becomes increasingly opaque, which biases the data towards higher than actual SQM sky brightness measurements. Langill's 3-year study accounted for filter degradation and reports a filter darkening rate of 0.0015 magnitude / square arcsecond / month (Langill and George 2017). We began our study using factory-new SQM units, and with only 13 months of usage, we expect their filters will be close to factory specifications. However, as we continue to gather data, we will factor in the effect of filter aging.

We identified 15 nights containing periods of exceptional dark sky conditions: free of cloud cover, moon or active aurora. We determined the average SQM sky brightness that fell on these days, within the optimal dark sky periods. The sky brightness averages, appearing in figure 7 as horizontal traces, point to a full magnitude difference in sky brightness between the rural AUGSO site and the near-urban AUGO / AURT site. The best dark sky conditions at AUGSO averaged around 21.6 visual magnitudes / square arcsecond (incredibly, as good as found at Kitt Peak), and 20.6 at AURT, on the edge of the town of Athabasca.

The SQM data set shows pronounced dark periods on August 12, 15 and 17 in 2018 that may be due to peak smoke conditions that occurred at around the same time. PM2.5 air pollution measurements over south Edmonton peaked in a natural pollution event due to wildfires several hundred km to the west during this period. PM2.5 measurements describe the quantity of fine particulate matter such as smoke in the atmosphere. These peaks in airborne particulates point to the heavy wildfire smoke that blanketed Alberta at this time. This interesting correlation between air pollution and sky darkening demonstrates that the SQM can be applied to atmospheric environmental monitoring. Remarkably, on some days the smoke was so dense that the SQM meters recorded it in daytime, although at magnitude levels lower than those shown in Figure 6.

Summary

AURT continues to serve as Athabasca University's astronomical teaching and research observatory and has found a role in providing student-led data gathering for intermediate and advanced undergraduate astronomy students. It may form a valuable resource for students in a proposed distance education M.Sc. program in Science. Since joining Skynet in 2013, AURT has been used by national and international observers and has a unique role as Skynet's most northerly observatory. As such, AURT fills an important niche in that it is capable of viewing objects only accessible at high latitudes and can take advantage of long observation periods during winter months. The development of AURT has paralleled and complemented Athabasca University's development of auroral observatories and has certainly benefited from the advanced infrastructure developed for its original and current auroral research facilities. We continue to use AURT for

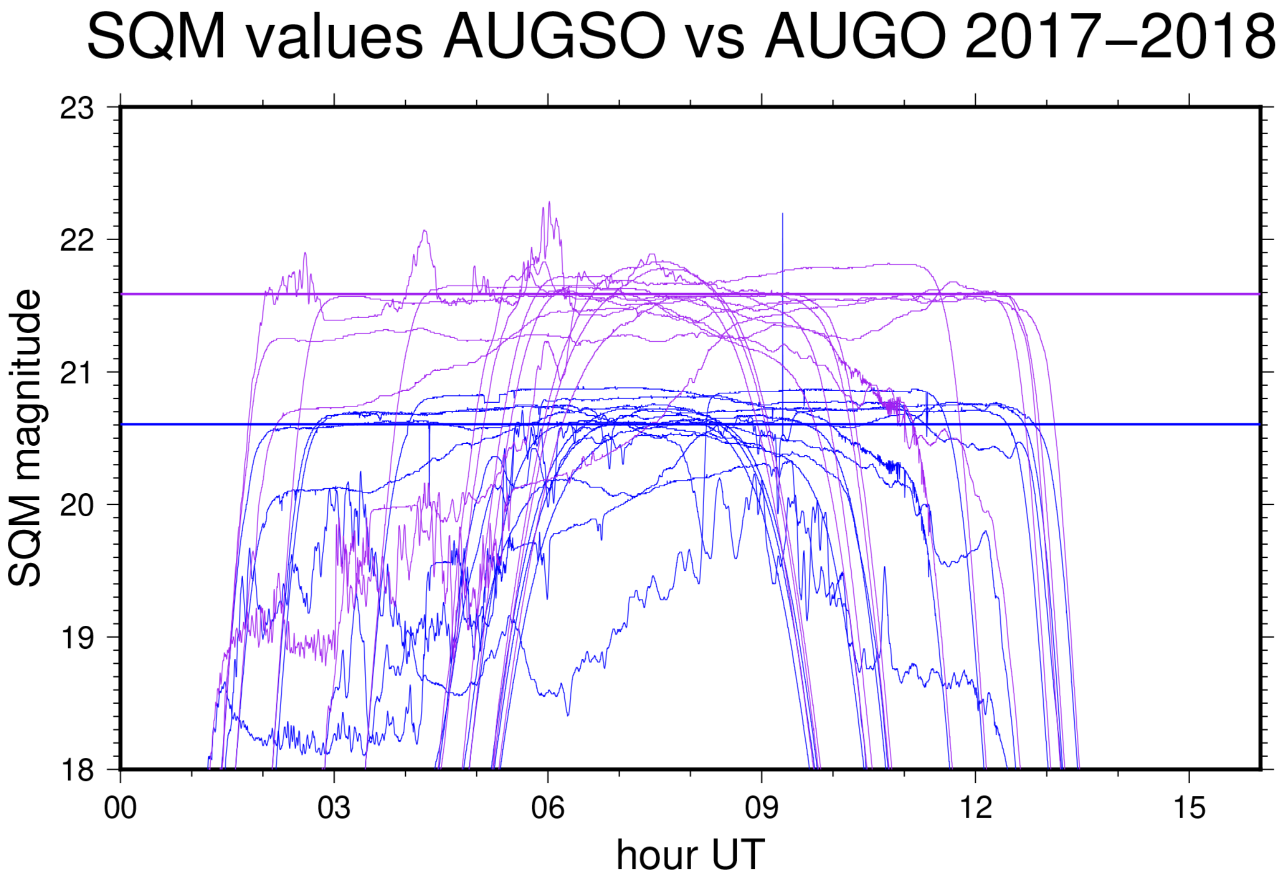

Figure 7. A subset of SQM sky brightness measurements from the AURT / AUGO observatory (in blue) and AUGSO observatory (in purple) taken between October 2017 and 2018. A clear distinction between the sites can be seen by overlying the data from 15 nights identified to have optimal dark sky conditions. The flat horizontal lines represent the average SQM sky brightness magnitude detected at the sites. At AUGSO, average sky brightness magnitude is 21.6, while at AURT / AUGSO, it is 20.6, a full magnitude lower. SQM measurements were taken within the span of time in the data when sky conditions were dark and clear, free from clouds, moon or aurora.

collaborative teaching and research opportunities. Recently we have partnered with UNC's Skynet group to host their robotic telescope at our AUGSO auroral observatory, which is an exceptional site due to its high-quality facilities and pristine dark-sky conditions. Although we cannot at this point see an expected brightening of the night sky over AURT due to insufficient data and the many variables at hand affecting dark sky conditions, we see a 1 magnitude difference in visual magnitude between the AUGSO and AURT sites. From the data we see that AUGSO is a remarkably dark site. As we continue to gather SQM data at both locations, we expect we will see a trend in light pollution. On the other hand, if dark sky conditions remain stable at both sites, this will point to effective light pollution mitigation practices being followed at the local level, which we would very much like to see.

Acknowledgments

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New Transit Measurements of WASP 43b and HD 189733b

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Abstract

Known exoplanets not only provide excellent targets for students who are learning to acquire data with remote observatories and to process the data but also fulfill a scientific need for repeated measurements to determine the stability of known parameters. We present recent measurements taken by undergraduate students with a remotely accessed telescope at the Dark Skies Observatory Collaborative in West Texas on two well-studied exoplanets. WASP 43b has a published orbital period of 0.81347753 days and its host K7V star has a visual magnitude of 12.4. HD 189733b has a published orbital period of 2.21857312 days around its K1V star of visual magnitude 7.67. Both planets orbit within the corona of their host stars and, as such, appear to experience changes in their orbital periods, transit timings, and other parameters. We examined the historical trends, combined them with our measurements in the mid-transit timings for the stars, and determined there are significant changes. Astronomers–from college students to professionals–need this continued monitoring in order to keep system models up to date.

Keywords

planets and satellites–detection–dynamical evolution and stability–exoplanets

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Introduction

When an exoplanet passes between its star and the Earth, it blocks out a fraction of that star's observable light in a transit of the star. From the initial ingress of the exoplanet's shadow onto the star, through its full eclipse time, to its egress from the star, the time duration of the total eclipse depends not only on the planet's orbital period, but also the radii of both the planet and star, as well as the planet's impact parameter (the distance above or below the equator of the star) and distance from the star.

The transit duration corresponds to the time an exoplanet's shadow covers any part of the star. In Fig.1, between the first and final contacts, A and B, the sector of arc α is the fraction of the circular orbit for which the planet eclipses the star, $\alpha/2\pi$. The transit duration time, $T_{duration}$ is the corresponding fraction $P\alpha/2\pi$ of the orbital period. Expressing α in terms of the stellar and planetary radii, the radius of the orbit a and the impact parameter b, it is a simple matter of geometry and trigonometry to obtain the result shown in Eq.1 (Seager and Mallen-Ornelas, 2003).

$$T_{duration} = P\frac{\alpha}{2\pi} = \frac{P}{\pi} sin^{-1}\left(\frac{\sqrt{(R_* + R_P)^2 - (bR_*)^2)}}{a}\right) \quad (1)$$

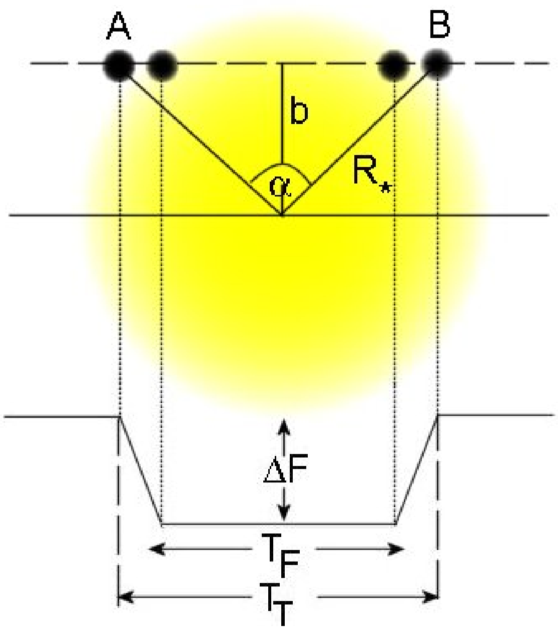

Figure 1. The transit geometry determines the transit duration which is dependent on the radius of the star R_*, the radius of the planet R_P, the impact parameter b, and the orbital radius a.

Through the measurements of these parameters, characteristics of the planet and star can be determined.

The transit is observed as a decrease in stellar flux in the light curve. A typical light curve for an exoplanet transit shows a measurable decrease in the flux on the order of about 10 - 50 mmags (millimags), or approximately 1 - 5% of the star's observed flux. The transit depth corresponds to the ratio of the cross-sectional areas of the planet to the star, i.e., to the ratio of their squared radii. The shape of the light curve reveals the relatively constant rise and fall of the flux in relation to the ingress and egress of the planet. Between these regions, however, the light curve generally follows a much flatter trend when the entire planet is eclipsing the star and the eclipsed area is unchanging. The midpoint of this flat region defines the midpoint time, or epoch, of the transit and is the point at which the centers of the planet and the star are observationally aligned and from which future transits are periodically predicted. The duration of the transit is manifest as the width of the well-shaped curve, from just before its ingress to after its egress. Figure 2 shows a light curve extracted from data illustrating these characteristics.

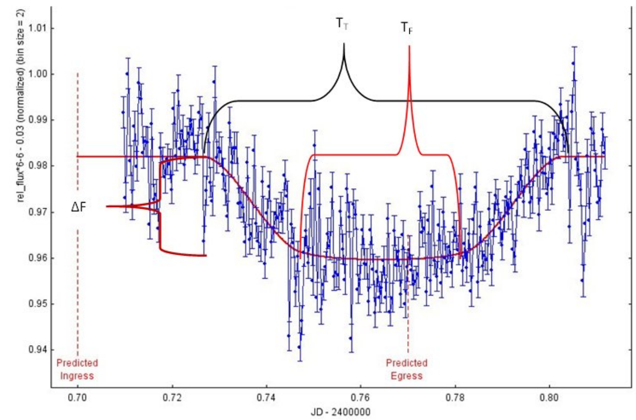

Figure 2. The shape of the light curve characteristically includes the depth and width of the transit, and its ingress, egress and epoch, thereby delineating both the planet's full eclipse and its total eclipse. In addition, the curve exhibits the effects of limb darkening.

In Fig. 2 the blue data points have a model curve fitted as a solid red line. The shape of the transit fit is not flat but curved as a result of limb darkening: At its limb the star emits less light than from the interior and so the planet blocks less light. By determining a model least-squares fit to the light curve, four key physical parameters can be measured: The planet's orbit period P, the transit flat time T_F (of the full eclipse), the total transit time T_T (of the total eclipse), and the change in stellar photon flux ΔF; the last three of these are denoted in Fig. 2. The period is not immediately apparent in the light curve, but can be obtained from a periodogram analysis of the light curves from several separate transits. The total and flat transit times as well as the transit depth are measured from the model curve.

From these four parameters Seager showed that parameters can be deduced, including the semi-major axis a and angle of inclination i of the planet's elliptical orbit, as well as the radii R_P and R_* the planet and star, respectively (Seager and Mallen-Ornelas, 2003). Figure 3 illustrates the relationships among the measured parameters and the calculated parameters.

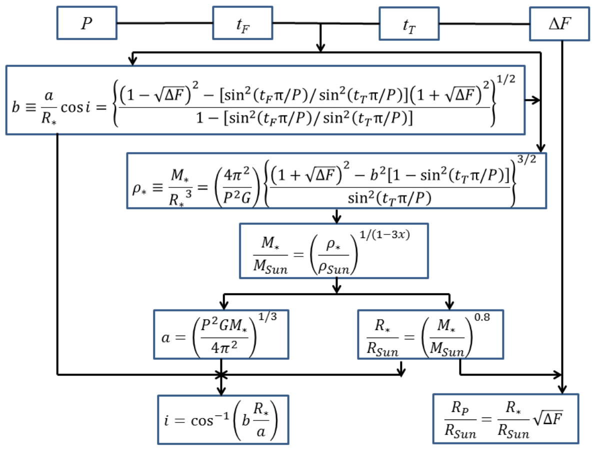

Figure 3. In measuring the period, transit flat time, total transit time, and change in flux, other key parameters can be deduced, including the planet's impact parameter, the star's mass and density, the semi-major axis and angle of inclination of the planet's orbit, and the sizes of both the planet and star. The latter four are the most important to this analysis.

WASP 43b

WASP 43b was discovered in 2011 in the Wide Angle Search for Planets (WASP) Project (Hellier et al., 2011). The planet is described as a hot Jupiter transiting a cool K7V star with a surface temperature of 4400 K, mass of 0.6 $M_\odot$, and a 15.6 day rotational period. The hot Jupiter has a mass m = 2.052 M_{Jup} masses, orbital period $P = 0.81347753 \pm 7 \times 10^{-7}$ days, and semi-major axis $a = 0.01526$ AU. WASP 43b is the hot Jupiter-type exoplanet closest to its parent star and, as such, the planet is expected to be phase locked with its rotation period equaling its orbital period so that the same side always faces the star.

HD 189733b

The transiting exoplanet HD 189733b was discovered in 2005 in the constellation Vulpecula near the Dumbbell Nebula, M27 (Bouchy et al., 2005). It orbits a spectral type KV star, HD 189733, which has an apparent magnitude of 7.67 mag. Although HD 189733 is part of a binary system, its far-out companion star has an orbital period of 3,200 years and does not affect the transits of the exoplanet. At a distance of 63.4 light-years from Earth, HD 189733b is the closest observable hot Jupiter to the Earth. Its mass is m = 1.142 M_{Jup} and its semi-major axis is a = 0.03142 AU.

The most unusual feature of HD 189733b is that it orbits within the star's corona, which extends out to 0.033 AU from the star, with a period $P = 2.21857312 \pm 6.6 \times 10^{-7}$ days. The planet races around its star with an average velocity of about 152.5 km/s (341,133 mph). The supersonic motion through the coronal plasma and its close proximity to the star superheat the planet to temperatures of 930 °C and creates shock waves as far out as 12.75 R_P in front of it (Llama et al., 2013).

Methods

Observations of the transits were made at the Dark Skies Observatory Collaborative (DSOC) in West Texas, near McDonald Observatory, by remotely operating the telescope from Irving, Texas. To take the images we used an f/8 Ritchey-Chrétien 16-in telescope attached to a Bisque ME II mount, as shown in Fig.4, to which was attached an SBIG ST-10 CCD camera of un-binned resolution 2184 by 1472 pixels, with a Johnson R-band filter. Because the CCD quantum efficiency peaks at 660 nanometers we used the R-band filter exclusively for our observations to maximize the camera's efficiency.

Observations were made by undergraduate students controlling the remote telescope by using TeamViewer, TheSkyX (TSX) and MaximDL (MDL) software. Approximately two hours before the predetermined start time for the transit, the DSOC control computer, and also the Bisque mount, are turned on via a switch securely accessed online. The control computer is then accessed from the Irving lab computer with the TeamViewer software, which is installed on both computers. The observatory roof is also opened to allow the telescope and cameras time to equilibrate thermally. To reduce thermal noise, the camera is set to cool continuously at $-20°$ C.

Once the star has been targeted, the exposure time is determined for a signal-to-noise ratio that avoids saturating the image (saturation occurs at

Figure 4. A Bisque ME II mount supports both the Ritchey-Chrétien 16-in telescope and the SBIG ST-10 CCD camera.

Table 1. Ephemerides for transits of WASP 43b used to determine nights for observations.

UT date	Ingress	Mid-transit	Egress
3/20/2018	8.40	8.98	9.56
3/21/2018	3.92	4.5	5.08
3/25/2018	5.54	6.12	6.7
3/29/2018	6.16	7.74	8.32

about 55,000 counts). The remote setup then automatically takes data on the star throughout the transit. Flats, darks and bias images are taken for calibration.

The ephemerides were generated from data on on the Czech Exoplanet Transit Database site (Poddaný et al., 2010). Table 1 shows the calculated ephemerides of transits of WSP 43b occurring in March 2018. Out of those listed in the table, only the 3/21/2018 transit was visible. At the other times the transit occurred at either too low altitude or near to the Moon. The ephemerides for the transits of HD 189733b are shown in Table 2. The 7/12/2017 and the 9/1/2017 transit of HD 189733b were successfully observed, whereas the other predicted transits were obscured either by sunlight, clouds, or rain.

Table 2. Ephemerides for transits of HD 189733b used to determine nights for observations.

UT date	Ingress	Mid-transit	Egress
7/12/2017	4.73	5.60	6.47
7/23/2017	6.96	7.83	8.70
8/1/2017	3.94	4.81	5.68
8/12/2017	6.17	7.04	7.91
8/21/2017	3.16	4.03	4.90
9/1/2017	5.40	6.27	7.14

AstroImageJ: Photometric Reduction

Post-observation data analysis includes subtracting the calibration images (flat frames, bias frames and dark frames) from the raw data images, and, from those corrected images, creating the light curve, which is flux or magnitude as a function of recorded time. The calibration image processing, or photometric reduction, takes place with the use of the AstroImageJ (AIJ) software (Collins et al., 2017). The data processor (DP) module creates a master frame for each of the calibration types (flat, bias, and dark), which it uses to calibrate the images one by one. After the images have been calibrated, the target star as well as several comparison stars. AstroImageJ automatically records the flux and a magnitude of each star using standard aperture photometry.

Once a light curve has been produced from the data, a model, or synthetic, curve is determined by a least-squares fit to the data. From the model fit physical parameters of the transit that were described earlier can be measured. The model curve takes into account four user-specified parameters and fits seven transit parameters and multiple detrending parameters to calculate the physical planetary parameters. The orbital period and eccentricity, the argument of its periapsis, and stellar radius are the specified input values. From the model light curve the transit parameters are the raw baseline flux, the squared ratio of planet-star radii $(R_P/R_*)^2$, the ratio of the planet's semi-major axis of its orbit to the star's radius a/R_* , the transit midpoint or center T_c, the orbital inclination i, and the quadratic limb darkening curves at ingress and egress. The model curve attempts several different variations of these parameters, incrementing them each iteration with a step size peculiar to the parameter, until it reaches the best set of fits. The goodness of the fit is measured by the χ^2/dof value, where *dof* is the degrees of freedom. For an ideal fit χ^2/dof should be approximately one. Further work with different combinations of the detrending parameters, as well as fitting the transit parameters for different set values, yield improved values for χ^2/dof.

Use of Historical Data and O-C Analysis

Another important method in this work centers on the use of historical data to extract changes in the periods, transit depths, and transit widths of known exoplanets. We use the Czech Exoplanet Transit Database (ETD) from which data on well-known transits that have been contributed by numerous observers can be downloaded and analyzed (Poddanỳ et al., 2010). The quality of the data in the database is ranked from 1 to 5, where 1 represents data with the smallest uncertainties. With multiple values of transit midpoints, it is possible to perform an O-C analysis, which calculates the difference between the observed mid-transit times and the calculated mid-transit times obtained from knowledge of the orbital period. In order to calculate O-C for a known period P, the product of the cycle number n and the period, that is, the calculated value, is subtracted from the measured (observed) mid-transit time. Equation 2 gives the O-C calculation where E is the starting observed mid-transit time, n is the cycle number, and P is the orbital period of the exoplanet.

$$O - C = HJD_{mid} - (nP + E) \tag{2}$$

Results

WASP 43b Period

The light curve obtained for WASP 43b for the 2/21/2018 transit is shown in Fig. 5. The 2×2 binned data are plotted in blue along their with uncertainties and the transit model curve is shown in black. Shown in red is the light curve of a comparison star. The predicted ingress and egress of the transit are also indicated as per the ephemerides. The best fit parameters from the model curve of Fig. 5 are given in Table 3.

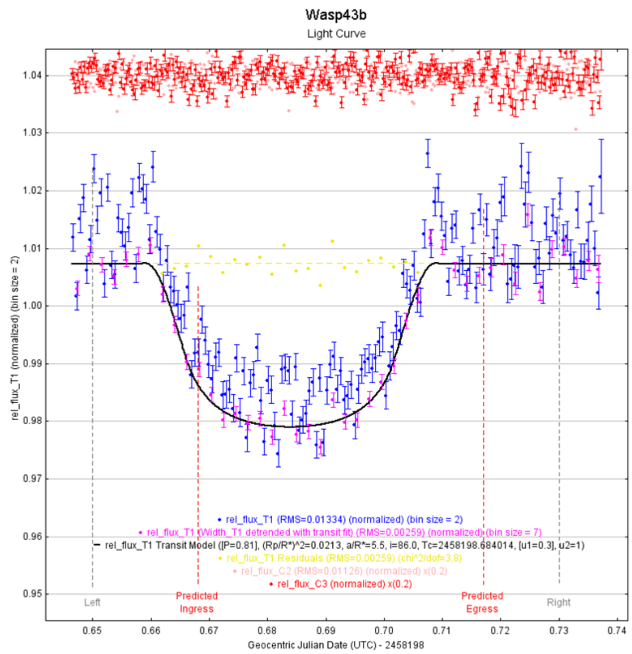

Figure 5. Processed light curve for WASP 43b showing the 2×2 binned data points in blue and the best fitted model curve is shown in black.

Table 3. Transit Fit for 03/21/2018 of WASP 43b

Parameter	Best Fit
Raw baseline flux	0.574172383
$(R_P/R_*)^2$	0.021258953
a/R_*	5.548254771
T_C	2458198.684013694
Inclination i	85.95
Quad LD $u1$	0.3000
Quad LD $u2$	0.9999

We combined six years of historical data from the Czech Exoplanet Transit Database (Poddanỳ et al., 2010) with our data to construct a graph of O-C for the mid-transit times as a function of observation date. The resulting graph is shown in Fig. 6. The graph reveals a negative slope, which indicates a possible anomaly–that the initially accepted period for the exoplanet is not consistent with observations. The best straight line fit is found to be

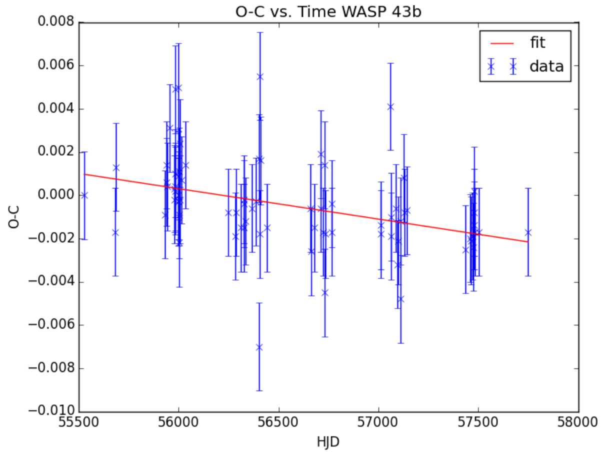

Figure 6. The observed minus calculated (O-C) transit midpoints for WASP 43b are graphed in blue as a function of time from historical data and our measurements. A linear fit to the data is shown in red. The negative slope of the fitted line indicates a period for the starting epoch that is too small.

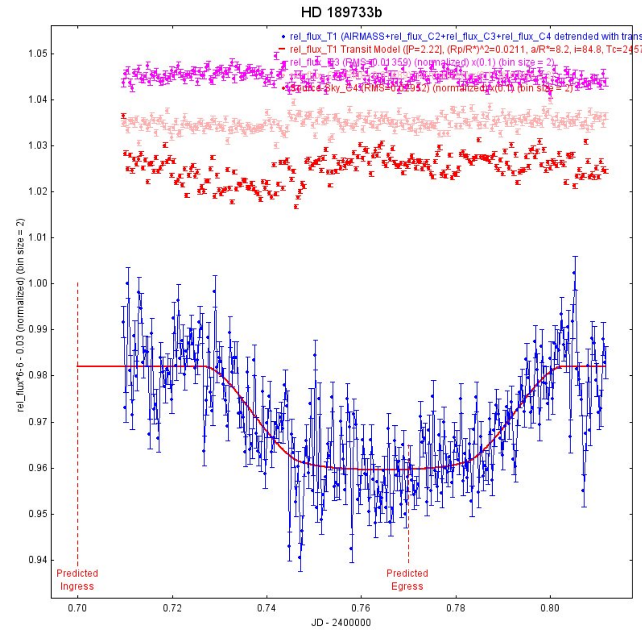

Figure 7. Processed light curve for HD 189733b showing the 2×2 binned data points in blue and the best fitted curve in red.

$$O-C = 0.07909288 - 0.00000141 \times HJD_{mid} \quad (3)$$

with a χ^2/dof of 0.868. The fitted curve yields a correction of 1.15×10^{-6} day or 0.0017 min to the period of WASP 43b. This anomaly in the period found is therefore on the order of 1 millionth of the period and is within our experimental uncertainty of the orbital period. Hoyer et al. also used a compilation of data to determine that the change in the orbit of WASP 43b is $P_{dot} = \frac{dP}{dt} = 1.5 \pm 7.3$ ms/yr, which is also consistent with a constant orbital period, and rules out orbital decay of the exoplanet (Hoyer et al., 2016).

HD 189733b Transit Period O-C vs. Epoch

The processed light curve for HD 189733b is shown in Fig. 7 and the values extracted from the fit are given in Table 4. Light curve analysis and modeling produce planetary parameters, which, when combined with auxiliary historical data, allow for inferences to be drawn regarding the orbital evolution of HD 189733. The inclusion of historical data is necessary in order to observe the accumulation of small changes over a very long time period; the Exoplanet Transit Database has recorded data for HD 189733b for as far back as September 2005, and continues, currently, up to September 2016 (Poddaný et al., 2010). By including our measurements with all these measurements, the transit evolution of HD 189733b can be extended back a full twelve years, and changes can be deduced that are predictive of the planet's future evolution.

Table 4. Transit Fit for 07/12/2017 of HD 189733b

Parameter	Best Fit
Raw baseline flux	8.477195017
$(R_P/R_*)^2$	0.024323961
a/R_*	8.644306433
T_C	2457997.762563860
Inclination i	85.51
Quad LD $u1$	0.947585262
Quad LD $u2$	-0.243269972
AIRMASS	0.007914396

Measurable changes are found in the mid-transit times, as shown in Fig. 8 in which O-C values are plotted as a function of cycle number. Least-squares fits to the data were made. We use the

Akaike Information Criterion (AIC) to determine if a parabolic fit is a better or worse-fitting model of the data than a linear fit. The AIC is calculated from

$$AIC = N\log(RSS/N) + 2k \tag{4}$$

where N is the number of observations, k the number of model parameters, and RSS the residual of the sum of squares for the fit. We find that the quadratic fit gives a lower AIC and indicates a better fit of the data. A parabolic fit of the form Ax^2+Bx+C,yields the coefficients shown in Table 5. We made fits for both the best of the historical data, Ranks 1-2,(see the first three rows in Table 5) which included our data and also for all the data (Table 5 second three rows. The fitted curve shown in red in Fig. 8 is for all the data. We discuss the meaning of negative coefficient for the quadratic term in the next section.

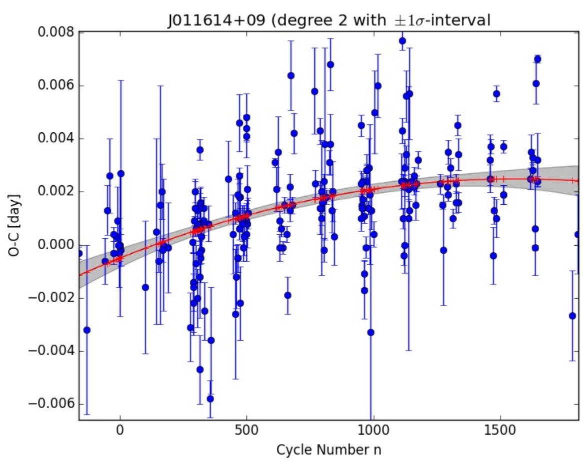

Figure 8. The graph includes both the historical data and the 7/12/17 and 9/1/17 transit data, plotting them against a $\pm 1\sigma$ deviation band. Though period calculations for O-C normally fall on the order of hundredths, these points are only thousandths.

Discussion

Several researchers have shown that precise measurements of transit time variations of exoplanets can be sensitive to other planetary bodies, such as exo-moons. In addition, transit timing variations of the exoplanets closest to their host stars can provide tests of tidal dissipation theory (Watson and Marsh, 2010). Researchers also have evidence of period changes which are attributed to mass loss by exoplanets. For example, Linsky analyzed HD 209458b using spectroscopic data (Linsky et al., 2010). Exospheric heating leading to mass loss due to X-ray and extreme ultraviolet radiation have also been estimated (Ehrenreich and Désert, 2011). Evidence of a slow period change due to frictional drag and subsequent mass loss by an exoplanet traveling with the corona of its star has also been presented (Jiang et al., 2016). Since WASP 43b is known to have such an intracoronal orbit, it would be expected that its period should be changing. The historical data plotted in Fig. 6 shows, however, a period that is consistent with it being constant over time. The least squares fit to the data suggests that any period anomaly is within 0.0017 min out of a period of 0.8134775 days. The observed variations in mid-transit times for WASP 43b were found to be within the uncertainty in measurement of the orbital period. The question that remains is why the period is constant even though WASP 43b is definitely orbiting within its star's corona.

Table 5. Summary of Curve Fitting Parameters

O-C: Parabolic Fit, Ranks 1-2	
A	-1.2283E-09 ± 5.8368E-10
B	3.8315E-06 ± 9.7849E-07
C	-5.0421E-04 ± 3.5170E-04
O-C: Parabolic Fit, Ranks 1-5	
A	-1.6325E-09 ± 4.4875E-10
B	0.0000 ± 0.0000
C	-0.0002 ± 0.0003

Projection of HD 189733b Orbital Dynamics

Figure 8 plots the deviation between the observed and calculated mid-transit times for many transits over several cycles. In such an O-C diagram the shape reveals information: If the graph is linear, the slight error in the epochal period is simply propagating over multiple transits, causing the increased magnitude of deviation. If the graph is parabolic, however, the deviations are accelerating, and therefore, the orbital period is evolving. This can be attributed to a nonzero rate-of-change of the planet's mass. The negative value of the quadratic coefficient (A) for the graph in Fig. 8 reveals a decreasing period. The best fit to the data is parabolic (with a negative value for A) for any collection of ranks of the data, as indicated in Table 5. The uncertainty in the quadratic coefficient (A) indicates that better historical data is nonetheless needed.

Orbital mechanics predicts several significant parameter changes attributable to a negative quadratic coefficient A for the O-C curve. The first of these is the rate-of-change of the period. Since A is negative, the rate-of-change is also negative and it is given by

$$\begin{aligned} P_{dot} &= \frac{dP}{dt} = \frac{2A}{P} = -(2.08 \times 10^{-10} \\ &= \pm 9.88 \times 10^{-11})\frac{days}{day} \end{aligned} \tag{5}$$

Thus the period is decreasing at a rate of 2.08×10^{-10} days per day. The parameter also describes a non-conservative mass loss from the planet of mass m which is given by

$$\begin{aligned} m_{dot} &= \frac{P_{dot}}{P}\frac{m+M_*}{2} \approx \frac{P_{dot}}{P}\frac{m_*}{2} \\ &= -(1.44 \times 10^{-5} \pm 6.95 \times 10^{-6})\frac{M_{Jup}}{yr} \end{aligned} \tag{6}$$

Thus the planet is losing mass at a rate of $1.44 \times 10-5$ Jupiter masses per year. For the case of a circular orbit, which is approximately the case for HD 189733b given that its eccentricity is 0.0041, and for constant total mass of the star-planet system, the rate-of-change of the semi-major axis, a_{dot}, decreases proportionally to the period's rate-of-change:

$$\begin{aligned} a_{dot} &= \frac{da}{dt} = \frac{2}{3}\frac{P_{dot}}{P}a \\ &= -(0.20 \times 10^{-13} \pm 6.24 \times 10^{-14})\frac{AU}{yr}. \end{aligned} \tag{7}$$

Therefore we can conclude that the planet is spiraling inwards at a rate of 9.20×10^{-13} AU per year. This conclusion implies that the planet will crash into the star when its current semi-major axis reaches the radius of the star. That time can be calculated by integrating Eq. 7:

$$\int_{a_0}^{R_*} \frac{da}{a} = c\int_0^t dt, \tag{8}$$

where the constant is $c = \frac{2}{3}\frac{P_{dot}}{P}$. This results in

$$t = \frac{1}{c} ln(\frac{R_*}{a_0}), \tag{9}$$

where a_0 is the initial orbital radius of the exoplanet.

Using the values determined from our analysis, the time for HD 189733b to crash into its star is $t_{fallintostar} = (93 \pm 45)$ million years. Improved and additional data could further verify this prediction, but these orbital dynamics are the best for the current data. Numerical simulations conclude that tidal disruption of the orbit of HD 189733b would lead to an unstable orbit on a timescale in 1.0×10^9 yr (Levrard et al., 2009). Other dissipative mechanisms, such as the intracoronal motion of the planet must be invoked to explain the decay of the planetary orbit on the order of millions of years.

Conclusion

Both WASP 43b and HD 189733b orbit within the coronas of their host stars and, as such, would be expected to experience changes in their orbital periods, transit timings, and other parameters. We examined the historical trends and combined them with our measurements of the mid-transit times for transits about the two stars. We found no significant period change for WASP 43b but a measurable change in the period of HD 189733b. Although both planets have intracoronal orbits, why one exoplanet exhibits a decaying orbit but the other does not is a subject for further research. Investigation of close–in exoplanets—those with intracoronal orbits—may reveal more facets of their orbital evolution and time scales.

We find that undergraduate students can learn how to operate a telescope remotely, acquire quality data, conduct the reduction of the raw data into light curves, and fit models to the data that allow significant scientific conclusions to be drawn.

Although data presented in this work only contributes to previous knowledge, it inspires curiosity to discover more about exoplanets. Taking and analyzing data on known exoplanets is also a way in which amateur astronomers and students can “check up” on parameters of exoplanets to see if any parameters have changed and to keep models up to date.

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Capturing the Cosmos: Teaching Astronomy (and more) through Astrophotography in Middle School

Saeed Salimpour[1]*

Abstract

The Universe provides a canvas for exploration, it sets the stage waiting to be captured and explored by imagination and science. Its capacity to provide innate aesthetically pleasing visuals and the mysteries they hold, piques the curiosity of everyone. This paper provides an overview and results from an astronomy elective as implemented in a middle school classroom over the course of 11 weeks, at a non-governmental school in regional Victoria, Australia. Students who previously had no exposure to astronomy or image processing used the Las Cumbres Observatory (LCO) network of robotic remote telescopes to capture images of astronomical objects and processed them to create colour images. The preliminary Learning Progression (LP) focusing on inquiry skills and the results of the student project are highlighted.

Keywords

Astronomy Education — Image processing — Robotic Telescopes — Remote Telescopes — Middle School Science

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Introduction

The beauty of the night sky is one of the most awe-inspiring sights, the numerous points of light scattered across a seemingly infinite ocean of black, with the fuzzy white band of Milky Way majestically punctuating the blackness. Anyone who has had the opportunity to observe the night sky away from the suffocating lights of the city, can attest to this humbling and majestic experience.

Our eyes, despite their capabilities, are blind to some of the most fascinating objects contained within the observable Universe. Only sensitive to a sliver of the Electromagnetic (EM) Spectrum, called Visible Light, our eyes are ill-equipped to detect the spectrum of visual symphony produced by the myriad objects in the Universe – galaxies, nebula, clusters of stars, planets and much more. An excerpt of this symphony is seen in long exposure images of the night sky, revealing the astounding beauty and mystery hidden to our eyes.

The dawn of photography in the mid-19th century and its application to Astronomy (Osterman et al., 2007), opened our eyes to some very extraordinary, enigmatic and awe-inspiring vistas. Astrophotography is no longer limited to big research observatories. The affordability of telescopes, imaging cameras and easy access to software (Covington, 1999; Gomez and Fitzgerald, 2017; Han et al., 2018; Legault, 2014) has allowed amateurs to “Capture the Cosmos”, or rather the objects it contains in astounding beauty. These images are not only aesthetically captivating, they are also scientifically rich. Although astrophotography started with the aim of recording scientific information from astronomical objects, it has serendipitously highlighted the innate aesthetics of astronomical objects.

The notion of astronomy as being a "Gateway Science" has been used to highlight how astronomy can be used to re-invigorate the science classroom, pique the curiosity of the students and engage them with science in general (NRC, 2001, 2011; Salimpour et al., 2018b, 2020). The richness and mystery of topics in astronomy provides a springboard into various concepts in science from basic motion to optics and beyond. Research has shown the positive classroom perceptions and knowledge changes that result from exposure to astronomy (Danaia et al., 2012, 2017), although, so far, there is some work to do to understand student attitude changes (Bartlett et al., 2018).

Over the past couple of decades, there has been a dramatic increase in Robotic and Remote telescopes, owing to the rapid progress and feasibility of technology (Gomez and Fitzgerald, 2017). However, despite this, the reviews by Salimpour et al. (2018a), show that within the school curricula, the use of Robotic/Remote telescopes (RRTs) is not explicit. The onus is on teachers to incorporate this into their lessons, given that most curricula afford the flexibility to incorporate lessons which make use of Robotic telescopes (RTs). However, as highlighted by (Cutts et al., 2018), the average science teacher lacks the knowledge required to guide students through such endeavours, and that teacher training is vital to ensure the consistent and successful implementation of RRT.

This paper provides an overview and results from an 11-week astronomy elective implemented in a Year 8 classroom at a non-governmental school in regional Victoria. A review of curricula from around the OECD, shows that middle school science curricula often include topics on light, colour and the basics of optics (Salimpour et al., 2020). This elective allowed those concepts to be taught within the rich and practical landscape of astronomical imaging. This is one example of using astronomy as a "Gateway Science".

Capturing the Light

Since the first image of an astronomical object in 1858 by William Underwood, taken of Comet Donati (North, 2008), we have seen a fantastic expansion to our view of the Universe. In the early days, astronomical photography was aimed at capturing scientific data, rather than creating a striking image. Albeit, the images created were striking given that no one had ever seen these objects in this manner. The image of the Orion Nebula (M42) by Ainslee Common Figure 1 (Osterman et al., 2007), earned the Royal Astronomical Society's Gold Medal in 1884 (RAS, 1996). This image set the stage in what was to become a new age in astronomical observations. Astronomical images of that era although black & white, carried a curiosity piquing quality, and aesthetic. Perhaps because they were never seen before, or the forms, shapes and patterns carry with them innate qualities that speak to our subconscious aesthetic.

In the mid 20th century, the image of the Andromeda galaxy (M31) by William C. Miller Figure 2 demonstrated the potential of astronomical colour photography (Miller, 1962). In the late 1970s, the work of David Malin at the Anglo-Australian Telescope, instigated the era of colour astrophotography both scientifically and aesthetically (Malin and Murdin, 1984; Malin et al., 1993). By combining images of astronomical objects taken on glass plates sensitive to different wavelengths of light, Malin was able to use dark room techniques to create striking colour images, that told the story of the physics at work. However, to the untrained eye, these images were awe-inspiring works of art in their own right.

The launch of the Hubble Space Telescope (HST) in 1990 and the images produced via its myriad of instruments over the decades, took colour imaging to an entirely new level. Bringing to the public, mesmerizing views of the Universe that their eyes could not see and their imagination could not synthesize. The colour images of David Malin and the HST image processing team revealed that the Universe

Figure 1. Orion Nebula image taken by Ainslee Common in 1883. Image credit: (Malin et al., 1993)

Figure 2. The first ever true colour-corrected image of M31. Image credit: (Malin et al., 1993)

is not a dark cold place, rather, it is permeated with rich, dynamic objects, exhibiting intricate forms and a symphony of colours hidden to our limited eyes.

In the past couple of decades, the increasing affordability of telescopes and imaging cameras has brought deep sky-imaging within the reach of amateurs, who create both aesthetically pleasing and scientifically rich images (RMG, 2017). These images, although requiring hours of work, are based on the same fundamental principles used by Malin, and the HST. Therefore, they provide fertile ground to expound the fundamental science they encapsulate in the science classroom.

Science, Art, or Both?

One aspect of astronomical images that is shared by everyone, is the beauty and mystery invoked when looking at these images. The beauty of an image is closely linked to the notion of aesthetics; however, aesthetics is nontrivial, complex and multi-faceted, rooted in philosophy and culture, both subjective and objective (Wickman, 2006). Engaging in a debate about aesthetics is beyond the scope of this paper, suffice to say that looking at images of galaxies and nebulae invokes an aesthetic experience both visually and psychologically. This experience is often global, which is judged by the prevalence in media attention afforded to astrophotography competitions.

There is a growing movement in education research to find ways in using aesthetics to re-invigorate school science in the 21st century (Lemke, 2001; Watts, 2001; Wickman, 2006). The idea of aesthetics in education while not novel (Dewey, 2005), has yet to be effectively implemented in science education. This is perhaps owing to the stereotypical binary that is propagated about Art and Science, ergo, by extension aesthetics is seen as related to Art rather than Science. This distinction goes back to the late 18th century and Kant (1931), with his proposition of Pure reason, Practical reason and Aesthetics. However, at a fundamental level there is no distinction (Root-Bernstein, 1989).

Over past few years, there has been a growing movement towards the integration of Art in STEM, leading to STEAM (Science, Technology, Engineering, Art, Mathematics) (Herro and Quigley, 2016; Kim and Bolger, 2017; Liao, 2016; Pomeroy, 2012; Zevin et al., 2015). The novelty of STEAM has instigated different reports (Kim and Park, 2012; Pomeroy, 2012; Zevin et al., 2015). Despite this, there are no empirically researched pedagogical strategies that demonstrate the effective integration (Herro and Quigley, 2016). It is worth mentioning that the intergration of disciplines into currricula is not new. The notion of an "integrated curriculum", which is what the whole STEM, STEAM movement echoes goes back 1970s (Bernstein, 1975; Pring, 1971).

During the 1980s and 90s, the Freyberg Integrated Studies project aimed at bringing innovation to curriculum and pedagogy (McKinnon et al., 1991). This decade marked the start of thematic, integrated approaches to curriculum, which saw a growing interest in incorporating integrated units of work (Lipson et al., 1993). An example was reported in Australia with the 1996 review of the New South Wales (NSW) Science Curriculum, wherein, primary teachers wanted integrated units of work in science (McKinnon 2017, personal communication). The problems with curriculum integration has been highlighted by (Mason, 1996), who highlights some of the motivation behind the support for curriculum integration: Psychological/developmental, Sociocultural, Motivational and Pedagogical. The problems identified include: Trivialisation, Assessment, Skills, Teacher knowledge, and School structure.

One could perhaps deduce that the notion of STEAM as implemented in the classroom, is to a degree governed by the "teacher's style and epistemologies".

This elective draws on the notion of aesthetics as the foundation to teach fundamental concepts in astronomy. It builds on aesthetics not only in terms of visual beauty, but rather, aesthetics in terms of experiences (Wickman, 2006). Using aesthetics provides an impetus to explore the science, by taking students on an experiential journey which they can relate to, that of beauty, mystery and discovery.

Development of Preliminary Learning Progression

Learning Progressions (LPs) have become prevalent in science education (Alonzo and Gotwals, 2012) and have gained popularity in astronomy education research (AER) (Colantonio et al., 2018; Plummer and Maynard, 2014; Testa et al., 2015). Despite their potential for being valuable to science education, there are some cautions, such as the premature imposition of constraints on instruction (Shavelson and Kurpius, 2012), if LPs are under-researched they lead to reinforcing naïve conceptions (Shavelson and Kurpius, 2012), the need for professional development for teachers (Shavelson and Kurpius, 2012), LPs should be tested in a variety of classrooms to determine that they are working as intended (Krajcik, 2012) and most importantly researchers must be critical of their work by avoiding "force fitting data" to the LPs (Krajcik, 2012). Good LPs require extensive validation to ensure they are empirically valid (Plummer, 2012). Although there are varied definitions of LPs, in general they provide a roadmap for the gradual sophistication in knowledge and skills in learners as they move from naïve notions to expert notions in the learning process (Alonzo and Gotwals, 2012). Stages in LPs do not necessarily follow the knowledge levels as explicated by the discipline, given that the focus is on a developmental approach (Piaget and Cook, 1952) and how students reason when presented with new ideas (Alonzo and Gotwals, 2012).

The development of the LP for this elective was based on a Design-based approach cycle (Collective, 2003), of multiple implementations over a period of three years. Initially, a theoretical LP was developed by reviewing literature on AER, filtering out some of the key concepts with which students have difficulty, and determining how those concepts fit into the Big Idea Goal (BIG), which is related to astronomical imaging. This allowed three overarching themes to be synthesized:

1. Basics
2. Objects in the Universe
3. Image processing

Basics dealt with the theoretical minimum that students would need, to be able to pick objects based on their location and time of year. It is aimed at understanding celestial motions from a geocentric reference frame, based on what they can observe. Objects in the Universe, was aimed at familiarizing students with the various types of objects in the Universe and their characteristics, thereby allowing students to identify those objects. Image processing, was aimed at showing students the process of colour image creation, familiarizing them at a conceptual level with the mathematical principles of image processing. In addition, this section included tutorials on using the required software.

The above framework was used to develop a preliminary hypothetical LP, which was then refined to be in its current form, as shown in Table 1. It is presented as a potential road map into how students moved to higher levels of sophistication in terms of their content knowledge and skills, in the context of the BIG. The LP uses the content capital that students bring into the classroom as the basis for creating conceptual change through gradual levels of sophistication, whereby each level provides them with new insights to question their preconceived ideas.

Elective Design and Implementation

Although in the Australian Middle School curriculum (Year 7-9), this elective does not explicitly address any of the curriculum statements, it does provide a context for teaching concepts of light, the notions of matter, and working with real scientific data. Looking at the Next Generation Science Standards (NGSS, 2018)), this elective has the potential of being used to introduce or extend the concept of Electromagnetic Radiation PSB4.

The elective was designed using material from Our Solar Siblings (Fitzgerald et al., 2018) and modified to work within the timeline and the abilities of the students. Students were in Year 8, at a non-governmental school in regional Victoria, Australia. The elective consisted of two 55 minute lessons per week, extending over a single term of 11 weeks, although in reality accounting for all the classes, it was around 9 weeks. The class consisted of 12 students (10 girls, 2 boys). Students arrived into the class with exposure to popular media topics on astronomy and the usual curious questions about black holes, aliens, the size of the Universe and the fate of the Universe.

A concept inventory – The Astronomy Knowledge Questionnaire (Lazendic-Galloway et al., 2017), coupled with in-class discussions, was used as a formative assessment tool to determine the conceptual and content knowledge of students. The results revealed that the majority of students, albeit familiar with some terminology in astronomy, had very limited knowledge on astronomical concepts, and held misconceptions, with regards to seasons, phases of the Moon, motion of stars, and astronomical images. Based on the results, the elective was designed in such a way as to not only address some of those misconceptions, rather, augment the student's knowledge in astronomy.

Students were provided with some introduction to astronomy via Socratic questioning (Elder and Paul, 1998). Where the task was to scaffold the students in exploring different concepts. This provided the stage for an inquiry-based approach, by integrating the student's content capital into the discussions and using that as a conduit to guide them to valid scientific conceptions.

The next step was to use a "Big Idea" concept to set the stage for the remainder of the elective. Big ideas are defined as concepts/questions/statements which have far-reaching implications (NRC, 2007), and deep explanatory power (Smith et al., 2004). Selecting a "Big Idea" in astronomy can be challenging (Plummer, 2012), and requires extensive investigation. However, given the limited time, the approach was to pick a topic to which the students already had a vast amount of exposure and could be implemented via RTs in the classroom – astronomical imaging was the logical pathway. This step allowed us to synthesize a Big Idea Goal (BIG), by taking the traditional Big Idea notion and making it into a practical outcome, that students aimed to achieve. For this elective the BIG was synthesized as: "I want to create a "pretty" colour image of an astronomical object". This led to the students to ask:

- What skills do I need to learn?
- What theoretical knowledge do I need?
- What tools would I need?
- What do I already know about astronomical imaging?
- What object do I choose?
- How do I know what object to choose?

Activities chosen from the Our Solar Siblings Project 1 (Fitzgerald et al., 2015), were used to facilitate the learning of theoretical concepts, which included learning about the various objects in the Universe and initial concepts about the Universe. Following some interactive lessons on Celestial Mechanics using Stellarium, basic optics and familiarizing students with the instruments they would be using to capture their images, students were asked to pick five objects that they would like to image. A GoogleForm was created to facilitate student selections, which were then queued via the LCO Observations portal.

While waiting for the images, students were introduced to the basics of imaging and image processing, starting with the Electromagnetic Spectrum and the physiology of the human eye. They were then introduced to FITS Liberator and Adobe Photoshop. The use of FITS liberator, allowed for a conceptual explanation of the idea behind stretching images, and how this was achieved using mathematical functions. A small activity was designed to get students practicing these skills by trying to create colour images using images from the Hubble Space Telescope Legacy Archive.

Results

The students worked in pairs or individually, in total 6 different objects were imaged, some students picked the same object; however, with different exposure times. The objects were: NGC5128 (Centaurus A); NGC5139 (Omega Centauri); M17 (Omega Nebula); NGC 4567/NGC 4568 (Siamese Twins); M41; M51(Whirlpool galaxy). Two images were standouts Figure 3 and Figure 4, especially because

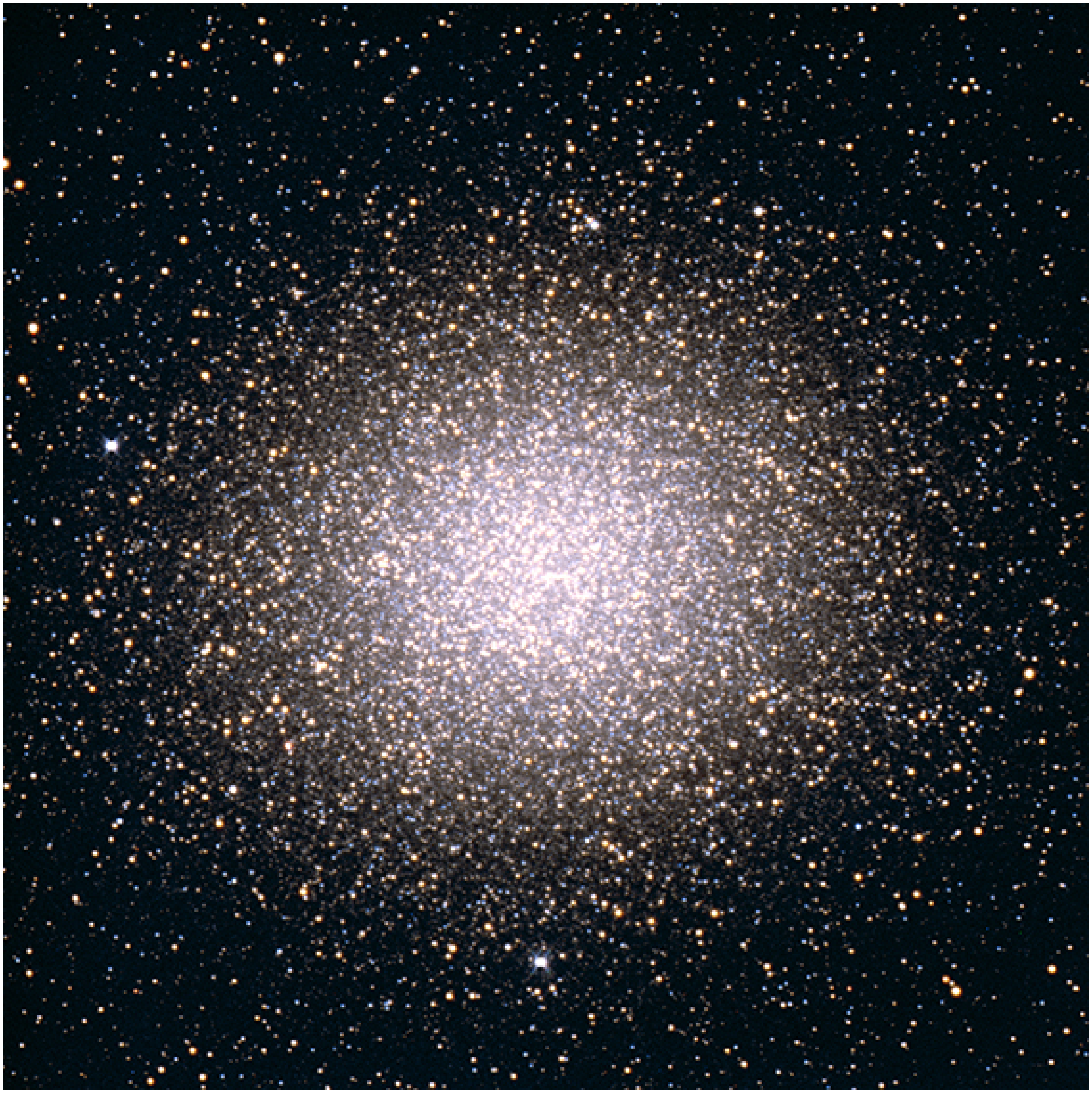

Figure 3. Colour image of Omega Centauri (NGC5139). Notice how the processing has revealed the colour of the stars in the cluster

Figure 4. Colour image of the Omega Nebula (M17).

the students who processed them had no previous exposure to astronomical imaging and only limited exposure to basic astronomy in primary school.

One aim of this elective from an educational perspective was to explore how to tap into the power of RRTs in Middle School to teach various concepts in astronomy, by highlighting the underlying physics and mathematics in the context of astronomical imaging and image processing. Furthermore, it was about showing the synergy that exists between Science and Art, and how this synergy can be practically applied in the classroom. This can be achieved by unpacking the notion of aesthetics and aesthetic experiences (Wickman, 2006). Without creating a binary between Art and Science in the classroom.

The BIG gave students a tangible outcome, they wanted to create "pretty pictures", which although requires technical skills, also requires knowledge from various domains in Physics. Students had to learn this knowledge at the theoretical and practical minimum, which meant that they found a direct application of this knowledge to the BIG. The BIG also set the stage for a true integration of Art and Science, by drawing on the commonality that both share: observation, experimentation, deduction, inference, discovery and beauty from the lens of both discipline and aesthetics.

In-class observations highlighted the excitement that students experienced when they changed the blending mode of the layers in Photoshop, thus mixing the layers and revealing the colour image. This was truly a surprise to them and in many ways a discovery in the broadest sense of the word. Discussions with the students revealed that this surprise was owing to the sense of not knowing what their images would look like, and the lack of confidence they had in themselves. This raises a valuable insight. True scientific discovery is not about knowing the "correct" answer, rather it is about discovering that the knowledge and skills you have could be used to generate new knowledge. Although students had seen the images published on the internet, with a myriad of colour palettes, they did not anticipate that they had the acquired knowledge to create the same image. Although it is worth noting that when students compared their images with those on the internet, some were discouraged as to why their images were not the same as those. They questioned whether their images were poor, or the images on the internet were fake. This opened the discussion into the discrepancy, which led to deeper discussions about colour, filters, and telescopes.

Secondly, it highlights the power of ownership, although the students were excited when they used archived images in the practice run, knowing that this image was created by them, brought with it vastly different level of motivation. Research into the concept of ownership, and how that affects student learning, has yet to be studied in detail.. However, there is a professional general consensus that it seems to s have an impact (Gould et al., 2006; McKinnon and Geissinger, 2002; McKinnon et al., 2002). Anecdotal evidence from this elective hints at ownership having a positive impact on student motivation and learning. Although a deep empirical study is required to explore these findings.

Looking at their images, the students, in addition to using terminology innate to the Arts to describe their images, now could explain the Physics behind what was occurring in the image. They could now articulate the "beauty of the science" in their images. One could argue that this is one implementation of STEAM in classroom, or more specifically an integrated curriculum.

One interesting observation was the challenge that certain students had with being given the freedom to make choices. Discussions with the students revealed that this is potentially owing to the fact that most of middle school science is based around recipe-based experiments. Whereby the students aim to get the "correct" answer by following the instructions given by the teacher. They are also good at searching the internet to do "research" when writing an essay or report, however, they are hesitant to venture into the unknown, using only their current knowledge as a guide. These students are not in the top 10-20%, nor in the bottom 10-20%, they are the middle band, which are often easily discouraged and include students with a variety of abilities and levels.

Based on anecdotal observations, this is in essence, attributed to self-efficacy. There has been research in educational psychology with regards to the effects of self-efficacy on teaching and learning (Bandura, 1982; Britner and Pajares, 2006; Greene, 2017; Schoon and Boone, 1998; Settlage et al., 2009; Zimmerman, 2000) and also the effects of emotions in science education (Bellocchi et al., 2017; Sinatra et al., 2014). One can also invoke the notion that aesthetic experiences can have wide ranging impacts on how students learn (Wickman, 2006). Although students may be excited by topics in astronomy (e.g.: blackholes, exoplanets), and inspired by the images they see in the media, this does not necessarily equate to higher levels of self-efficacy in all students when they are tasked with an inquiry-based learning task. Therefore, it is vital to embed activities that enhance student self-efficacy, before embarking on such open-ended inquiry tasks, especially when students have had little or no exposure.

Discussion

The implementation of the teaching sequence was based on:

- Teaching students the theoretical minimum.
- Allowing students to experiment with sample data
- Students imaging and processing their astronomical object of choice

One of the stages in the elective was teaching students the relevant software, students were provided with sample images from the Hubble Space Telescope Legacy Archive. This provided them with a context to learn how to use the both FITS Liberator and Adobe Photoshop. To reduce the cognitive load on students, and familiarise them with using the software, tutorial videos were made showing:

- How to install FITS Liberator, and check that Adobe Photoshop was installed (This was because the school had a site license to Adobe Creative Cloud
- How to use FITS Liberator
- How to use Adobe Photoshop
- How to create a colour image using sample data

The use of the tutorial videos meant that troubleshooting installations was kept to the bare minimum, and was done via email outside of class time. This allowed class time to be spent on discussions around the fundamentals behind imaging, the physics, and the use and theory of colour. The images students created with the HST Legacy data, were used as a content for discussions. This draws on the work done in the context of colour imaging and the aesthetics of astronomical images (Rector et al., 2017) and (Smith et al., 2015).

Why does my image look different?

Students when working on creating colour images with the data(images) they obtained using the robotic telescopes, found it challenging and at times discouraging when their images were quite different than those found on the internet. This was further complicated in instances when students with the same two images had different end results.

Some students intentionally decided to go with a particular colour palette, which was guided by how they interpreted the various aspects of the object being imaged. They discovered by experimenting with variations in the Hue, or reversing the image.

In order to address this stage in the learning, classroom discussions were based on scaffolding students through a series of questions, which required:

- Students explicitly identifying the visual differences between their images and those they had found.
- Students comparing the instruments, filters, software, exposure used for each image
- Students determining the goal of each image.

The above led to discussions about the underlying concepts, some of the key ideas that were put forward by students included:

- The way the images were stretched in FITS Liberator
- The exposure time for the images
- The resolution of the telescope
- The field of view of the CCD
- The way colour correction was implemented in Photoshop, post standard steps

Table 1. Proposed LP for Astronomical Imaging

Level	Skill/Knowledge
4	• Determining the best exposure for images by taking into consideration the nature of the object, apparent magnitude of the object, the sensitivity of the instrumentation and the filters being used • Applying stretch functions with an aim of highlighting key features • Combining images taken in various filters to create a colour image of an astronomical object • Making independent decisions about colour palette and the goal of the image
3	• Selecting astronomical objects for imaging by taking into consideration the visibility of the object at a particular time of year from a particular location • Determining whether an astronomical object selected for imaging will fit in the telescope Field-of-View (FoV), by taking into consideration the angular size • Understanding the various objects in the Universe and their characteristics
2	• Understanding the motions of celestial objects in the context of Right Ascension (RA) and Declination (DEC) • Understanding that Right Ascension (RA) and Declination (DEC) are a geocentric coordinate system • Understanding the relationship between degrees, arcminutes and arcseconds
1	• Understanding the magnitude system in astronomy • Understanding the fundamental workings of the human eye and how it relates to imaging • Understanding that the human eye can only see in a small wavelength range, called the Visible Spectrum • Understanding the workings of telescopes in terms of light and optics • Understanding the workings of CCDs, and how they capture images • Understanding the theory of colour, its use and the physics behind colour • Understanding the software used to process images
Entry	• Belief that astronomical images viewed in the media are taken in colour • Belief that astronomical images are computer generated graphics and not real • Belief that astronomical objects can be imaged at any time of the year • Inaccurate understanding that all objects imaged will be large as seen in the media

- The purpose of the image being education, science or just pushing the boundaries of image processing

Ownership

The power of ownership was evident once the students were given printed copies of their images. Students, even those who had found it challenging, and at first were not happy with the images they created, were delighted to see their images in print. They commented on the fact that they had created the image, and were proud to display it at home, or their parents would frame the image. This is an important aspect of authentic experiences, whereby students found purpose in the work they were doing, and especially because they were making decisions, and at times learning that their decisions did not have the predicted outcome. The idea of ownership started with the fact that they had to learn how to use the software through videos, there was no direction instruction by the instructor, rather just troubleshooting and conceptual guidance. This grew, evolved and was nurtured because they ultimately had to make some challenging decisions when picking their targets and processing the images.

Reflections on the Learning Progression

This LP for astronomical imaging in Table 1 was developed over a period of time via various cohorts, and so was guided by the implementation of colour imaging in the classroom. A learning progression by its very nature is guided and developed by instruction, interaction with students' prior knowledge and construction of new knowledge. It should be emphasised that the LP presented here is not a teaching sequence, it can be used to develop a teaching sequence, or guide curriculum development. The LP shows at what level of sophistication each of the various skills and knowledge are when it comes to astronomical colour imaging in the classroom. At any given stage, in the reality of the classroom there will be students at various levels of the learning progression.

Although this LP is presented as one coherent progression, it encapsulates two pathways: a) Target selection and b)Making a colour image. Although, some would argue that it needs to be two LPs, we argue based on experience that to implement a coherent elective, they need to be merged, as this is vital to delivering an authentic experience.

Furthermore, this LP takes a mid to coarse-grained approach (the level of detail), this is because the aim was to determine the theoretical minimum that is required for students to engage in authentic image processing. If a fine-grained approach were taken, then it would make sense to split the learning progression into the two pathways stated above.

At the start of the project students asked six questions, which can be linked to the levels of the LP:

What skills do I need to learn?

This is addressed throughout the learning progression, because there are a range of skills at various levels of sophistication. For example, skills in image processing, or rather using the software. Students start with the basics in **Level 1**, but by Level 4 they understand the intricacies of image processing at their developmental level, and in the context of this elective.

What theoretical knowledge do I need?

Theoretical knowledge exists at various levels from understanding celestial motions, to the instrumentation, the objects in the Universe, their characteristics, the theory behind image processing, and the theory of colour.

What tools would I need?

This is addressed in **Level 1**, it is really about introducing students to telescopes, cameras and the software. Taking a fine-grained approach, one could zoom into each of the skills, however, the aim is to identify the key skills and knowledge that are attainable at the developmental stage of a middle school student with no background in astronomy.

What do I already know about astronomical imaging?

This is addressed mainly in the **Entry stage** where the teacher through discussion has the opportunity to gain insights into students conceptions.

What object do I choose?
How do I know what object to choose?

These two questions are addressed in **Levels 2 and 3**. It requires not only knowledge of celestial motion, but also the types of objects and the specifications of the telescope.

Level 4 in the LP is where students can independently engage in astronomical colour imaging. In essence it brings together all the fundamentals from preceding levels.

It must be emphasized that the BIG was to make "pretty" pictures, which carries with it a subjective aesthetic, yet a global aesthetic experience. This latter experience is at the heart of science. The aesthetic experience of taking Black & White images, and creating a colour image, is a positive aesthetic experience. Unlike the positive aesthetic experience, which must be learned through disciplinary knowledge, e.g. the beauty in a mathematical equation, the aesthetic experience afforded by a colour astronomical image is universal (Wickman, 2006) for those not visually impaired.

The LP utilised in this study is hypothetical and as such requires further refinement. This approach is in the process of being adapted into an empirically validated LP, which provides teachers with a roadmap to one avenue of implementing RRTs in a middle school science classroom. The LP will also provide curriculum developers with a framework on connecting concepts across disciplines and embedding the practical applications of concepts into the curriculum statements.

Conclusion

The beauty of the Universe can be appreciated by everyone irrespective of their culture, religion or political persuasion. An image of a galaxy, nebula, or even a nightscape showing the Milky Way, invokes experiences that go beyond the visual aesthetics of the image, instigating a journey through the Universe and discussions of its mysteries. Student engagement in school science is ebbing, this has instigated educators and policy makers to seek ways in bringing about a change. Astronomy, with its richness of topics and awe-inspiring visuals is suited to instigate this change – a "Gateway Science". Astronomy automatically instigates discussions about the mysterious and the awe-inspiring. Most students let their imagination run wild when asking questions, conjuring up scenarios, which often can be answered using our current knowledge and drawing on the students' pre-existing knowledge. With this in mind, a Year 8 elective was implemented that allowed the students to use RRTs to capture images of astronomical objects they found interesting, and combine those images to create a "pretty" colour image. This elective is but one example of how astronomy can be used in teaching core science concepts, using a single Big Idea Goal, which is tangible and familiar to students.

Some interesting insights gleaned from this study revealed:

- The challenge experienced by certain students in making choices, especially those who are accustomed to being given recipe-based experiments in school science
- The surprise and excitement experienced by students when they first glimpsed the colour image they had created
- The discrepancy in quality between their own images and those published on the internet was a source of despair
- The constant need for some students to be told whether their image was "good"
- The combined use of art and science terminology by the students to describe their image

We appreciate and emphasise that there is much work that needs to be done in developing this LP (Krajcik, 2012; Shavelson and Kurpius, 2012). Therefore, we present this LP as a starting point. The next stage will be an empirical validation of the preliminary LP developed and implemented in this elective, which will provide a roadmap for curriculum developers and interested teachers in bringing engaging science into the middle school science classroom using RRTs. This brief case study highlights the enormous potential that astronomical imaging using RRTs has on teaching in the classroom, and how they can be easily connected to current curriculum topics.

Furthermore, it demonstrates how Arts can be integrated with Science, in a practical classroom setting, without jeopardizing either discipline, rather, drawing on the commonalities of each discipline. This synergy further supports the consensus that astronomy can truly be considered a "Gateway Science", maybe it is also a "Gateway to Learning".

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Evaluation of the Astronomy Research Seminar

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Abstract
The need for a scientifically literate populace is clear now more than ever in recent human history as evidenced by global climate change and current political discourse and opining around it. Several decades of research and practice in science education still appear to leave much to be desired in terms of student understanding about the nature of science, scientific research and communication, and the need for scientific literacy. While there are potentially many avenues for students to pursue science in education and career paths, the Astronomy Research Seminar seems to have tapped into an intrinsic value in participating within and contributing to a Community-of-Practice as a way of learning. Based on an initial evaluation of students' experience and educational and career choices, the seminar has a meaningful impact on students. Furthermore, for many individuals it transforms their identities as scientists or at least budding-scientists and gives them a glimpse into the idea that they can participate in the scientific endeavor. As has been shown recently (Freed 2019) the seminar model is scalable as evidenced by the numerous variations that have developed over the past several years. This paper provides a deeper look into how students think and feel about their research experience in the seminar.

Keywords
Evaluation — Student Research — Astronomy Research Seminar

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Introduction

The Astronomy Research Seminar (ARS) is predicated on the philosophy and pedagogy around the value of learning within a Community-of-Practice (Wenger 1999; Genet et al. 2016, 2017). Within this framework, learning takes place as a Community with members ranging from the novice to the veteran, each learning from the other, and individuals are transformed by their learning and participation. The Astronomy Research Seminar and the Community-of-Practice in which it exists have both expanded significantly over the past several years. After initially being offered through Cuesta Community College in San Luis Obispo, CA, the seminar is now offered by numerous institutions and organizations throughout the country, either in-person or as a hybrid or totally online course. In its spread it has taken on several different forms over the years (Freed 2019).

The ARS is quite different from, and perhaps complementary to, general astronomy courses at the high school and college level, as it focuses on a very narrow field of study, with an emphasis on student-lead research and publication. There are no prerequisites and the aim is not an accumulation of a large body of content knowledge, but rather a few specific research-oriented, collaborative, and communication-based skills. These are all meant to be widely applicable well outside the domain of astronomy and even of science itself, while contemporaneously improving scientific literacy and understanding. Evaluation of such programs is critical to determining their value and outcomes as well as strategies for improvement.

There is a growing body of literature looking at changes in attitude, Bartlett et al. 2018; Wittman 2009; Zeilik et al. 1999, learning gains (e.g. bailey2012development) and interest in astronomy resulting from participation in courses or research programs for students and/or educators. The emotional impacts of looking through a telescope, collecting one's own data and contributing to scientific knowledge, and the influence on learning and then educational and career choices is less well studied although becoming an important part of the literature . This is aided by the development of new validated instruments to measure attitudes (Bartlett et al. 2018) and self-efficacy in astronomy (Freed et al. prep). The work presented here aims to provide an initial evaluation of the astronomy research seminar's influence on students' understanding of scientific research, and their sense of self-efficacy within the Community-of-Practice.

Evaluation

Data Collection

Data was collected through online surveys, phone and video conference interviews, and student reflection papers as described below. One of the surveys is provided in Appendix A as an example.

Surveys

One hundred students in total have completed one of the six surveys given to students at different institutions. The ex-post-facto survey was sent to students who had been in the course previously, dating as far back as 2009, who were contacted through various means, including social media or connections they had maintained over the years. Of the nine participants who responded to the survey six were female and three were male. The Boyce-Astro Survey was conducted when the students were all present at the final day of the seminar, thereby capturing data from a large percentage of the participants in those seminars. The rest of the surveys were embedded within the learning management system at the end of the online or hybrid courses in 2016 and 2017 and were optional for students. The questions from the ex-post-facto survey, Boyce Astro survey and Cuesta Spring 2017 surveys were almost identical, while the other three surveys were less extensive. Not all surveys asked for gender data. The survey statistics on the number of students, gender and school level when taking the seminar are summarized in Table 1 below.

Interviews

Interviews were conducted over Zoom video conferencing with eleven students and three instructors. The interviews were recorded and transcribed for analysis.

Student Reflection Data

One institution providing the astronomy research seminar had their students write up reflections in response to several questions about the seminar after having completed it instead of completing a survey. The eighteen reflection papers were analyzed here. It is important to note that this is a private, online high school for exceptionally advanced and self-motivated students. For example, numerous seventh and eighth graders successfully complete Advanced Placement courses at this school. Thus, this school represents a different demographic than many public community colleges.

In this research there were four main themes that interview and survey questions revolved around or that students brought up of their own accord. These were:

- The experience of doing scientific research
- The value of working in teams
- The importance of writing a paper for publication
- The impact of involvement within a Community-of-Practice

Each of these are addressed here.

Program and year of course	Number of student survey respondents	Gender (when asked, and provided)		School level when the seminar was taken	
		Female	*Male*	*Undergraduate*	*High School*
Students from 2009-2017, Ex post facto	9	6	3	5	4
Boyce Astro 2016-2018	57	28	28	30 (2 post-college)	24 (1 8th grade)
Cuesta Spring 2017	23	N/A	N/A	21	2
Cuesta Summer 2017	5	N/A	N/A	5	0
Cuesta Spring 2018	2	N/A	N/A	5	0
InStAR Hybrid Summer 2018	4	N/A	N/A	4	0
TOTAL	**100**	**34**	**31**	**72**	**31**

Figure 1. Distribution of survey responses, gender and school level when taking the seminar

Data Analysis

In the surveys and interviews one of the first questions was "How did the astronomy research seminar most benefit you?". This was put in first to elicit responses minimally influenced by ideas embedded in a more specific question such as the idea of teamwork in the question "Was there any value in working in teams?".

The nine students who responded to this particular survey gave the following answers:

- "Greatly improved my scientific writing skills. It was my first glimpse into the scientific process."
- "Made my college applications more interesting, and expanded my understanding of astronomy."
- "I learned how people create and submit research"
- "It introduced me into the world of scientific collaboration and publishing a scientific paper."
- "It introduced me to the idea of evidence-based research and the process of writing and submitting a research article."
- "I wish to become a professor, so I benefited from the experience of writing and publishing a paper"
- "Just an amazing process for learning"
- "Getting published"
- "Unsure."

This question has been asked of other seminar students and was reported on in Freed (2018). As was found in the previous study, the students feel that one of the most important aspects of the program is learning how to write a scientific paper. Forty four percent of the students here included "writing" or "scientific paper" in their answers, which is similar to the 45% shown in the earlier study of 23 participants.

The experience of doing scientific research

A key principle underlying the research seminar is that it provides, as much as possible, a genuine experience of the nature of professional science for students in the early part of their educational careers. The challenges include their lack of content knowledge, experience with conducting and managing research, and scientific writing. However, the seminar structure and requirements try to provide a framework in which this can all be addressed in the hopes that the student experience will be that of true scientists and that students will understand that they are scientists and can contribute meaningfully to the community. In Tables 2-5 showing survey data, the number of responses for each question is given in parentheses.

About two thirds of the students surveyed felt confident that the process they went through was similar to what professional scientists would do and that they were doing real research. Another 22% felt it was "somewhat" like what professionals do and 32% felt it was "somewhat" like real research. These combined numbers are similar to the 90% who felt that their research contributed at least in a small way to the scientific community. This is in stark contrast to general introductory science courses in college and most lab-based science courses in high school, where skills and content are taught but no new research is done.

Student Reflections

The question "Is the project you are doing changing your thoughts about what it means to do scientific research? Was it different than expected?" was posed. Out of the 18 students, 17 (94%) stated that there were things about the research project that were different than they expected. The tone of each response, however, was very positive, overall.

Seven of the 18 students (39%) commented that they now understand that scientific research is more difficult or more time-consuming than they had expected, although none of the student responses indicated they felt this was negative.

- "I never expected the data would be so difficult to analyze"
- "...now I realize the difficulty in actually doing the research"
- "This made me realize how time-consuming scientific research/writing is"
- "It is much harder and slower than I expected."

Of the 18 students, five (28%) mentioned the importance and/or difficulty of the writing process as something new for them.

- "I also never realized how important papers really are. They are absolutely necessary and have to be constructed very carefully so that you can share your results."
- "I originally thought it was more out in the field, collecting data, and taking measurements, but this project has shown me that it is mostly looking at data, and working on your actual paper."

Most of the responses indicated that the students really enjoyed and valued their experience despite it being different than expected, and in many cases much more challenging.

- "The research feels like it does have an actual scientific value which is a good feeling."
- "We got to do research on the more fundamental level, and look at raw unprocessed data and draw conclusions ourselves. We are used to looking at Wikipedia and saying "This star has been identified as a quadruple star". Now we are able to draw those conclusions ourselves."
- "I'd also known that there were binary... systems... but it didn't really capture my interest until I looked at the systems, and graphed their orbits, and added my now-significant findings to the data. In short, this class is infinitely more awesome than I expected."
- "I have learned that students can be real researchers too."

It is an important point to note that not all the seminar students were on a science track. Many were already leaning in that direction, and for some it solidified their direction, while some who were not considering science ended up changing to a science track after having gone through the seminar.

Working in teams

The astronomy research seminar requires that students work in teams as a pedagogical and philosophical approach. Not only is this representative of true

The experience of doing scientific research			
Do you feel that your team went through (at least roughly) the same research process that professional research teams go through? (86 responses)	Yes	Somewhat	Not at all
	65	22	13
Did the seminar make you feel like you were doing real research, or did it seem mostly like an academic lab class as in chemistry, biology, or physics with known outcomes? (88 responses)	Real Research that will contribute to scientific knowledge	Somewhat like real research	Mostly like an academic lab class
	63	32	4
Do you feel that your research contributed to the scientific community? (99 responses)	Yes	Yes, but only in a minor way	No, in the end it was just another academic exercise
	34	56	10

Figure 2. Percentage of student answers to survey questions relating to the experience of doing scientific research

scientific research, but the value that a diverse team with different experiences, skills and knowledge can bring to collaborative work is critically important for preparing students for the world beyond school and producing the highest quality work.

Community college students

- "Being a team researcher was amazing. It was something I had always wanted to do and something I hope to do more of in the future"

- "This was my first exposure to a team research group, so I was able to take a lot away from this process. I learned the aspect of project planning, management, and critical thinking during the first few weeks of the class when we were brainstorming about what our project could actually look like. I was also able to learn more about technical writing and editing during the research paper portion of this process"

- "I played team lead in this research. The initial responsibility to my team was intimidating at first, and it did not go away until the end of the course. I am fine with unequal workload, that's how life is, but all played an equal role in supporting the team."

High School

- "Team researching is actually pretty hard at first. You have to open your mind to ideas that might not be yours and still constantly suggest new ones. In addition, you need to say what you think about an idea without sounding too harsh about. Since there are two different views, adaptation is required. After a while though, you start thinking the same and this becomes easier and easier. [One of the students] doesn't seem to like research, so I have taken that role in my group."

Many students have commented on how much they learned about taking on a leadership role and learning about team management. A team of students from one Community College who went through the seminar in the summer of 2018 has already put together a team to do another research project more independently. It is common for students to become self-motivated once they understand that they can play an active role in true research.

Student Reflections

The question "What is it like being a team researcher? Is it different than laboratory classes you have taken?" was posed. One hundred percent of the students appreciated working as a team to do the research project. Interestingly some even commented on both the advantages as well as the challenges of working in teams but all of them felt it was beneficial.

Working in Teams			
Did it work to have a team of student researchers or would it have worked better to do the research on your own? (99 responses)	The team was great.	The team was OK.	I would rather work on my own.
	73	20	7
Do you feel your team managed its own research, or did the research supervisor actually run the show for you? (93 responses)	Yes, the team managed its own research	Sort of but the research supervisor helped a lot	No, the research supervisor managed the research
	87	12	1
Did you feel that you were able to make real choices, or was the path pretty well set in stone? (86 responses)	Our team developed its own ideas and had plenty of choices.	There was some choice	There were no choices.
	50	34	16
Do you feel that you were able to make a significant contribution to your team's research project? (88 responses)	Yes	Only marginally	No
	70	24	6
Did your contribution to your team's research make you feel like you could contribute to teams in the future? (88 responses)	Yes	Somewhat	Not really
	80	17	3

Figure 3. Percentage of student answers to survey questions relating to working in teams

- "Being a team researcher is difficult but better I think than if I was researching on my own. It is good to be part of a team because everyone has different things they are good at, so altogether a group can be good at everything!"
- "Working as part of a team when doing research can be very useful for advancing the project quickly and in-depth...Also, teams allow for peer review of each other's work, and can provide a system of checks and balances to ensure the highest quality of work is produced."
- "Being a team researcher complicates and simplifies the project. Coordinating activities and work can be difficult...and finding the time to work together can be challenging...Working together simplifies things because there are more ideas brought to the table..."
- "I enjoy being a team researcher. The way we divide up the work really works for the group as a whole, because each member does what they feel comfortable doing."
- "I have enjoyed being a team researcher. Our team roles change each week based on what we need to accomplish and dividing the work has been a successful strategy for matching our strengths with various aspects of the project in addition to learning new skills."

These students really seem to understand the value of working as a team and leaning on individuals' strengths and they come to this realization through the research seminar. It was interesting to note the comments from one student who apparently is "that person", the one who ends up doing all the work in a traditional group project setting:

- "It's definitely different from any other projects I've done. In all the other projects, I was the person who did everything. If there was a paper, I knew everything that was in it, and where it all came from. It's a little bit weird to look at the document and find that everything changed."

The importance of writing a paper for publication

The astronomy research seminar is designed to allow half of the course for writing and rewriting the research paper. This often surprises students and new instructors until they have gone through the process and seen the challenges of preparing a truly publishable paper. The seminar developers have often thought that the amount of time and focus on writing might be off-putting to some students. However, feedback and survey and interview results over the years have shown this not to be the case. Rather, more often than not, the writing ends up being one of the greatest benefits that students report on. Furthermore, many students, in their reflections, interviews or survey answers, talked about the benefits of writing as a team where it lessened the individual writing load while allowing each student to focus on their particular strengths and interests.

Only 3% of the students felt that the intense amount of writing made the seminar "less fun". Most students felt that the writing was a really good part of the experience and for many students learning how to write scientifically was one of the biggest benefits of the astronomy research seminar.

- "The publication requirement, and the reviewing process especially, made sure that our writing was clear, concise, and that we weren't missing any information so that our results/-analysis would make sense in the context of the paper."

Student Reflections

The question "How important is it to you to have a paper submitted for publication? How do you think being coauthor of a research paper might affect your career?" was posed. Twelve of the 18 students (67%) mentioned that they thought it would be helpful for their career to have a published paper.

- "Having a research paper with my name is very important. Colleges will be impressed if I have a research paper that was published, and I want to get into prestigious colleges"
- "I would like to publish a paper and it is important to me. It might allow me to stand out as a scientist when I apply for college and gives me a competitive edge on knowing how real scientific research works."

Several of the students made the point that it was certainly not the reason they took the seminar, or it was less important than the research experience itself, or that contributing to the science was a bigger benefit.

- "...it will certainly look nice on my resume. I do however see more value in the content than in the credentials."
- "When I enrolled in this course, to me it was less important to have a paper submitted for publication, and more important to learn about astronomy and what astronomers do. While I find having a paper cool (especially for bragging rights), to me it is more important to learn about astronomy and how to manipulate the software."
- "I'm not doing this paper for the credentials I might get later in life, but rather because I actually want to contribute to the science community."
- "For me it isn't all that important in terms of big picture/career stuff. I want to submit a paper for publication because I have worked hard on it and want other people to see what our team has poured our energy and thought into. I joined this class because it sounded interesting, I enjoy astronomy, and Kalee is an incredible teacher. I did not join because I thought It would be important to have a paper published (even though that is INCREDIBLY cool and probably kind of helpful for potential future opportunities/applications to schools)"

Seven of the 18 (39%) explicitly stated they didn't think it would help their careers or it was not that important to them to have a published paper.

- "It is not as important to me that the paper is submitted for publication as my peers, as I don't plan to go into the field. . . "
- "It is important to me because I think it would just be a SUPER SUPER SUPER amazing

The importance of writing and publishing a scientific paper				
With the advantage of hindsight, how important do you think it was that the seminar insisted on published results? (This question said "check all that apply", therefore the percentages add up to more than 100.)	Without the publication requirement the seminar would not have had much benefit to me.	The publication requirement really made the seminar different than any course I had taken before then.	The publication requirement really sharpened our team's critical thinking.	The publication requirement took all the fun out of the seminar because we had to spend most of the time writing and rewriting our papers.
	43	64	59	3
When you realized how much careful writing scientists have to do, did this discourage you from thinking about becoming a scientist? (88 responses)	Not at all; critical careful writing is cool	Not really; writing is necessary		Yes, it discouraged me
	93	5		2

Figure 4. Percentage of student survey responses regarding the value of writing and publishing a scientific paper

thing to be able to do!!!!!!! But it wouldn't really affect my career as a ballet dancer at all."

Significantly, one student went so far as to explicitly state they were not yet a scientist. This particular reflection goes against the premise that having students do research, publish their work and become immersed in a Community-of-Practice will help them feel like they are scientists.

- "...our paper is probably going to be hidden in the far corner of some digital database (which is physically impossible) and not touched by anyone who has any sense of who to trust in terms of scientific papers. This will serve as an exercise, and if I ever become an actual scientist, these experiences will help me deliver my first "formal" paper."

The impact of involvement within a Community-of-Practice

> "Learning is a matter of engagement: it depends on opportunities to contribute actively to the practices of communities that we value and that value us, to integrate their enterprises into our understanding of the world, and to make creative use of their respective repertoires." (Wenger 1999, p227)

Students in the Astronomy Research Seminar are explicitly taught the fundamental concepts of a Community-of-Practice as defined by Wenger (1999) and are encouraged to reach out and engage with experts outside of the course they are taking. For example, all student teams that have been through the seminar have contacted Dr. Brian Mason at the US Naval Observatory who curates the Washington Double Star Catalog to request past observations of the systems they are studying. Furthermore, teams are often connected to other people within the field who have experience in double star research, AstroImageJ expertise, or other areas in which they can assist students. Occasionally, outside instructors will join a team meeting to learn about the research seminar, and in this way students are temporarily playing an instructor role as someone, in this case, perhaps an experienced astronomy instructor, is learning from them. As Wegner points out, again in Communities of Practice: Learning, Meaning and Identity, "When old-timers and newcomers are engaged in separate practices, they lose the benefit of their interactions...Communities are thus deprived of the contributions of potentially the most dynamic, albeit inexperienced, segment of their membership - the segment that has the greatest stake in their future".

Survey Data

Ninety four percent of the students surveyed felt that they were at least somewhat immersed in a Community-of-Practice and all of the students surveyed found the external reviews of their paper at least somewhat helpful, if not very helpful in the writing process. Students were often enthralled with the idea that they could communicate directly with experts in the field, whether it was professional astronomers, software programmers or advanced amateurs with decades of experience researching and publishing their results on double stars. One example of this was a team that had a Skype meeting with Gianluca Sordiglioni (in Italy), the author of the Stelle Doppie double star online search engine. The team included information obtained directly from Sordiglioni in their published paper (Badami et al. 2018) and expressed excitement about the conversation and being able to get personal help from the program developer.

One of the many goals of the seminar is having students become immersed in a community of practice and to really learn the value of collaboration amongst themselves and with outside groups such as the wider astronomical community. Sometimes this was accomplished simply through discussion which led to them reaching out to experts in the field. Additionally, videos were created explicitly to explain to the students the value not only of collaboration but highlighting to them their role in the greater community. One example of this was that at the second annual Conference on Robotic Telescopes, Student Research, and Education (RTSRE): a community college instructor wanted to learn about the research seminar and sat in on the Zoom meeting being conducted with students and was able to get first-hand experience with how the seminar is conducted. Another example of how the seminar students are incorporated in the community was that as they were going through the seminar using Las Cumbres Observatory (LCO) telescopes this information was shared not only with Wayne Rosing, the founder of LCO, but also in the LCO Education Partner monthly meetings with LCO's Global director and education director of the telescopes so they were getting real-time feedback about how their partnership was impacting students. The students knew that astronomy professionals were aware of their work, which gave them an extra sense of pride and tangible connection to the Community-of-Practice of which they were a part.

Impacting Students Lives

Having sat in meetings with about a dozen different teams over the past four years it has been impressive to hear the responses and feedback from the majority of students who go through the various research seminars. For many it has helped guide their educational and career paths and for many it has influenced their understanding of the process of science, the value of communication and collaboration and the challenges of and appreciation for scientific writing. The sentiments expressed below are commonly heard in conversation among seminar students.

- "My team contributed some pretty amazing skills across the board and we produced absolute magic."
- "Once we were able to navigate through our communication issues, all team members contributed to the very best of their abilities...I am very proud of what we were able to accomplish together in such a short period of time and I would be honored to work with any of them again on future projects!"
- "I had an amazing experience with the...program, and would recommend it to anyone with a passion for astronomy. I learned so much from this seminar, and it helped me gain an understanding of how the scientific community worked. It also connected me with many different people with similar passions as me."
- "This class definitely gave me the fever for research. As a future scientist, the question

The Value of the community-of-Practice			
Did you feel immersed in a Community-of-Practice? (88 survey responses)	Yes	Somewhat	No
	56	39	6
How helpful was the external review in improving your team's paper?	Very helpful	Somewhat	Not at all
	88	12	0

Figure 5. Percentage of student answers to survey questions relating to working within a Community-of-Practice

> of why is always on my mind. If I have the opportunity to participate in team research in the future, I will certainly take the leap."

Based on interviews, survey results, student reflections and the large number of students who have propagated the seminar at new institutions after their initial involvement, it is clear that this approach to education has far reaching impacts. Furthermore, the influence on individual students' lives, educations, and careers speaks to the power of the underlying pedagogical approaches of the seminar in having students take ownership and responsibility for their research, work in collaborative teams, and go through the rigorous process of learning to write quality scientific papers.

In the summer of 2018 a team of students and their instructor who had done the research seminar and published a paper had the opportunity to visit the Mount Wilson Observatory and the instructor gave the following feedback:

- "We had *such* a wonderful time at Mount Wilson–it was a mind-blowingly incredible and perfect day. So many of the students and parents told me that the experience was really transformative for them, and it was so much fun for me as well. . . .Tom Meneghini and his amazing staff might just have created a few new scientists on Saturday!"

Case Study: Mark Brewer

Brewer took the seminar as a junior in college in 2011, resulting in his first of 13 publications (Brewer 2011), and loved it so much he immediately started his own version which he provided for students from middle school up to college as well as the general public. Brewer has 13 Journal of Double Star Observations publications to his name, most of which include numerous students that he has brought into his weekend double star workshops.

When asked what kind of influence the seminar had on him, aside from the obvious influence in motivating him to hold his own workshops, he had a lot to say:

- "It was showing how much hands-on experience was big in the workforce. Having the piece of paper [publication] helps out but most organizations [and] government programs they want to see that you actually have some hands-on experience. That means a lot. Obviously, the piece of paper means a lot too, but I saw that the hands-on experience was important... I was able to go from an intern to a full-time employee and I currently still only hold an associate's degree... I'm going on five years in an atmospheric program and I was an intern for almost two years in an astronomy program."

In response to the statement "It sounds like you would almost credit the research seminar with giving you an understanding of the importance of the hands-on experience", Brewer replied,

- "Yes. And the publications. That was big too because that showed that, overall, I could do the hands-on part of science. I was overall a scientist and the engineering type...there are a lot of open doors too."

Brewer has held five workshops with a total of about 70 participants who all learned to collect and analyze data and write a scientific paper for publication.

When asked "Was your ability or confidence in your ability to [do scientific research and publish] influenced by the seminar?", Brewer responded,

- "Oh definitely. When I came up for my internship here, we were using JPL's electrical communication program and I was running a solar differential imaging motion monitor and a 14-in Schmidt-Cassegrain telescope on a fork mount with a wedge. And that's exactly what I used [in the seminar]. I was using an 8-inch, but it was the exact same thing, just scaled up. They didn't have to teach me how to run the telescope."

Brewer has expressed a high level of self-efficacy, not only in doing double star research, but in applying skills he learned in the program in diverse settings, including his employment. Additionally, by running his own seminars he has acted upon a strong sense of self-efficacy in the teaching aspects of the research program. Brewer has written about and presented his double star research program at the Society for Astronomical Sciences Annual Symposium (Brewer et al. 2014).

Case Study: The Growth of a Scientist, Mentor and Researcher

One particular seminar participant was the kind of student who was not interested in school, earning his GED and leaving high school early with mediocre interest in education. After ten years in retail he decided to go back to school, unsure about what to study or what his interests were. In his first year as an undergraduate at a community college, he was taking physics and, in his words, "I bumped into Irena Stojimirovic, an astronomy 101 professor at Mesa College who introduced me to the Boyce program...My academics have accelerated since being introduced to this program." He participated in the Astronomy Research Seminar through Miramar College in San Diego and has been mentoring students in the program for the two years since then. After presenting his research at the first RTSRE Conference in 2017, he put a lot of effort into considering what to present at the 2nd RTSRE conference that would have true scientific value and meaning to the community.

- "The thing we are most stressed about is actually doing something that's worthwhile of presentation and that also meets the standards of inquiry which is what I think the whole conference is revolving around."

He reflected,

- "Some of the students were trying to form fit their results into a model that their teacher gave them rather than taking unexpected results and interpreting on the fly. Last year gave me a heck of a lot of understanding on how you ask these sorts of questions, the perspective that I should take when coming at it from a professional educator and a researcher point of view vs the students point of view. Since the [RTSRE] conference I have mentored a few different students."

When asked about the eight student teams he's mentored he replied

- "Over the past three semesters all of them have published papers. I really want to highlight that it's a personal goal for me, each semester I want the teams to add a new bit of flavor or a new layer of research to what they have done. [Student x], he didn't just do a measure and report paper; he also did a Speckle Interferometry paper with Richard Harshaw. He worked with Richard Harshaw on his own motivation to do something that was outside the recommended criteria provided to us by Boyce. . . [He] found something that was really fascinating to him and he asked the question, 'What do I need to do this?' [The instructors said] 'we know somebody. Let me put you in contact with him and see what you can do.' That first semester [Student x] busted out a Speckle paper. Last [year] I had two students who focused on doing Common Proper motion analysis on both of their papers. Every paper last semester...had a Common Proper Motion analysis integrated into it. What's the point for students who are taking higher end physics classes and are trying to get into a STEM field to ask the same questions that are already being asked? If you want to know more there's a possibility... let's figure out how to do it. Each semester there are a few students who flake off...but other ones who take the whole project and run with it with the motivation that makes me feel inspired and left in awe."

This former student epitomizes a student who has become fully integrated into the Community-of-Practice and transformed his identity as a scientist as well as his educational and career path. He is thinking critically not only about the astronomy research but about the educational aspects as well. As Wenger (1999) states in his book Communities-of-Practice "Learners must be able to invest themselves in communities of practice in the process of approaching a subject matter. Unlike in a classroom, where everyone is learning the same thing, participants in a community of practice contribute in a variety of interdependent ways that become material for building an identity. What they learn is what allows them to contribute to the enterprise of the community and to engage with others around that enterprise" (Wenger (1999); p 271). This student has certainly invested himself in the Community and transformed his identity as a scientist, researcher and life-long learner.

Case Study: From a San Diego Community College to New Mexico Tech

One premise of the astronomy research seminar is that it changes lives and changes students' identities as scientists. One of numerous examples of the wide-ranging impact of the seminar is in the story of a community college student who first took the seminar in the Fall of 2016 through the Boyce-Astro program in San Diego. After having published two papers during the semester-long seminar, when he transferred to New Mexico Tech he immediately began mentoring students from there as they went through the online version of the seminar. In addition, he helped to run the first annual RTSRE Conference in June of 2017, and presented his research there. In an interview in April 2018, he stated

- "my question...was where do you go from the end of the seminar? Is it enough to get people interested in the field and then expect them to go about their own path?"

And about having been through the seminar he stated

- "It definitely cemented my direction. It gave me just enough of a taste to want to do more...I was on the fence between particle physics and astrophysics...but this pushed me to one side. And so, I guess, to answer my own question, maybe it is enough to be introduced to the meat and potatoes, so to speak, of astronomy".

What stands out about this interview was the thoughtfulness and scientific questioning this student went through in considering both science and educational research about science. He proceeded to then do a study on the influence of the astronomy research seminar on other students, all while working on a degree in astrophysics at New Mexico Tech. This is another example of a seminar student who, after being immersed within the Community-of-Practice, has invested himself fully within it.

Impacting Teachers' Lives

The educators who take on the research seminar themselves and then bring their students on board have a transformative experience through the process. As high school science teachers generally don't have experience in conducting and publishing scientific research, this program can be as powerful for them as for the students in identifying themselves as scientists. Additionally, it transforms their approach to science teaching in philosophy and pedagogy. Kalee Tock (2019) of Stanford OHS has written about the experience stating

- "I found myself reflecting often on the scientific process and the ways in which actual research differs from the picture we paint for students in introductory science classes...in real science you have to be open to pursuing other paths than the one upon which you originally set out. The experiments that we do in most of our science classes run counter to this because we grade students on their answers to a specific question."

She continues

- "While the place of student innovation in classroom lab experiments is limited at best, this sort of inventiveness plays a huge role in the scientific enterprise. Real, impactful science depends on scientists' being ready to intentionally study different, more interesting questions than the ones they set out to ask...But, we do them a disservice in pretending that the cycle of hypothesis - data - conclusion they follow in traditional lab experiments mimics the way science is actually done."

In an interview Ms. Tock described how, after having been a teacher for over a decade, it was through conducting the research seminar for two semesters that she finally feels like she is a subject matter expert in this area due to her research experience with the students over the course of the year. In addition to the direct impact on her students of providing a research and publication experience, she has integrated herself fully within the Community-of-Practice, presenting talks and workshops at the first and second annual RTSRE conferences as well as other national conferences. She has also provided opportunities for her students to present at these conferences, enabling them to become integrated into the larger Community.

Conclusion and Future Directions

The astronomy research seminar, in its various forms over the past 10+ years has had a significant impact on the STEM pathways of many students, in addition to being an identity-transforming experience for many. One of the biggest indicators of how students are inspired or transformed by this research experience early in their education (pre-graduate school) is the many offshoot programs and advanced research projects the students themselves have created, as well as the way many of them have become fully integrated into the larger Community-of-Practice, helping to run conferences, edit conference proceedings, and guide other students through the research experience themselves.

While there are many students for whom the experience was not as transformative and life-changing, most of them feel that it was a great experience, different from any other courses or opportunities they have had in school, even as an undergraduate science major. Having sat in on about a dozen research seminars over the past four years and interacted with scores of students within the seminars, the author of this paper has heard time and again how exciting it is for students to do this kind of research, go through the team-work development process, write a paper (even through many iterations), and to then have their research published.

Many educators from middle school through community college and from all parts of the country are looking for ways to include research or provide research opportunities for their students (personal communications) and the Astronomy Research Seminar is an impactful and scalable way to achieve this. Combined with the effort to improve science literacy and participation in STEM fields in this country, the Astronomy Research Seminar strives to provide transformative experiences in scientific research for students, giving them the opportunity to become part of a larger community. Feedback from this and future evaluations will enable modifications to the existing programs as well as new ones as they spring up, hopefully helping to create a society of citizens knowledgeable about the processes of science and scientific communication and fully aware of their importance for our global community.

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The Double STARS Research Seminar: An analysis of its effects and methodologies

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Abstract

The Double STARS (STEM Through Astronomy Research for Students) seminar is a hybrid online/in-person research experience aiming to encourage critical thinking and data analysis through observational astronomy via robotic telescopes. Presented here is a program analysis from the perspective of the authors, two undergraduate students who have previously participated in the program, who are now mentoring students in both California and New Mexico. Data collected from 57 past students, both online and in-person, are presented in order to give a broader understanding of the successes and challenges the program has faced. This paper provides the education community with valuable knowledge of how similar programs can be adapted to best suit the needs of students as well as the ways in which programs such as these may help students in the areas of professional development, research, and overall scientific understanding.

Keywords

Student Research — Double Stars — Robotic Telescopes

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Introduction

The authors both started out as students of the Double STARS (STEM Through Astronomy Research for Students) seminar (Boyce and Boyce 2017) during the fall of 2016 and spring of 2017, respectively, at community colleges in San Diego, California, and have subsequently moved on to mentor their peers at San Diego Mesa College and the New Mexico Institute of Mining and Technology. After publishing multiple papers dealing with the astrometry of double star systems (see Korat et al. 2017; White et al. 2018) on the authors became interested in the questions of exactly how effective these programs were in developing an understanding of the scientific process, and how the Double STARS seminar could be shaped to maximally affect the students involved with it.

This paper aims to provide the education community with the perspective of the students involved in the Double STARS seminar (hereafter, the seminar), as well as the ways in which the program has helped students in the areas of professional development and overall scientific understanding. Section 2 will briefly describe the background of the seminar. Section 3 will give an overview of the survey conducted, and how it was implemented. Section 4 will take an in depth look at the methodologies of the seminar, and discuss the positive and negative short-term affects for the students involved, utilizing the results from the survey. While no long term effects are yet measured, we believe the survey and anecdotal evidence provided will be of value to the educational community.

Background of the DoubleSTARS Seminar

The first iteration of the seminar—implemented by Boyce-Astro, the observational astronomy program within BRIEF (Boyce Research Initiatives and Education Foundation)—came to fruition in the fall of 2016 after Pat and Grady Boyce spent two years alongside Russ Genet (e.g. Johnson et al. 2015) developing the structure and curriculum of the program (Boyce and Boyce 2017). The seminar would eventually evolved into a hybrid online/in-person program allowing its reach to become far greater than if it were limited to only formal classrooms. Following the first successful semester in the fall of 2016, two more seminars were added to the program to encompass a wider breadth of the field, and to allow the students who successfully completed the first semester to continue on to more advanced and independent research.

The STARS (STEM Through Astronomy Research for Students) seminars, as they became known, are divided into three separate portions as follows:

- Double STARS: a first semester seminar based around the astrometry of double star systems
- Variable STARS: a second semester seminar based around both single-image and time series photometry
- Advanced STARS: a guided independent research in stellar astronomy, exoplanets, and asteroids.

The Survey

Google Forms was utilized in order to conduct the survey, and consisted of multiple-choice, likert scale and open-ended questions. Some typical questions are provided in Figure 1. This survey was sent to every single student that had taken part in the seminar from the spring 2016 to the spring 2018. A fairly even distribution of respondents from each of the last 4 semesters was received; with exception of the first semester the program was offered. The distribution is shown in Figure 2. Approximately 31%, or 57, of those participants responded over the course of about 5 weeks.

The first section of the survey aimed to gain a better understanding of the demographics of the respondents. The broad results are presented in Figure 3. As was expected, most students who had decided on a major were focusing on the STEM fields. The undecided 23% is composed of mostly high school students for which no major has been declared. There were 10 different fields represented by the respondents. It is notable that a program without specific recruiting guidelines represents such a diverse population of students.

The seminar works with people from many different levels of education. As seen in Figure 4, most of the participants of the program were either High School students, or in some sort of higher education. It was only in the last semester surveyed that the program was first trialled at a four-year college, New Mexico Tech, where one the authors (SW) took the program after transferring from San Diego Mesa College. While the students here were very capable of completing the project, there was some difficulty keeping the interest of the junior level participants because the author was already knowledgeable in the aspects the seminar covered. It may be best for entry-level programs similar to the Double STARS seminar to focus on high schools and community colleges because of the difficulty in keeping higher education level participants interested and engaged in all aspects of the program while utilizing one core curriculum for all students involved.

Finally, the gender breakdown of the survey participants was analyzed. Out of the 57 total respondents, 49% were female and 51% were male. The demographic of the survey respondents broadly mirrored the breakdown of students who have taken the seminar, which is 52% male and 48% female. The seminar has been adopted by other educational programs in the San Diego area, such as the Better Education for Women in Science and Engineering

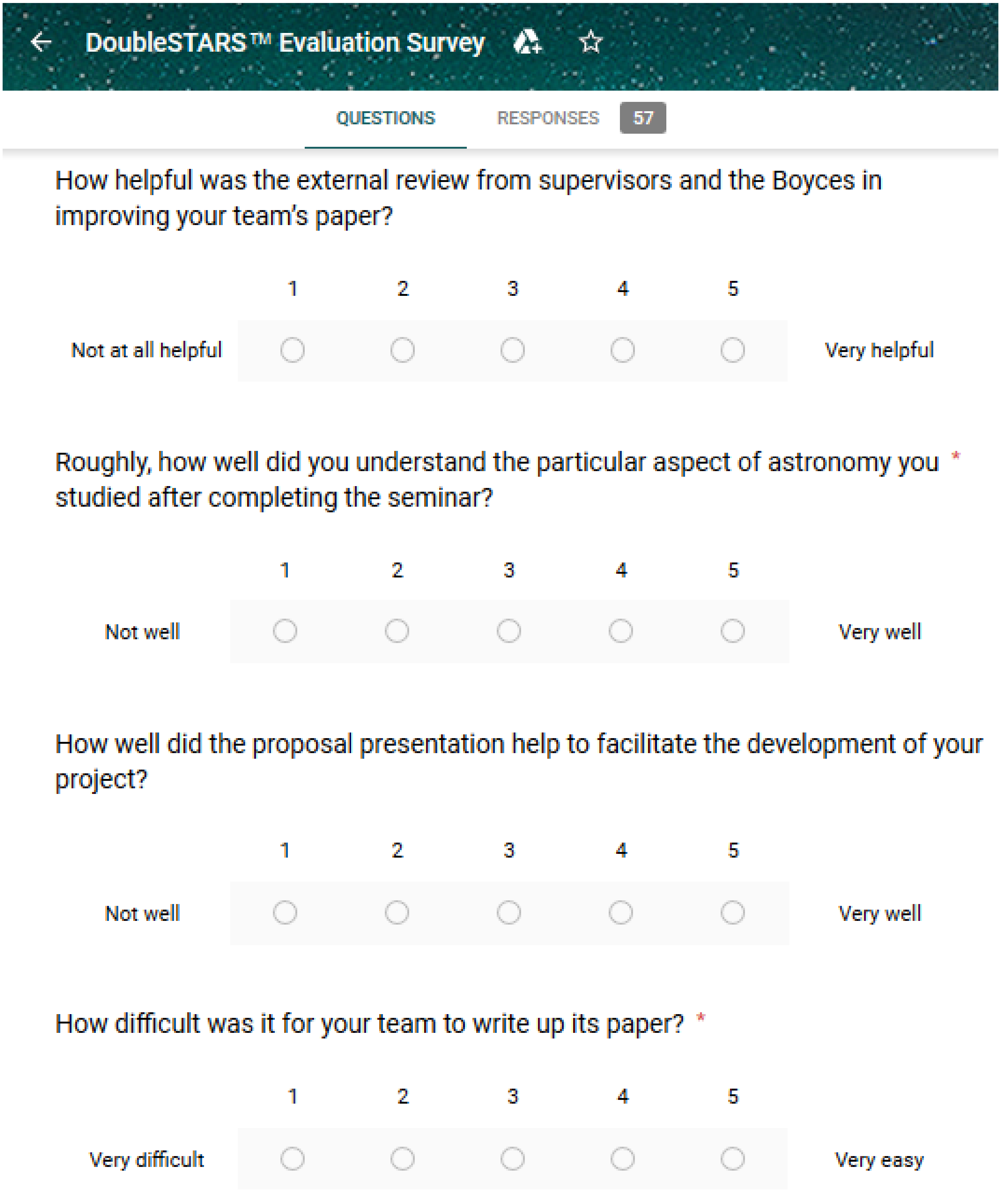


Figure 1. An example of the survey distributed to participants of the seminar.

— better known as BeWise — contributed slightly

to the demographics of the survey respondants and

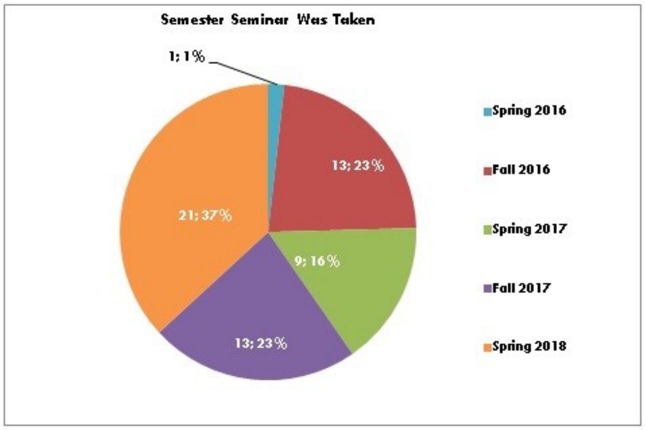


Figure 2. Semester that survey respondents took the seminar.

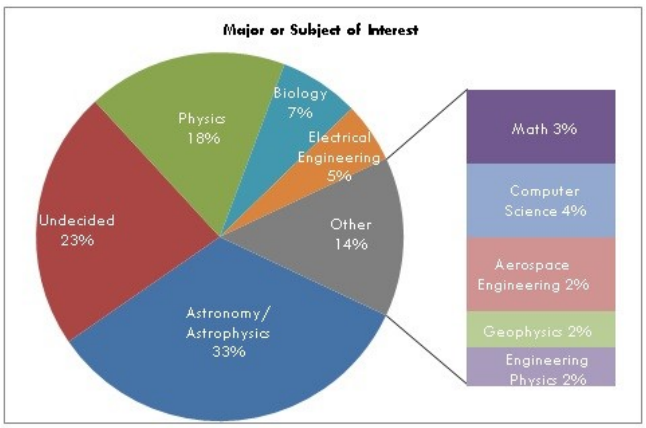


Figure 3. Major or subject of interest of survey participants.

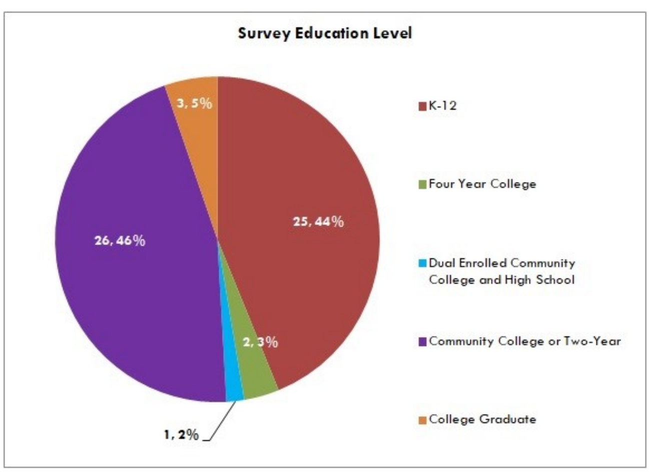


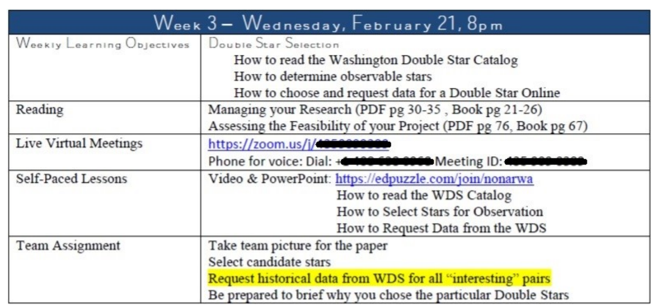
Figure 4. Education level of the survey participant when taking the seminar.

to the program as a whole.

Methodologies and Their Effects

The seminar takes place over 16 weeks, and coincides with the Spring or Fall semester for most students. This time period allows for the students to have enough time to: learn the material, develop and present a proposal presentation, acquire test and final images, analyze their images, present what they found at a final presentation with their fellow researchers, and draft their final paper.

The students are provided a syllabus which lists assignments and deliverables for each week at the beginning of the semester, and links to online web content. An example of a typical weekly taks is shown in Figure 5. For students taking the online version of the seminar, weekly Zoom meetings are held to review assigned materials and cover any other concerns brought up by students. The online meetings, typically an hour long, are open to all students taking the course during the semester, and any participants with questions or concerns are encouraged to join in.



Week 3 – Wednesday, February 21, 8pm	
Weekly Learning Objectives	Double Star Selection How to read the Washington Double Star Catalog How to determine observable stars How to choose and request data for a Double Star Online
Reading	Managing your Research (PDF pg 30-35 , Book pg 21-26) Assessing the Feasibility of your Project (PDF pg 76, Book pg 67)
Live Virtual Meetings	https://zoom.us/j/[redacted] Phone for voice: Dial: [redacted] Meeting ID: [redacted]
Self-Paced Lessons	Video & PowerPoint: https://edpuzzle.com/join/nonarwa How to read the WDS Catalog How to Select Stars for Observation How to Request Data from the WDS
Team Assignment	Take team picture for the paper Select candidate stars Request historical data from WDS for all "interesting" pairs Be prepared to brief why you chose the particular Double Stars

Figure 5. Example week from the DoubleSTARS Seminar syllabus

The syllabus lists out all of the required readings from Russ Genet's Small Telescope Astronomical Research (STAR) Handbook (Genet et al. 2015), shown in Figure 6, as well as the Edpuzzle videos created by Grady Boyce. The STAR Handbook is provided to the students as a PDF, and is an invaluable tool for learning the intricacies required in portions of the research. Edpuzzle is utilized to distribute self-paced video lectures, and uniquely allows questions during playback to ensure comprehension of the subject at hand. Students have access to a library of video content that covers every aspect of the course.

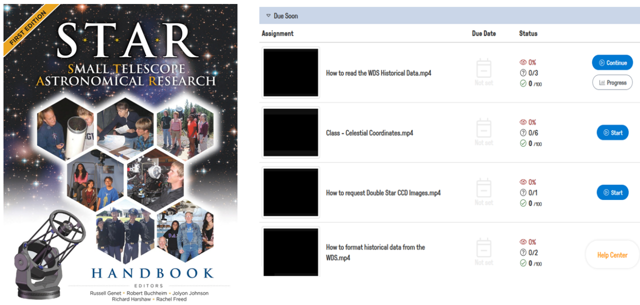


Figure 6. Russ Genet's STAR Handbook (left), and an example of the EdPuzzle webpage (right).

The seminar can be broken down into 7 main milestone points:

- Week 1-2: Team selection and role assignment
- Week 3-5: System selection and historical research
- Week 6: Proposal presentation and test images
- Week 7: Order final observations
- Week 7-15: Data analysis, initial drafts, final presentation preparation
- Week 15: Final presentation
- Week 16: Final draft (expected) due date

These milestone points were utilized as the methodologies of the seminar, and each one will be considered individually along with supporting data from the survey, where available, to express the effects they have on the students involved.

Week 1-2: Team Selection and Role Assignment

During the first week students are provided with the course materials, introduced to their teammates, and role assignments are chosen. Team selection processes vary depending on who is teaching the program. For example, at Mesa College where the program is taught by astronomy professor Dr. Irena Stojimirovic, students are split into teams based on their skills, strengths, and willingness to take on the position. Team leadership is chosen among teams and is not always decided during these first two weeks. Regardless of the roles taken on, all students are required to learn the same material in order to communicate effectively amongst themselves, and in order to provide a failsafe in the case of a student being unable to complete their assigned task or in the event of an unexpected life circumstance arising.

Almost half of the survey respondents had interdisciplinary skills that supported their team and the requirements of the project. The broad distribution of reported unique talents is presented in Figure 7. Students indicated that they did not have any applicable skills, and that they wished that they had a unique talent that helped out the team. In these students' specific survey responses, they said that, despite lacking what they considered to be relevant skills, the program motivated them to continue within the STEM field, and that this was an experience different from any other they have had in a school class. It is anecdoctally reported by project personnel that often times the students who feel the most under-prepared for this type of research that come up with unique, inventive methodologies and solutions to the problems faced within the seminar.

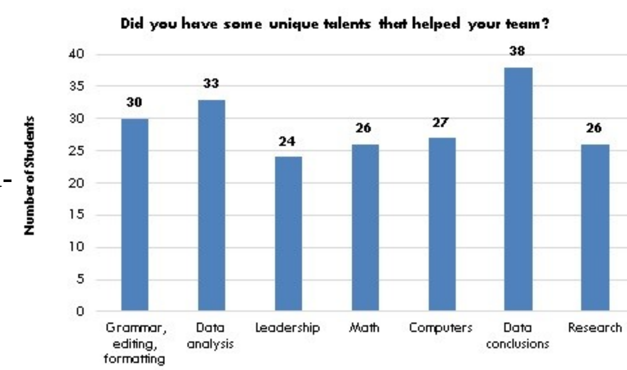


Figure 7. Survey question regarding individual talents of the respondent that helped them contribute to their team.

This question allowed "other" responses, and some of these responses were:

- "I am good with computers so was able to contribute in technical areas; I wish I could've helped more. . . "

- “I am able to pick up the pace where others left off “

Like with any team-based project, there are varying levels of participation, as shown in Figure 8. A majority of the respondents noted that there was some lack of involvement by at least one of their teammates. Roughly half of that majority said that this was not an issue for them; while the others stated that this was a concern, and that they should not have been included as coauthors. This lack of participation from select students has been observed while involved with this program as mentors, and it is often an issue that there seems to be no clear answers for. The issue lies in that it has no been possible to properly motivate all of the students who are not passionate about conducting the research.

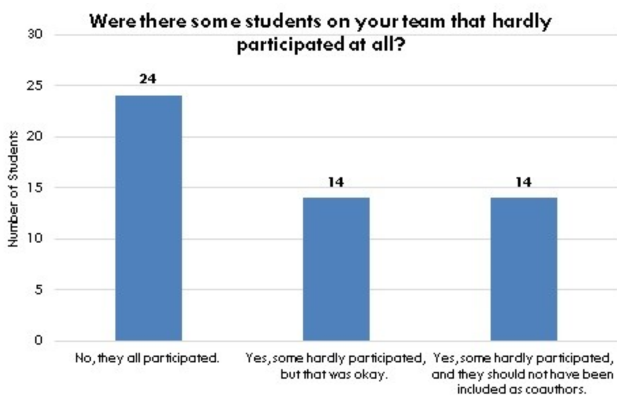


Figure 8. Survey question regarding the participation of team members.

Week 3-5: System Selection and Historical Research

During weeks 3-5, the students are asked to explore the Washington Double Star Catalog (Mason et al. 2010) in order to find a system that both lies inside of certain pre-set parameters and that they find interesting and worthy of research. This is often a part of the seminar that is reported as most daunting for students, as they have only just figured out what double stars are, and yet they are asked to look at massive lists of data in an attempt to find their systems using qualitative analysis as opposed to using strict quantitative guidelines.As of the Fall 2018 semester of the program, the ways in which students look for potential double star systems to study has been updated. The students now utilize a spreadsheet of in depth astrometric data (Harshaw 2018) from the Gaia data release 1 and data release 2 (Gaia et al. 2018).

After selecting a small number of potential systems, historical data is requested from the US Naval Observatory, and the students look at multiple online resources while waiting for that data to be returned to them. Typically, students utilize resources such as StelleDoppie, Simbad, and now the Gaia data release 1 and 2 in order to find existing data about the system. The students are also encouraged to dig into old publications about their systems, and begin to form the introduction to their own papers at this time. The students’ introductions typically involve a brief outlining of what the different types of double star systems are, the historical data found on their system, and the initial discoverer of the double star system—all of which will also be used in their upcoming proposal presentations.

Week 6: Proposal Presentation and Test Images

The proposal presentation in the seminar provides students with a few different opportunities rolled into one single event. The purpose of the presentation is for the students to have a venue to demonstrate what they have learned, the historical research they have performed, and the candidate systems they have chosen for their project. The students are required to show, at minimum, basic information about the stars, what telescope system and possible filters they will use to image with, a Gantt chart with their timeline for the semester, and why they find this system interesting for observations. All of that information is necessary when writing up their paper towards the end of the semester. This experience also gives students a chance to speak in front of a large group, sometimes for the first time, and provides them with valuable feedback concerning the systems they chose.

While some students might find talking in front of a large group to be stressful, the proposal presentation greatly assisted them in the development of their project. The general distributions of answers to this question are presented in Figure 9. Only one student said that this process provided no benefit to them. In a previous semester, students were required to not only present this information, but write it out similar to how scientists would write a grant proposal. They were required to apply for telescope time, and the groups with the best proposals were given extra time for their observations. This system could be utilized for all semesters, as it is nearest to the reality of scientific research, and students would potentially take the observation period more seriously.

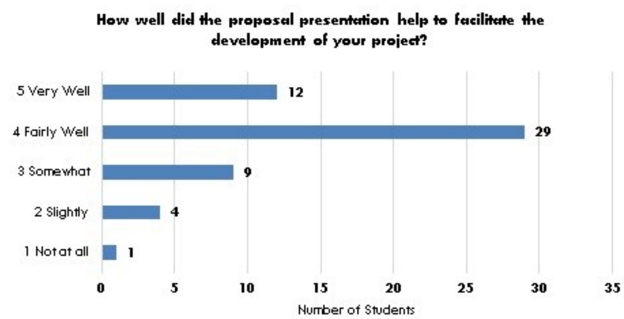


Figure 9. Survey question regarding the usefulness of the seminar proposal presentation.

The students take test images to confirm that the exposure lengths and filters they chose are ideal for imaging their selected system. During the first two semesters, Grady Boyce was responsible for ordering images through iTelescope (Boyce et al. 2016), with that responsibility being passed onto the student mentors in the Fall of 2017. In the Spring 2018 semester, BRIEF began working with the Las Cumbres Observatory (LCO) (Brown et al. 2013), and students were then trained on how to request data using that system. Utilizing the LCO telescopes and the Our Solar Siblings (OSS) pipeline (Fitzgerald 2018) freed up students to concentrate more on analyzing their data and writing their papers. This is because of the ease with which the images can be ordered through LCO, with the images being platesolved and "ready-to-use" once they receive them from the OSS pipeline.

This final week of preparation for the proposal and test imaging before going into the "real" data collection helps students by allowing them to plan, test, and receive back their images before submitting their final observation requests. The test image process allows them to adjust for any issues in their original plans before moving on to taking the science images.

Week 7: Ordering final observations

After taking their test images and reviewing them to make sure the exposure times and filter selections they chose will work, the students then move on to taking their final images. This process typically takes around 1-2 weeks from the time they take their images until they are available for students to begin analysis on. During this time period, students are encouraged to begin planning out the latter portions of their paper, and to prepare for image analysis and data collection. The distribution of responses, presented in Figure 10, shows that over three quarters of the respondents found the amount of time for imaging to be sufficient. We believe this is largely in part to the implementation of taking test images before simply jumping in and taking images for science purposes.

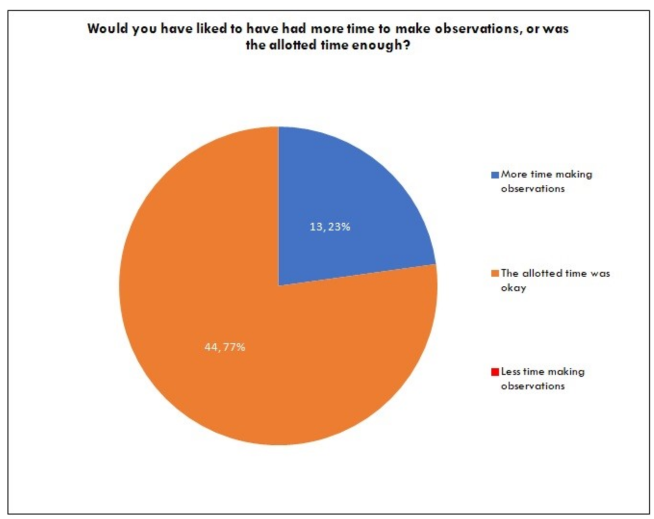


Figure 10. Survey question regarding the time allotment for observations during the seminar. No respondents thought there should be less time allocated for observations.

Week 7-15: Data Analysis, Initial Drafts, and Final Presentation Preparation

Over the next eight weeks students move on to data collection and analysis, start to form their initial drafts based off the work done so far and begin preparing for their final presentation. Over this time period, there are still scheduled group meetings, but they are now more focused on specific issues that might arise within each team.

When asked whether there should be prerequisites in order to take the seminar, the overwhelming response was no. The distribution of responses is shown in Figure 11. One respondent stated that, "I don't think the prerequisites were necessary because the instructors did a very good job of explaining everything we needed to know to complete this project." The one prerequisite that is asked by Boyce-Astro is a desire to contribute and participate in the process. Students have come into this program with next to no practical experience in astronomy, and walked away with a new insight into what interests them and what their capabilities as a student are.

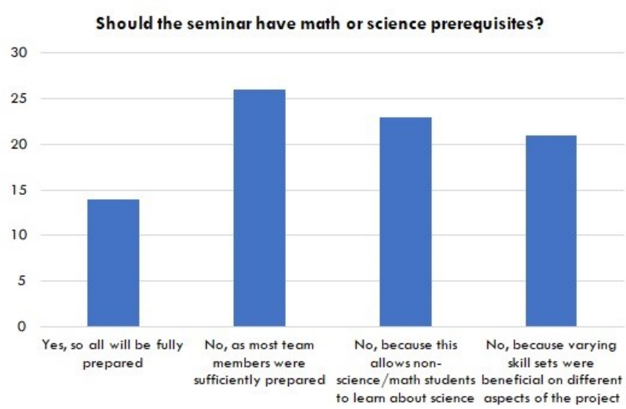


Figure 11. Survey question regarding whether or not the program should have math and/or science prerequisites.

This question allowed "other" responses, and some of these responses were:

- "The prerequisites should focus on character, work ethic, and analytical ability."
- "Prerequisites should not be required but should be suggested."
- "People with very little science pre-requisites should be vetted to ensure their motivations are in-line with the seminar."

As mentioned previously, the seminar requires students to develop a Gantt chart in order to keep their project on schedule. Having students develop this chart helps them maintain a rough timeline of events and deliverables, and also helps them learn how to properly allocate their time. The data around students' input on whether they were given enough time to form a well-written paper is presented in Figure 12. Overwhelmingly, the students believed they were given enough time to at least write a basic scientific paper, with only one student responding that there was not enough time to do a good job writing the paper.

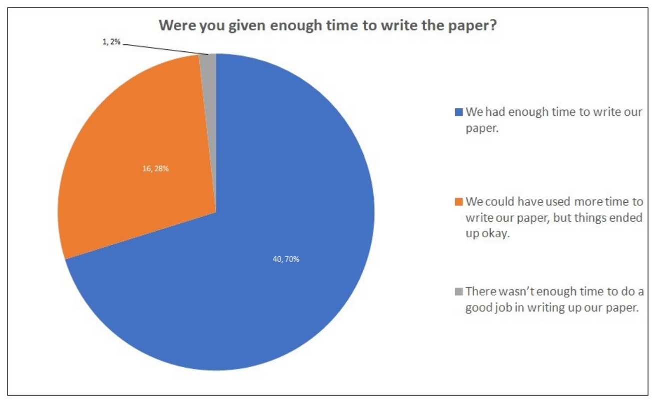


Figure 12. Survey question regarding the amount of time allotted to writing their paper.

One of the greatest benefits of a program being designed specifically for those new to the field is these students being able to collaborate with professional astronomers in undertaking their projects. When asked if they felt like they were immersed within a supportive professional-amateur community, 49% of the students indicated that they felt only somewhat immersed, with a single response stating that there was no immersion. The results for this question are represented in Figure 13. An as yet unanswered question for future research could be "What could make more students feel as if they were being supported more than they are currently?"

Students, be it in a program like this or in any other class situation, often feel a level of intimidation from their instructors. While some students feel comfortable engaging with their teachers, others might not be, and as a result, will not communicate as much as others. The introduction of Peer

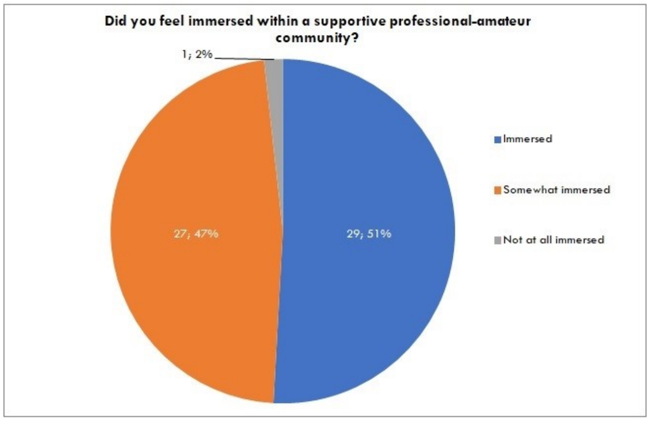


Figure 13. Survey question regarding the feeling of immersion within a professional-amateur community.

Advisors into the DoubleSTARS seminar allows students to reach out to someone who may not be as intimidating and busy as their instructor.

Conference attendance, as experienced by the authors and other participants, give students a valuable opportunity to interact with professionals in a way that is currently not done in the DoubleSTARS program. The students' successes and accomplishments in this field are largely due to their attendance, participation, and networking opportunities at local and international conferences. Attending these conferences allows students to gain experience answering tough questions that were posed by those viewing their posters and presentations, and also to see what kinds of research was being done outside of the narrow field of view they currently have.

Week 15: Final Presentation

During the final two weeks, drafts are ready to start going through peer review, if they have not already started, and the teams prepare their final presentation. The final presentation allows the students to show off their research to the same group of students and instructors as during the proposal presentation, and gives students a chance for final feedback regarding the methods they employed and conclusions they have drawn.

What students were taking away from the program after completion was explored in the survey, and the results from those questioned, presented in Figure 14, were quite encouraging. Out of the 57 people surveyed, 50 of them left this course feeling like they better understood the double star field than when they began, and not a single person reported zero post-completion understanding.

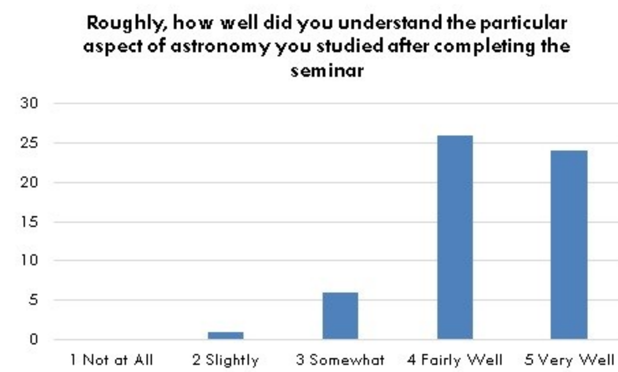


Figure 14. Survey question regarding the students' post research understanding of the field of double stars.

As discussed earlier, when dealing with how the authorship order is decided, the level of participation is taken into consideration by the group. The results from this aspect of the survey are presented in Figure 15. There are circumstances in most semesters where a student stops attending the program or participating with their team, and that student will generally either be put further down on the authorship order, or removed entirely and added to the acknowledgments depending on the amount of work contributed.

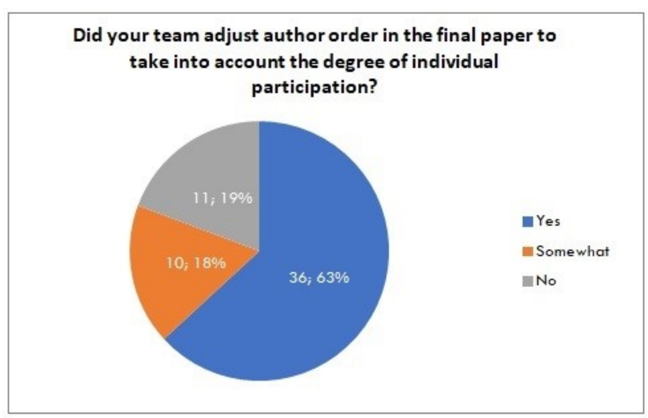


Figure 15. Survey question regarding the final author order and degree of individual participation.

Week 16: Final Draft (expected) Due Date

In the final week of the seminar, and after the students have completed their final presentations, the final draft of the paper the students have been working on is expected to be turned in for peer review. Of course, peer review comes with more revisions, and these are handled via email. Students were able to come away from this class having learned more about the field of double star astrometry. 95%, or 54 people, reported that they felt this class was more than just an academic exercise, and that they were able to contribute to the scientific community at least in a minor way. The responses to this question is presented in Figure 16.

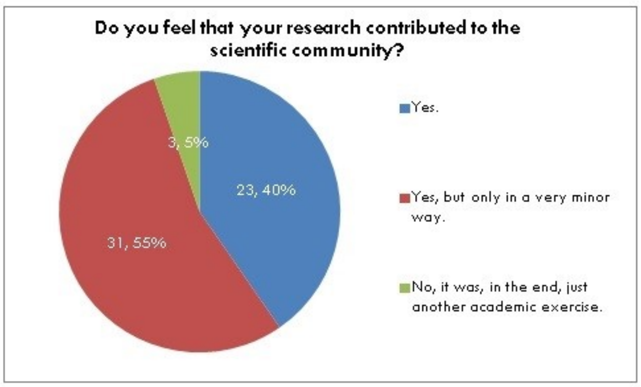


Figure 16. Survey question regarding individual contribution to the scientific community.

Conclusion

Students often feeling like the work they are doing is not “real science,” or like they’re not truly contributing to the scientific community. Admittedly, the authors themselves had these thoughts when we were on the student side of this program. This “imposter syndrome” and/or the feeling that students are “not doing real science” is an issue that was brought up multiple times in discussions at the RTSRE conferences, and is an issue that the educational community must face head on. The reality is that programs such as the DoubleSTARS seminar are not intended to be professional grade research programs performing cutting edge research. What these programs are intended to do is inspire early students to continue on in STEM related fields, as well as teaching them the basic skill sets that they will utilize throughout their early careers in a multitude of fields. More so now than ever before, the acquisition and sharing of data is an essential part of astronomy and the broader scientific community, and teaching students the methods that are utilized by scientists in every field across the board will allow them to make great leaps in their future careers.

Time and again, the work done with this seminar leads students to continue pursuing research careers, and accepting admission and scholarships to a multitude of colleges where they utilize the skills they obtained early on (e.g. Freed 2018, 2019a,b). This is something that has been expressed by our students, and is perfectly summarized by them when they were asked if there were any statements about the program they would like to make anonymously.

> *“The whole seminar was so phenomenal. It gave me a better appreciation for research and has since led to a new career in the biotech industry for myself as I am still pursuing my degree. Thank you Boyce-Astro and Jae [Calanog] for giving students a chance to prove themselves and to work with others who are working towards the same goal!”*

> *“I highly value the experience I gained by participating in this project, including skills such as analyzing data, working on a research team, and writing a professional-level research paper.”*

Acknowledgments

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Google CoLaboratory as a Platform for Python Coding with Students

Kalee Tock[1]*

Abstract

Google CoLaboratory (Google CoLab) is a powerful collaborative tool for coding in Python with students. This work presents a project to calculate the period of an eclipsing binary system that was completed by Stanford Online High School students using Google CoLaboratory. The Las Cumbres Observatory 0.4m telescopes were used to obtain images, and photometry from the Our Solar Siblings pipeline was imported into Google CoLaboratory using JSON (Javascript Object Notation) for analysis in Python. Some additional classroom applications of Google CoLaboratory are highlighted, such as converting between astronomical coordinate systems.

Keywords

Keyword1 — Keyword2 — Keyword3

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Introduction

Python modules have become increasingly popular in astronomy for data analysis. Astronomers cite Python's numerous modules, extensive user community, helpful documentation, ease of use, and most of all, the powerful plotting functionality as reasons for adopting Python in their research. The developer and user community that has grown up around Python is especially dynamic and supportive, which contrasts with and augments the astronomical community of practice Greenfield (2011). Outside of astronomy, applications in geociences are increasingly using Python because it is free, accessible, and multiplatform Lin (2012).

It can be difficult to introduce students to Python because of the complications of software installation and platform differences, particularly if students are using their own individual computers. Using a browser-based tool lessens several of these difficulties. Although Google CoLaboratory does necessitate use of the Chrome browser, the lack of additional software that is needed makes it particularly useful in a classroom environment to bypass platform and software issues and get students straight into coding.

In this project, two separate student groups developed Python code to calculate the period of an eclipsing binary system (Altunin et al. 2020; Badami et al. 2020). The Las Cumbres Observatory (LCO) 0.4m telescopes were used for image acquisition, and the Our Solar Siblings pipeline was used for photometry (Brown et al. 2013; Fitzgerald 2018). We had the most success imaging eclipsing binaries with apparent magnitude m $<$ 13, and selecting systems that had deep primary and secondary eclipses so as to be sure of seeing a definite dip in the lightcurve from our data. The Kepler Eclipsing Binary Catalogue hosted at Villanova University provided the list of systems from which the student groups selected their targets Kirk et al. (2016).

The Importance of Manually Inspecting Time Series Images

One important takeaway from this project was the importance of flipping through all of the images manually to determine which were and were not suitable for analysis before feeding them into the code. Images that showed evidence of atmospheric interference or of collimation problems, as shown in Figure 1, compromised the photometry. The students constructed a scale from 1 – 4 to rate the quality of their images, where 1 represented a high quality image with round, well-defined stars and 4 was an image that was corrupted by clouds, satellite trails, or imperfect tracking. They used this scale to see how the results changed when images of different quality ratings were included or excluded from the analysis.

Determining Appropriate Exposure Times for Variable Stars

Determining an appropriate exposure time is an iterative, trial-and-error sort of process. AstroImageJ (AIJ) Collins et al. (2017), a free software for manipulating astronomical images, allows the user to interactively determine the Right Ascension (RA) and Declination (DEC) of stars by simply moving their mouse over the star in the image. This is achieved by using the World Coordinate System plate solution. which allows the user to efficiently locate particular stars in the image. The user decides how big to make the circle, or aperture, and places the aperture over the star. Within the aperture, AIJ computes the centroid of the star as the average position of the pixels, weighed by a measurement of the light collected by each pixel, and automatically adjusts the aperture to be centered at the centroid.

The measurement of light is reported as a count of analog-digital-units (ADU's). When photons strike the camera CCD, electrons are knocked loose from their corresponding "buckets" on each pixel. The ADU count is the number of these electrons. AIJ reports the highest ADU count for a single pixel within the aperture as the "peak", and the total ADU count from all of the pixels within the aperture as "Int counts", or "integrated counts", shown in Figure 2. Where the centered aperture covers a fraction of a pixel, the corresponding fraction of the ADU count measured by that pixel is included in the integrated counts.

To avoid saturation, the "peak" should be comfortably lower than the total number of electrons that the bucket can hold, which is usually 65,535 but can vary depending on the telescope Buchheim (2015). However, the integrated counts needs to be high enough that the signal will not be overwhelmed by the inherent noise in the measurement. Noise comes from electrons jiggling out of their buckets due to causes that are not target star photons, like light from other sources or heat from the telescope that causes them to jiggle out without a photon stimulus. AIJ calculates the signal-to-noise (SNR) ratio from the aperture tool settings. It first counts up the photons inside the aperture radius: this is the signal. Then it subtracts off the average photons per area from the region between an inner annulus and an outer annulus that are both located outside the aperture. This is the noise. In general, an SNR between 100 and 200 is desirable, which usually corresponds to integrated counts of at least 100,000 ADU and less than 500,000 ADU Fitzgerald et al. (2018).

Another factor that must be kept in mind is that these stars are variable, which is the whole point of measuring their light in the first place. The brightening and dimming of the target star, combined with the clarity of the sky on the night the image is taken, might correspond to as much as a doubling or halving of the counts from any single image. So, it is important not only for the ADU counts to be in range, but for double or half that number of ADU counts to be in range also.

This is further complicated by the need for the ADU counts to be in range for several comparison stars (comp stars) in addition to the target star.

Comp Stars

Even though the specifications of the LCO telescopes and cameras are identical, the images are

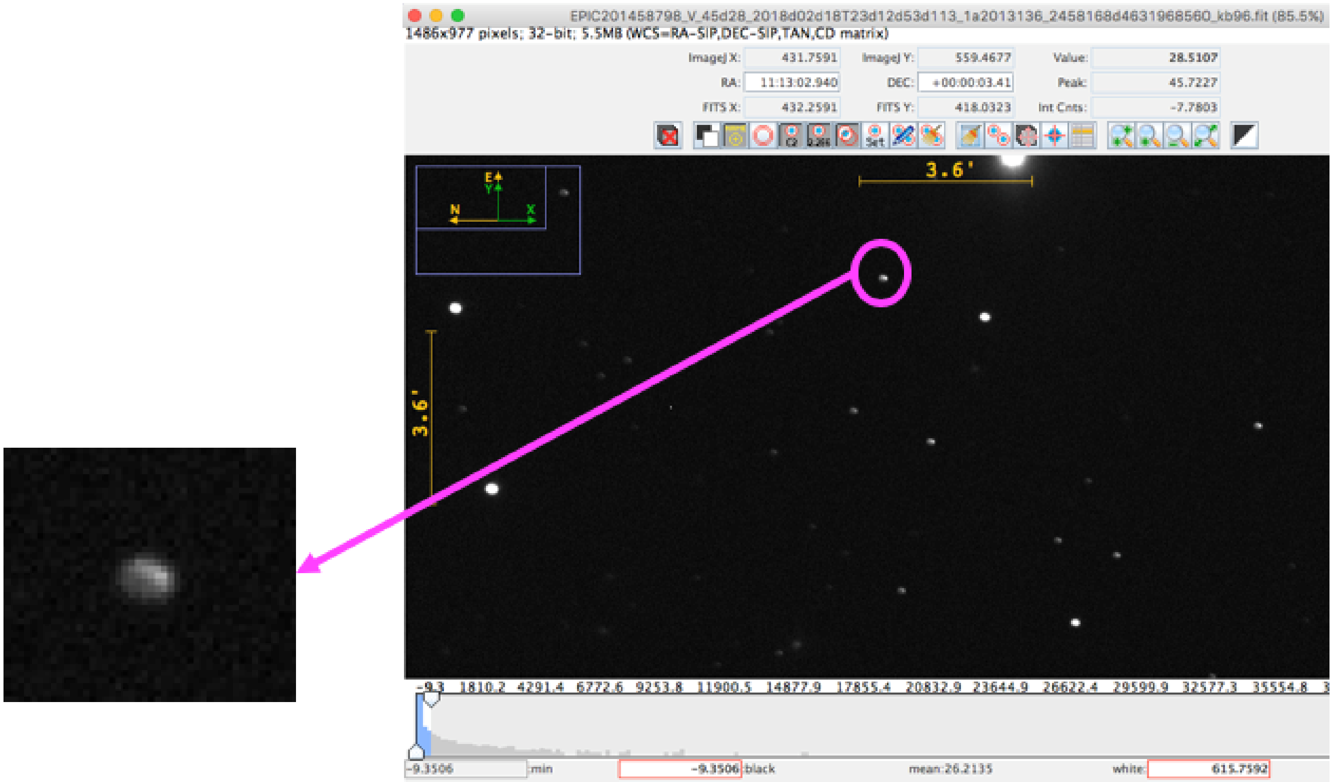

Figure 1. Sample image showing evidence of poor collimation

taken in multiple locations over the course of multiple nights Brown et al. (2013). Some skies are clearer than others, and some viewing angles are more direct than others. But, if atmospheric effects cause more or less light from the target to reach the telescope, then the atmosphere is likely to affect a nearby comp star in the same way. So, instead of reporting the measurement of light from the target directly, we report the ratio of target light to comp light. This ratio is equivalent to the difference in the star magnitudes, since magnitude is on a log scale.

Of course, this only works if the comp star is not itself inherently variable. To find the least variable comp star, the students plotted the differential magnitudes of several candidate comp stars relative to each other, looking for the flattest lines. It was helpful to arrange the plots as a matrix in order to disentangle the effect of one comp star from that another. For example, the slight swishiness of the sample comp star in Figure 3 below should not eliminate the comp star against which it was plotted, because this swishiness showed up in the plots of this comp star against all of the other candidates. In addition to examining the Comp vs. Comp plots visually, the students also compared the standard deviations of the magnitudes and the slopes from linear fits of each graph, took into account the roundness, color, and average counts from the comp star candidate compared to the target across all of the images, and examined the scatter in the final lightcurve.

Performing photometry manually in AstroImageJ on target and comps works well, and it is important to do it manually for several images to find appropriate exposure times, select comp stars, get a feel for the starfield, and understand what the numbers mean. However, each project had almost 600 images by the time it finished. It would be impractical and error-prone to perform the photometry in this way for that many images. Also, as it turns out, there is more than one way to count photons.

Photometry from the OSS Pipeline

The Our Solar Siblings (OSS) pipeline performs six types of photometry on images that are returned

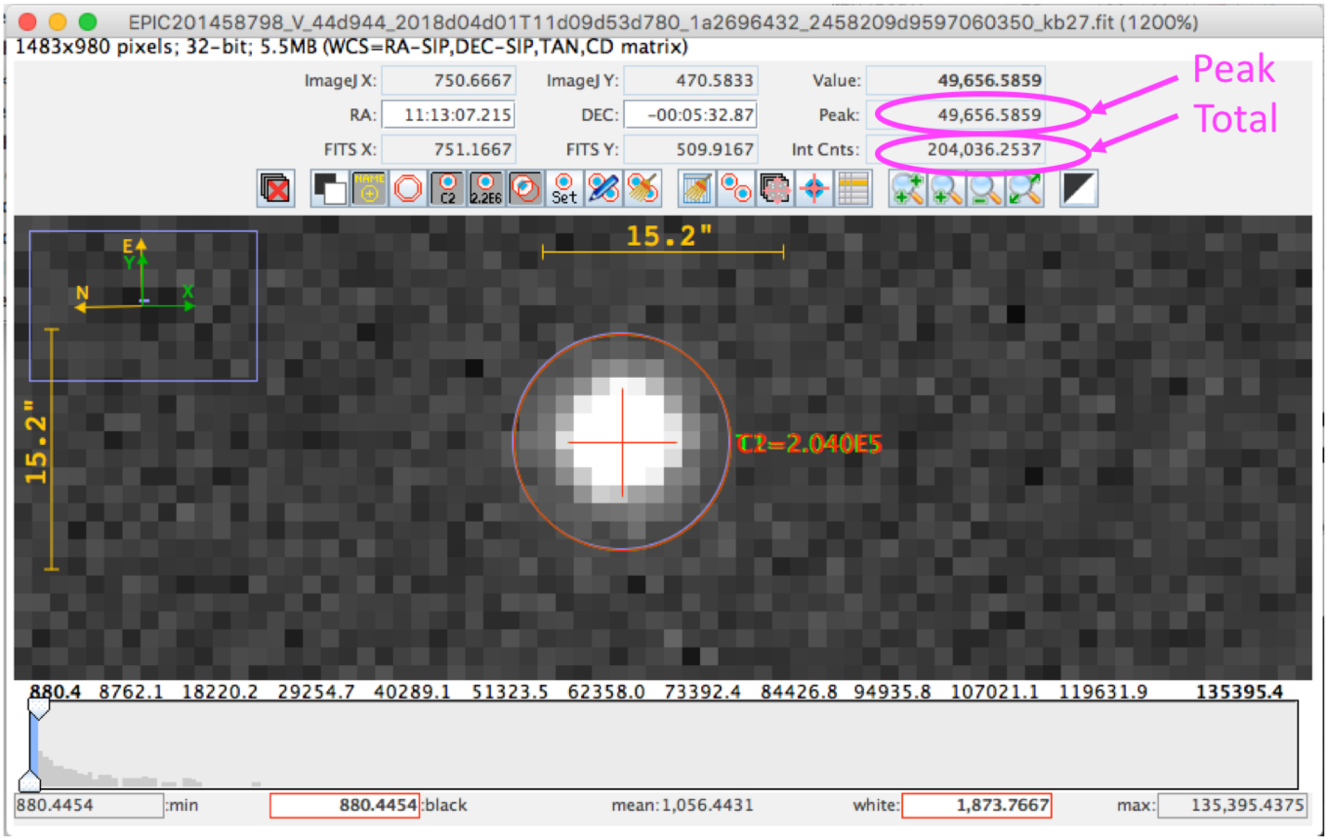

Figure 2. Aperture photometry in AstroImageJ, showing the peak ADU count and integrated counts within the aperture set by the user.

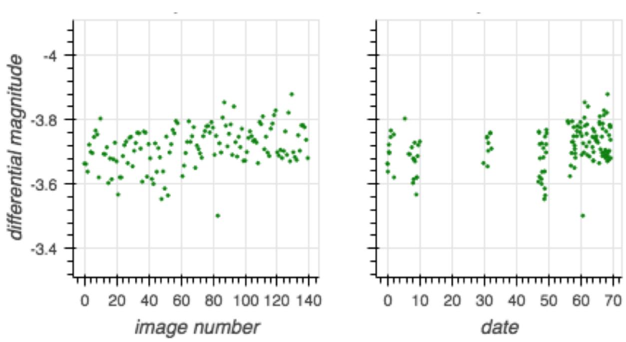

Figure 3. Sample comp star candidate eliminated on the basis of its non-linear differential magnitude plotted versus other comp stars

from LCO Fitzgerald (2018). The first three photometry types are similar to each other in that they represent straight sums of ADU counts within an aperture. These include aperture photometry (apt), which is the type of photometry described above that the students performed manually in AIJ. In addition, for each image, the pipeline returns source extractor photometry (sex), and source extractor kron photometry (sek). The sex and sek photometry algorithms measure integrated counts similar to apt, though sex varies the aperture radius for each star so as to capture 90% of the object's light, and sek models the star's image as elliptical rather than circular Holwerda (2005).

The remaining three photometry algorithms are called dao, dop, and psx. These use mathematical models called point-spread functions (PSF's) to measure the light from any given star in an image (Stetson 1987; Schechter et al. 1993; Bertin 2011; Bertin and Arnouts 1996). These algorithms operate on the premise that if the telescope were outside of Earth's atmosphere, the starlight from a target would fall on a single pixel of the CCD. Figure 4 shows the intensities of two stars A and B, where B is brighter. The horizontal axis is the pixel x-coordinate, and the intensity is shown as an ADU count spike at a single pixel.

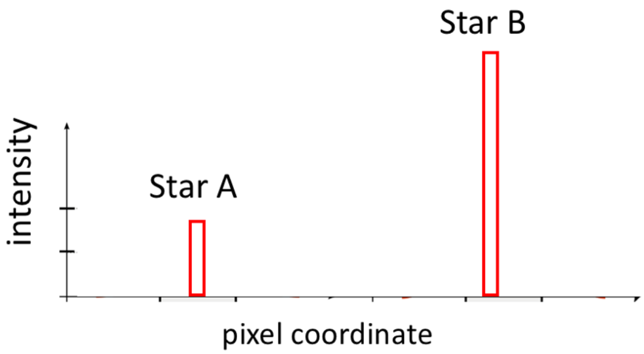

Figure 4. Starlight from two stars before passing through Earth's atmosphere, as they appear on a one-dimensional cross section of the CCD

As it passes through the atmosphere, however, the light is spread out by atmospheric blurring, optical quality and focus accuracy. The image of the star becomes a "point spread function" that is bright at the center and dimmer around the edges. Conservation of energy dictates that the peak intensity and also the total area under the point spread function are both proportional to the total number of photons from the star. Also, the full-width-at-half-maximum, or FWHM, is the same for all stars, as shown in Figure 5 Buchheim (2015).

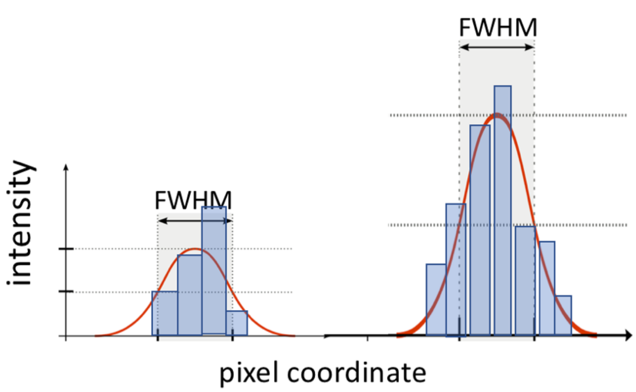

Figure 5. Starlight from two stars after passing through Earth's atmosphere, as they appear on a one-dimensional cross section of the CCD, fit to a point-spread function

All of this is usually true, before detection. However, we are collecting light in discrete buckets, pixel by pixel. Discrete buckets do not make a smooth curve, particularly if the centroid of the star is located in an awkward position relative to the pixel boundaries. So, the types of dao, dop, and psx are different mathematical models for what the shape of the smooth curve would be if the data could be taken continuously rather than discretely.

The details of dao, dop and psx, and the mathemtical methods which underpin them have been discussed in other papers (Stetson 1987; Schechter et al. 1993; Bertin 2011). We took the pragmatic approach of deciding to use the model that gave us the cleanest looking lightcurves. But to do that, it was necessary to determine how to plot the lightcurves in the first place.

Format of Data Returned By the OSS Pipeline

What it means to say that "the OSS pipeline performs 6 types of photometry" is that for every image, 6 separate, comma-delimited text files are produced. The name of each textfile contains information about the image and photometry used: target, filter, exposure time, date, airmass, telescope, and photometry type. In each of the text files are several lines, each line corresponding to one star that the photometry found in the image. The line begins with the RA and Dec of the star, and then has the integrated ADU count and the error for that star, as well as the x and y pixel coordinates of the star in the image. A schematic of the information associated with each image is shown in Figure 6.

Our goal was to locate the target star and the comp stars from these lists of stars in each image, and plot a lightcurve. But first, it was necessary to find a reliable way of storing and sharing the data with all of the students who were working on it. Also, there was more than one eclipsing binary project going: two class teams and a pilot project. So, there were tens of thousands of data lines, each pertaining to a star in a particular image.

Storing and Porting Data for Python

In order to shield students file IO, extraction of the image data from the filename using regular expressions, and designing data structures, it was helpful to design a data structure for each system that con-

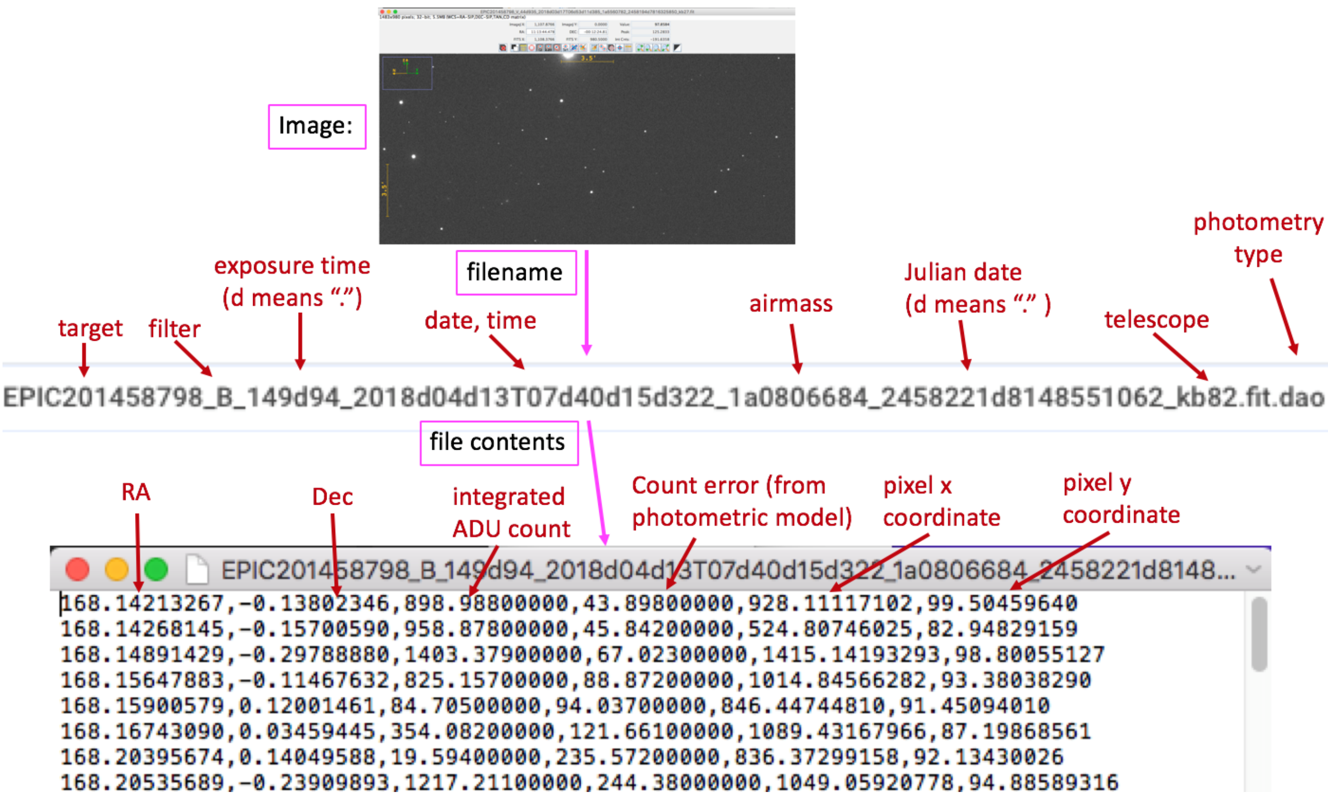

Figure 6. Schematic of the information returned for each image by the Our Solar Siblings pipeline

tained all of the information from all of the photometry files.

It is designed as a Python dictionary called "system" whose fields describe a given target. Among those fields are dictionaries for each photometry type. Each photometry type dictionary contains an array of images. Each image is itself a dictionary with fields for the filter, exposure time, date, and an array of stars. Within the star array, each star is a dictionary with fields for the RA, Dec, count, count error, and pixel coordinates. Figure 7 shows a schematic of the data structure into which the data from the files in Figure 6 get loaded.

Some simple code extracted information from the filenames and read the text files into this data structure on the instructor's home computer. Then, JSON was used to create one (enormous!) text file containing all of the data. This is accomplished with a single line of code:

```
json_file.write(json.dumps(system))
```

The text file generated by this command then gets copied to where it is needed (in my case, Google drive) and read back into the same Python data

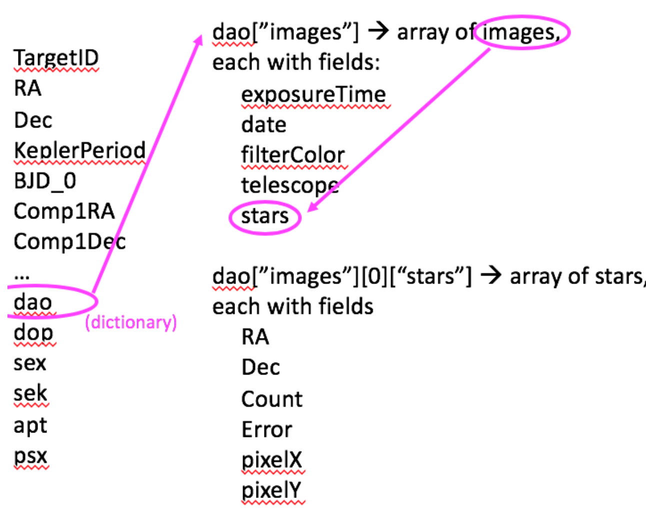

Figure 7. Schematic of the Python data structure that the students worked with

structure using the command:

```
system = json.loads(string)
```

I think this is a particularly good system for teachers, because it allows the teacher to design the data structure and make sure that all her students are using the same organization. Also, it does shield the students from file I/O and regular expressions and things that are more computer-science-y than astronomy-specific. Although, it could be argued that computer science and astronomy are intertwined, and students should be given more authentic experiences in their use, we must look at the practically and teacher training. The aim is to allow teachers of varying ability to take this lesson and construct a program that they are confident in delivering.

The text file generated by the json.dumps command could be examined if that were desirable, though it places enormous load on the computer memory. However, it is human-readable, and shows all of the structures and data. The beginning of the file that was generated for one of the systems is shown in Figure 8.

Google CoLaboratory

We used Google CoLaboratory for developing code to analyze our systems. CoLaboratory has the functionality of Google Docs for Python code, making it ideal for classroom use. The students were already using Google Docs to write their papers collaboratively, so having a consistent interface for writing code was helpful. To see CoLaboratory in action, open Google Drive on a Chrome browser. First, make a new CoLaboratory, by going to "File > New > More". New CoLaboratory users may need to click the "Connect More Apps" button before the yellow infinity-sign CoLaboratory option will appear.

CoLaboratory has two types of cells: code cells and text cells. Users start in a code cell by default. For example, one can type

```
print (Hello Astronomy!)
```

and then type Shift-Enter to run. The output of a cell appears below that cell in the CoLaboratory.

Text cells can be accessed by clicking the menu item at the top. Text cells allow the creation of human-readable explanations, including links and images, with an intuitive word-processing interface. As with the code cells, clicking shift-enter from within a cell displays the output text on the screen. Text cells are particularly useful for teaching because they allow integration of code with rich text describing the code and the theory behind it.

One useful application for the astronomy classroom is converting between degree and hh:mm:ss coordinates. To do this, it is necessary to install astropy by typing the following commands into a code cell:

```
!pip install astropy
from astropy.coordinates import SkyCoord
from astropy import units as u
```

In cases where it is desirable to convert a whole spreadsheet of coordinates from one format into another, or import a large JSON file into the code as was necessary for the eclipsing binary projects, we must understand how to make the CoLaboratory read data files from Google Drive.

Reading Data Files from Google Drive

The first important point about reading datafiles is that one should not do it from a personal account. The reason for this is that the code must be given permissions to do anything it wants to the account from which it reads datafiles. This is unwise if multiple people are editing code, no matter how trusted they are. It is best to make a throwaway Google drive account to store the data, for which the password can be freely shared. Note that the code does not need to be run from the throwaway Google drive account. When any CoLaboratory is run that reads files from Google drive, the user is prompted to specify an account and authenticate if necessary.

Timing Out

When a CoLaboratory is run, Google assigns a virtual machine to the user who is running it. After a long period of inactivity, it logs the user out to free up the virtual machine for other users. In practical terms, this means that after a long (where "long" generally means "a few hours") period of inactivity, the initial code cells will need to be re-run, any software like astropy will need to be re-installed, and data files will need to be re-loaded.

{"TargetID": "201826968", "RA_in_degrees": "178.3651", "Dec_in_degrees": "5.8594", "KeplerPeriod": "0.3617589", "BJD_0": "1974.234886", "Comp1RA_in_HHMMSS": "11h53m39.228s", "Comp1Dec_in_HHMMSS": "05d54m5.59s", "Comp2RA_in_HHMMSS": "11h53m40.44s", "Comp2Dec_in_HHMMSS": "05d49m43.56s", "Comp3RA_in_HHMMSS": "11h53m40.09s", "Comp3Dec_in_HHMMSS": "05d43m33.24s", "Comp4RA_in_HHMMSS": "11h53m40.83s", "Comp4Dec_in_HHMMSS": "05d45m31.25s", "Comp5RA_in_HHMMSS": "11h53m12.65s", "Comp5Dec_in_HHMMSS": "05d45m47.40s", "Comp6RA_in_HHMMSS": "11h53m11.52s", "Comp6Dec_in_HHMMSS": "05d47m34.36s", "CompRasInDeg": [178.41344999999998, 178.41849999999997, 178.41704166666665, 178.42012499999998, 178.30270833333333, 178.29799999999997], "CompDecsInDeg": [5.901552777777778, 5.828766666666667, 5.7259, 5.758680555555555, 5.763166666666667, 5.792877777777778], "psx": {"images": [{"filterColor": "B", "exposureTime": "49.938", "modifiedJulianDate": "2458170.9855853538", "telescope": "kb82", "category": "", "comments": "", "score": "", "stars": [{"RA": "178.2362010", "Dec": "+5.7156659", "pixelX": "1193.8076", "pixelY": "82.8025", "Count": "5184.38", "Error": "109.6183"}, {"RA": "178.5173112", "Dec": "+6.0868401", "pixelX": "18.9791", "pixelY": "960.4824", "Count": "0", "Error": "0"}, {"RA": "178.5137592", "Dec": "+6.0683268", "pixelX": "77.4402", "pixelY": "949.5721", "Count": "7987.723", "Error": "122.6227"}, {"RA": "178.5119282", "Dec": "+5.7143109", "pixelX": "1194.4917", "pixelY": "948.1808", "Count": "6433.571", "Error": "112.1856"}, {"RA": "178.5108078", "Dec": "+5.6938513", "pixelX": "1259.0665", "pixelY": "944.8024", "Count": "3168.842", "Error": "95.67119"}, {"RA": "178.5099907", "Dec": "+5.8028817", "pixelX": "914.9103", "pixelY": "940.9825", "Count": "4359.611", "Error": "103.8775"}, {"RA": "178.5097351", "Dec": "+5.7722586", "pixelX": "1011.7166", "pixelY": "940.5045", "Count": "2665.312", "Error": "94.08871"}, {"RA": "178.5032350", "Dec": "+5.6805435", "pixelX": "1301.1492", "pixelY": "921.2495", "Count": "5360.583", "Error": "106.679"}, {"RA": "178.5009520", "Dec": "+5.8847504", "pixelX": "656.7752", "pixelY": "911.6479", "Count": "5371.967", "Error": "109.0378"}, {"RA":

Figure 8. Initial lines of the json file generated for one of the systems described in this paper

Generating a Lightcurve from OSS Photometry Data

The tiny.cc/rtsre file contains code to load the data into Python, and construct a lightcurve in sek photometry. In order to accomplish this, it is necessary to find the closest star to the (preselected) target and (preselected) comp star in each of the images, making sure that the closest star is within at least 2 arcseconds of those star coordinates.

Bokeh

Bokeh is a powerful graphing software that outputs directly to the browser from CoLaboratory. We found it to be more useful and more accurate than matplotlib for the purpose of this project. A range of great features includes the ability to zoom in on particular regions of any graph after it is generated, as well as the ability to customize the colors and download the graph using the disc icon at the right. These features are highlighted in Figure 9 below.

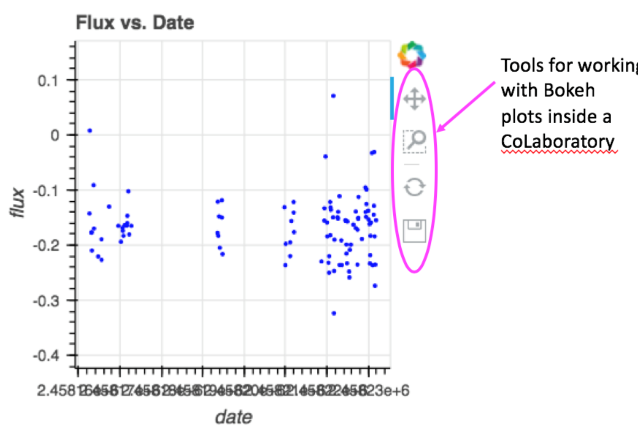

Figure 9. Sample Bokeh plot output within a CoLaboratory

Converting from Date to Phase

The reason that graph shown in Figure 9 above does not show a definite set of eclipses is that the system was sampled less than once every cycle. For the lightcurve to become apparent, the observations must be "phased", or plotted over the course of a single period. For example, if the period is 0.3 days, and the second observation occurred 0.45

days after the first observation, the second observation should be plotted at phase 0.5, because it is halfway through the period of the system relative to the first observation.

So, the way in which the lightcurve is plotted depends on the period of the system. This is problematic because the period of the system is what we are trying to calculate in the first place. As a first estimate, we use the period that the Kepler space telescope calculated for the system when it was observed 3 years ago Kirk et al. (2016). This is shown for sek photometry in Figure 10.

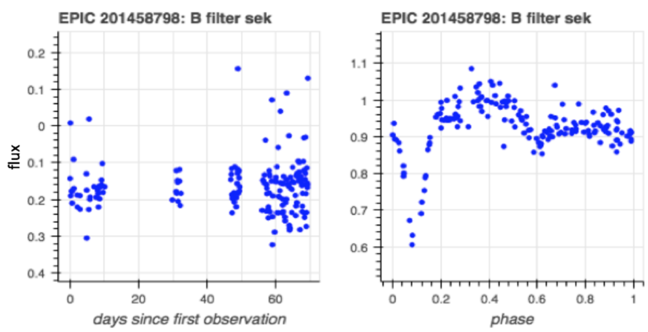

Figure 10. Example of a student eclipsing binary system plotted as flux versus days (left) and flux versus phase (right). Phase computed using period from Kepler

Selecting a Photometric Method

But, the period is not the only unknown. As explained above, the photometry is being done by the OSS pipeline in 6 different ways: dao, dop, psx, sek, sex, and apt. The reader will recall that we are taking the pragmatic approach of selecting the photometry for which the resulting lightcurve has the cleanest appearance. For one of our student groups, that turned out to be source extractor kron, or sek. For another group the standard source extractor (sex) photometry produced the best results. Some sample curves are shown in Figure 11 below.

Finding the Best Period

Having selected our photometry, the students' next task was to figure out a way to adjust the period. If the data are plotted with an incorrect period, the lightcurve looks very messy. This is evident using the Desmos tool written by Hagan Hensley. As the period is adjusted, the lightcurve changes, so that it is visually apparent when the appropriate period has been found.

Phase Dispersion Minimization: Standard Deviation and The Distance Method

However, a more mathematical justification is needed than "the lightcurve looks good". The students used two methods for finding the period mathematically.

Both of these methods operate on the premise that if the period is correct, then points on a flux-versus-phase graph that are close together in phase, will also be close in flux. Although there are parts of the curve where the flux changes rapidly with phase, points close in phase will still have fluxes that are more similar than they would be if the plots were constructed on the basis of an inappropriate period (Dworetsky 1983; Stellingwerf 1978).

The standard deviation method bins the observations into 10 groups by phase and sums the standard deviations of each bin's fluxes. The distance method sums the physical distances between adjacent-phase points on the flux-versus-phase graph. The methods are shown graphically in Figure 12. Iterating the period over multiple possible values and minimizing the respective sums gives the best period.

Fortunately, both methods yielded a clear winner for period. An example is shown in Figure 13. Also, it turned out that the minimum gave a period that was identical to the period provided via Kepler's dataset to within a few seconds. Plotting the lightcurve with this minimum period indeed yielded a very well-defined lightcurve. This gave us confidence in our method of calculating it.

Computing the Error

The literature is conflicting regarding computation of the error of a period obtained by phase dispersion minimization as we have done (Montgomery and Odonoghue 1999). Our best solution was to take as our error the distance in period-space between

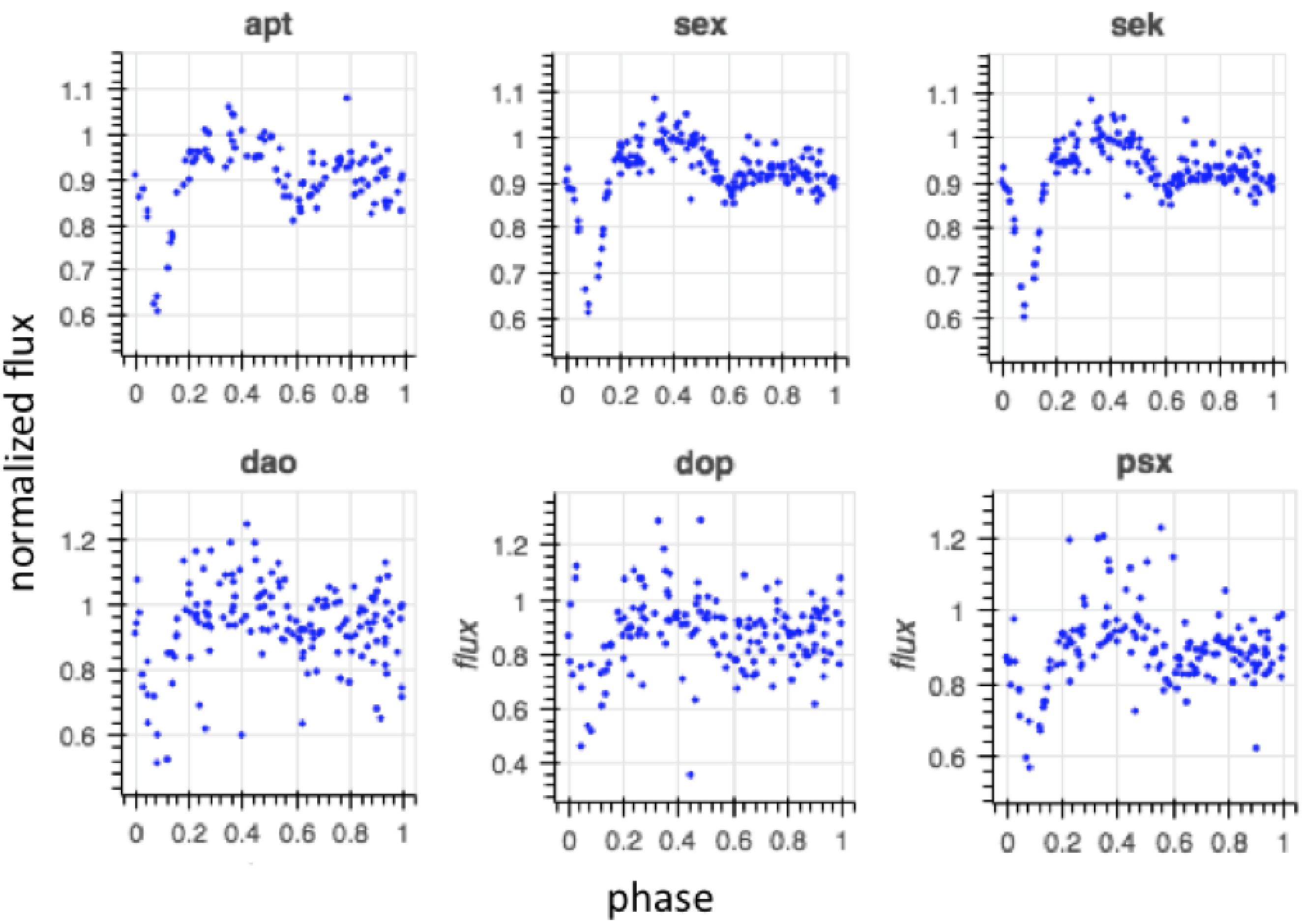

Figure 11. Sample lightcurves from the various photometry types, used to process 2x2 binned images from the LCO 0.4m telescopes. Phase computed using period from Kepler

the two points that fall 5% of the way up from the minimum point of the curve shown in Figure 13. Although 5% seems somewhat arbitrary, this does give the reader an idea of the range of periods that would yield a relatively low standard deviation or distance.

Future Work: Time Series Projects

Time series photometric analysis such as that done in these projects is useful for investigating eclipsing binaries, and that is what was done in these projects. However, there are some other types of variable star projects that could make use of the code that was developed here. The students are inspired by and excited about the possibility of studying exoplanets, which also cause a predictable variation in starlight when they pass in front of their host star. Other stars whose characteristics can be understood through photometry include RR Lyrae, which grow and shrink in a predictable cycle due to changing surface temperature.

The students would also like to re-examine the method used for determining the period error in this work, as they entertained some (well-founded) misgivings regarding the 5% method that we used. Finally, they would like to understand the temperature of the system using B – V curves (Sekiguchi and Fukugita 2000) . The instrumental B – V curve for the system featured here, shown in Figure 14, seems too noisy to be productive for further analysis. However, we have been pointed toward some modeling software that might be able to make sense of it.

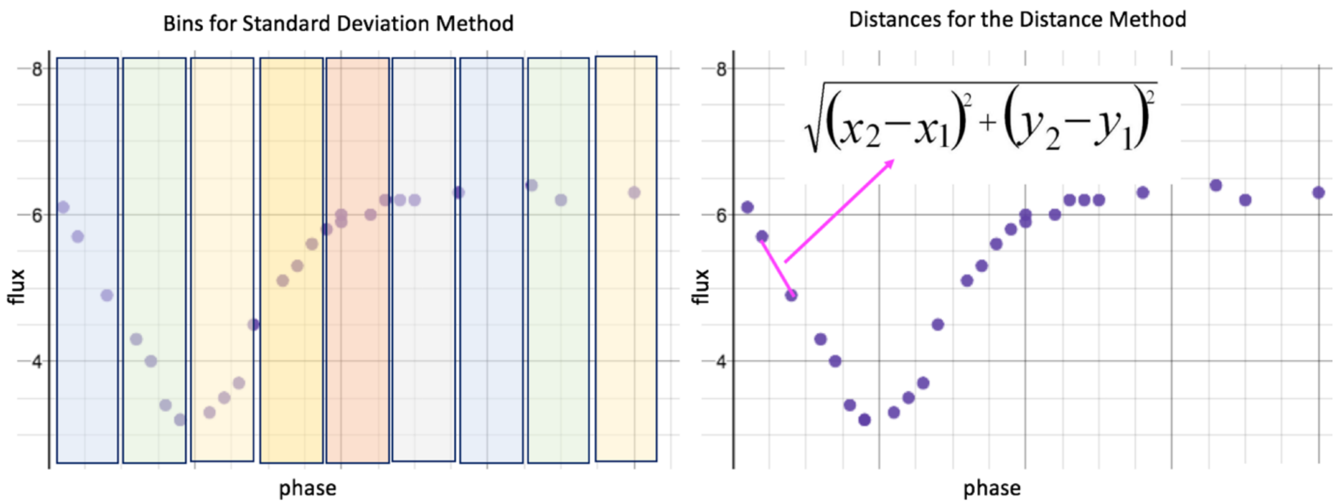

Figure 12. An illustration of the quantities to be minimized for the standard deviation and distance methods, respectively.

Future Work: CoLaboratory

One of the participants at the 2018 RTSRE conference suggested that there is an easier way to share datafiles online, using something called Firebase cloud storage. Apparently, if we use firebase, we will be able to access the file from Python directly using a ”requests.get” command, without having to give anyone permissions to any Gdrive account. So, possibly the contortions around filesharing will soon become more straightforward.

Also, I would like to find a way to flip through the raw .fits images within a CoLaboratory, so as to be able to rate their quality directly in the browser by scrolling without having to keep track of this separately in a spreadsheet. This does not appear to be possible currently, but I am looking for a solution.

Conclusion

Using Python code written together in Google CoLaboratory, students were able to investigate the photometry of images of an eclipsing binary system that were returned by the Our Solar Siblings pipeline. Google CoLaboratory is a powerful system for enabling students to perform such investigations, because it facilitates students writing code together at the same time in a shared document, viewing and learning from each others’ techniques and each others’ error messages.

Acknowledgments

I would like to thank my husband Theron for introducing me to JSON and for generally being my IT (and personal) support. My sons Ezra and Ryan helped me with Python syntax on multiple occasions (no, I am not too proud to ask for help from an 11-year old. Desperate times.). Special thanks go to Rachel Freed for introducing me to the wonderful world of astronomy research, for being an amazing mentor herself and for connecting me to other fantastic mentors. One of those was Michael Fitgerald, of Our Solar Siblings, a frequent source of invaluable help throughout this project and others. Thanks to Richard Harshaw and Bob Buchheim for patiently explaining how image saturation works and to Russ Genet for his encouragement. Thanks to the Las Cumbres Observatory robotic telescope network, which generously provided the telescope time and much-appreciated support throughout this project. Thanks especially to my incredible science division colleagues and the amazing students of Stanford Online High School, to whom I am grateful for plunging into this journey and sticking with it (and with me) throughout its many twists and turns!

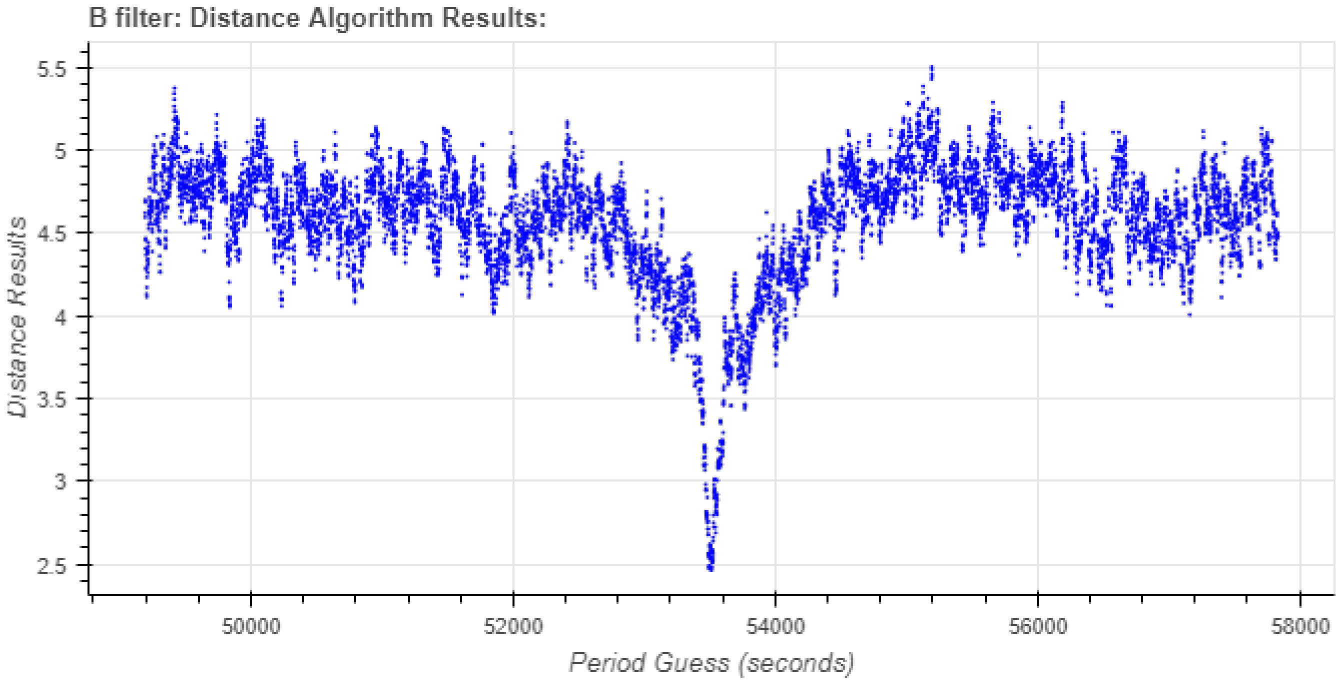

Figure 13. Sample results of the distance algorithm from one of the student projects

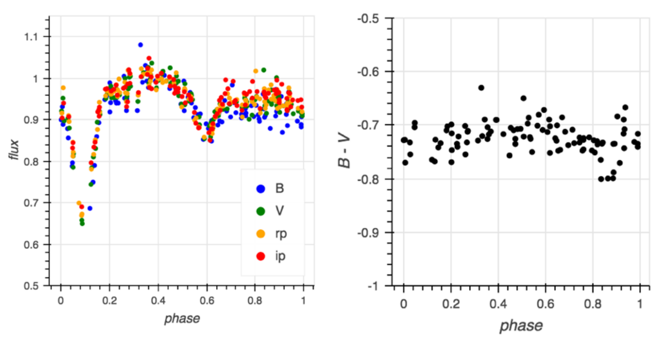

Figure 14. Sek photometry lightcurves for B, V, rp, and ip filters using Kepler Period (left) and instrumental B – V curve using sek photometry and Kepler Period (right)

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Factors Contributing to Attitudinal Gains in Introductory Astronomy Courses

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Abstract
Most students do not enroll in introductory astronomy as part of their major; For many, it is the last science course they will ever take. Thus, it has great potential to shape students' attitudes toward STEM fields for the rest of their life. We therefore argue that it is less important, when assessing the effectiveness of introductory astronomy courses, to explore traditional curricular learning gains than to explore the effects that various course components have on this attitude. We describe the results of our analysis of end-of-semester surveys returned by a total of 749 students in 2014-2015, at 10 institutions that employed at least part of the introductory astronomy lecture and lab curriculum we first implemented at the University of North Carolina at Chapel Hill in 2009. Surveys were designed to measure each student's attitude, and to probe the correlation of attitude with their utilization of, and satisfaction with, various course components, along with other measures of their academic background and their self-assessed performance in the course. We find that students' attitudes are significantly positively correlated with the grade they expect to receive, and with their rating of the course's overall effectiveness. To a lesser degree, we find that students' attitudes are positively correlated with their mathematical background, with whether they intend to major or pursue a career in STEM, and with their rating of the effectiveness of the instructor. We find that students' attitudes are negatively correlated with the amount of work they perceived the course to involve, and, surprisingly, with the size and reputation of their home institution. We also find that, for the subsets of students who were exposed to them, students' attitudes are positively correlated with their perception of the helpfulness of the lecture component of the course, and of telescope-based labs that utilized UNC-CH's Skynet Robotic Telescope Network.

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Background

Increasing interest and participation in STEM fields has been a major goal at the national level for many years, as the United States struggles to keep up globally with scientific and engineering pursuits (AAAS 1990; NRC 2007) while simultaneously declining in global rankings of science education (Kastberg et al., 2016; Provasnik et al., 2016). Meanwhile, little progress has been made on the front of increasing the number and quality of highly trained scientists and engineers in this country or of producing scientifically literate citizens (Alper, 2016).

Concurrently, as a potential solution to these issues, there have been dozens of attempts over the past two and a half decades to provide telescope access for education (Gomez and Fitzgerald, 2017), often under the presumption made by project personnel that, if the telescope is available and accessible, educators and students will inevitably use it for learning (Slater et al., 2014). In contrast, many of the programs developed over the past 25 years have not succeeded in their goals, with several even failing to launch after publication of their intended existence.

Astronomy is often referred to as the "Gateway Science" (NRC 2010), with an estimated 240,000 students taking introductory astronomy or "Intro Astro" in the US, according to a 2012 survey by the American Institute of Physics (Mulvey and Nicholson, 2014). It is often noted that Intro Astro is the last science class many students will ever take and is thus poised in an important position to promote scientific understanding and literacy for citizens as they leave the academic world and enter the workforce.

Skynet (Reichart et al., 2005; Martin et al., 2018) has in large part solved the decades-old struggle to provide telescope learning experiences for students, particularly at large enrollment scales. Since its inception in 2004, Skynet has grown to one of the largest robotic telescope networks in the world, with nearly 30 optical telescopes ranging in size from 14 to 40 inches in diameter, a 20-meter radio telescope, and with several more telescopes soon to be added. These telescopes are all controlled through a web-based portal used by professional astronomers and students alike. Approximately 50,000 students, from middle school through to senior undergraduate, have used Skynet to date.

A few researchers have pointed out that the value of remote telescope use in settings with large enrollments is unclear due to the current lack of risk-benefit analysis in the literature (e.g., Slater, 2018). While much of the focus on astro101 has been on learning gains (e.g., Prather et al., 2009; Schlingman et al., 2012; Williamson et al., 2016), much less attention has been paid to attitudes towards science, and astronomy in particular, in Intro Astro. This is due in part to a lack, until recently, of reliable and validated attitude assessment tools for astronomy (Bartlett et al., 2018), but also to the difficulties of curriculum design connecting expensive telescope resources to large enrollments (Slater, 2007).

In this paper, we explore the effects on students' attitudes towards astronomy (Zeilik et al., 1999), based on responses to end-of-semester surveys of 749 Intro Astro students at 10 institutions between 2014 and 2015. These students undertook, in whole or in part, an introductory astronomy lecture and lab curriculum first implemented at University of North Carolina at Chapel Hill (UNC-CH). This is the first known exploration of students' attitudes combining robotic telescopes and large enrollment Intro Astro courses.

Project Intro Astro

In 2009, we introduced a new introductory astronomy lecture and lab curriculum at UNC-CH. At most universities, introductory astronomy is taught as a two-semester sequence, but at UNC-CH it had always been taught in a single semester, which for the students was akin to drinking from a fire hose. In 2009, we split the old course into two new courses:

ASTR 101: The Solar System
Celestial motions of Earth, the sun, the moon, and the planets; the nature of light; ground and space-based telescopes; comparative planetology; Earth and the moon; terrestrial and gas planets and their moons; dwarf planets, asteroids, and comets; planetary system formation; extrasolar planets; the search for extraterrestrial intelligence (SETI).

ASTR 102: Stars, Galaxies, and Cosmology
The sun; stellar observables; star birth, evolution, and death; novae and supernovae; white dwarfs, neutron stars, and black holes; Einstein's theory of relativity; the Milky Way galaxy; normal galaxies, active galaxies, and quasars; dark matter and dark energy; cosmology; the early universe.

This created time to explore the material more thoroughly and more enjoyably, to introduce new material (e.g., a week of relativity in ASTR 102), and to introduce in-class demonstrations. Altogether, we developed over 50 in-class demonstrations, which we found to be particularly effective at conveying otherwise difficult concepts and at generating discussion, even in the largest classes. We have now taught these courses successfully to as few as approximately 10 students and to as many as approximately 400 students, where so far success has been measured by end-of-course evaluations that are among the highest in our department, as well as by rapidly growing introductory astronomy enrollment.

The centerpiece of our new introductory astronomy curriculum has been the modernization of our introductory astronomy laboratory course, ASTR 101L. For decades, ASTR 101L made use of the theater of the Morehead Planetarium and Science Center on the UNC-CH campus, for five day labs and small telescopes on our campus observing decks for five night labs. However, both sets of labs were problematic. Measurements within the planetarium chamber suffered from often greater than 100% error depending on where you sat. The visual observing labs suffered from Chapel Hill's weather, bright skies, proximity to athletic field lights ruining dark adaptation, inability to see the north star, which is necessary to properly align the telescopes, outdated and difficult to use telescopes, and a weak set of backup labs. Finally, neither set of labs strongly reinforced the lecture curriculum. Feedback from these labs was generally negative.

We developed a series of eight new labs, two of which are two-week labs, and six of which utilize UNC-CH's Skynet Robotic Telescope Network. After an introductory lab in which students learn how to use Skynet, the labs strongly reinforce both the new ASTR 101/102 lecture curriculum and one another. Among other things, students use Skynet to collect their own data to distinguish between geocentric and heliocentric models using the phase and angular size of Venus, to measure the mass of a Jovian planet using the orbit of one of its moons and Kepler's third law, to measure the distance to an asteroid using parallax measured simultaneously by Skynet telescopes in different hemispheres, and to measure the distance to a globular cluster using an RR Lyrae star as a standard candle. More is done with archival data that takes longer than a semester to collect (e.g., Cepheid stars, Type Ia supernovae, etc.)

In addition to the lecture, demo and lab curricula, we developed a set of multiple-choice homework problems and detailed solutions for both Astro 101 and Astro 102 within the WebAssign framework. Also, in an effort to explore the effectiveness of "flipping the classroom", we developed a set of in-class polling questions, and an interactive e-polling tool that allows the instructor to display and analyze numerical responses in real-time. We also provided all students free online access via YouTube to a complete archive of videotaped Astro 101 and, soon, Astro 102 lectures compiled from previous semesters.

After implementing this curriculum at UNC-CH in 2009, lab enrollments increased over 150%, all introductory astronomy enrollments increased over 100% – now one in four UNC-CH students take at least one of our courses – and astronomy-track majors and minors increased $\approx$300% (from $\approx$5 to $\approx$20 per year). Encouraged by this initial success, we soon began partnering with other regional institutions to help them adopt and adapt those parts of the lecture course, in-class exercises and demos, homework, and labs that were compatible with their broader curricula and educational philosophies. As of today, 14 institutions have adopted our curriculum in whole or in part, with a handful more scheduled to join in the coming year. In this report, we analyze student survey responses collected from 10 schools, ranging from 2-year community colleges to Research I universities, over 4 semesters in 2014-2015.

While we provided instructors at these partner institutions access to our full sets of homework, lab, e-book, e-polling, video, and other curriculum resources, they were free to accept, reject or adapt any element to best suit their institutional needs and educational goals. Table 1 summarizes the institutions that employed our curriculum in whole or in part, and whose students responded to the end-of-course survey, during the period of 2014-2015. Table 2 describes in greater detail the components of our curriculum that each instructor chose to implement in their section.

Table 1. Summary of institutional participation, by institution. Institution types: 1 = 2-year community college; 2 = 4-year college or university; 3 = Research I university

Institution	Type	Semesters	Sections	Instructors	Responses
Ashland Community & Technical College (ACTC)	2	2	3	1	12
Francis Marion University (FMU)	2	1	1	1	6
Fayetteville State University (FSU)	2	3	6	1	34
Glenville State College (GSC)	2	1	1	1	5
High Point University (HPU)	2	2	2	1	15
North Carolina Agricultural & Technical State University (NCAT)	2	3	3	2	29
North Carolina State University (NCSU)	3	2	2	1	6
University of North Carolina at Chapel Hill (UNC-CH)	3	4	11	2	427
University of Virginia (UVa)	3	2	2	1	28
Wake Technical Community College (WTCC)	1	4	10	5	187
Total=10	**NA**	**4**	**41**	**16**	**749**

Survey Structure, and Definition of Dependent and Independent Variables

Near the end of each semester, students in participating sections were provided with a link to a Qualtrics survey about their experience in Introductory Astronomy. For the four semesters analyzed in this report, we received an initial total of 827 completed surveys. After eliminating incomplete or obviously fraudulent instances, we arrived at a final dataset of 749 responses.

The survey consists of 43 multiple-choice and short-answer questions, some of which consist of multiple parts. The questions include basic demographic information and assessments of a student's background and preparation for the course, but are primarily geared towards determining a student's opinion of the course and their attitude towards specific course components and towards astronomy and science in general. Some questions ask students to rank their opinion of a course component, or their level of agreement with a statement, on a four- or five-step scale (quantitative questions). A number of these quantitative survey questions consist of multiple sub-questions. A few questions are in yes/no format, or otherwise establish whether or not a student engaged with particular components of the course (binary questions). The full text of the survey can be downloaded at: https://tinyurl.com/introastroreport

In order to facilitate analysis, responses to all questions were reassigned to a uniform numerical scale ranging from -1 to +1. For binary questions, this is as simple as assigning a "Yes" answer the value +1, and a "No" answer the value -1. For quantitative questions, this required both renormalizing the numerical range of the responses, and, in some cases, flipping the sign of the response to correct for whether the question had a "positive" or "negative" attitudinal orientation.

The responses to some multi-part quantitative questions were averaged (after numerical range normalization and attitudinal orientation correction) to produce a single numerical index for that question. An illustrative example is the astronomy/science "Attitude Index", which serves as the single dependent variable in the analysis that follows. This Attitude Index is computed from the respondents' answers to 33 questions that were designed to probe their attitudes towards Astronomy and science in general, after having taken Introductory Astronomy at their institution. Each question is in the form of a statement; students were instructed to indicate their level of agreement with each statement, from 1 (strongly disagree) to 3 (neither agree nor disagree) to 5 (strongly agree). By design, some statements were positively oriented (e.g., "I like astronomy", "Scientific concepts are easy to understand", "Scientific skills will make me more employable"), while some were negatively oriented (e.g., "Astronomy is irrelevant to my life", "I felt insecure when I had to do astronomy homework", "I find it difficult to understand scientific concepts"). Each response was converted to a numerical scale ranging from -1 (negative attitude) to +1 (positive attitude), taking into account the orientation of each question, and the results were averaged over the 33 questions, producing a single Attitude Index for each student respondent. While the perceived orientation of certain of these statements may be qualitative, with different students seeing the same statement as either positive or negative, the majority are unambiguous. The orientations we assigned to the Attitude Index questions are presented in Table 3.

In the analysis that follows, we explore the statistical dependence of Attitude Index (dependent variable) on a variety of other survey responses/indices (independent variables), using simultaneous multiple linear regression. After initially performing linear regression with 16 independent variables, we iteratively removed those independent variables that were uncorrelated with Attitude Index at the $p > 0.05$ level, refitting at each iteration. The results are summarized in Table 4. We found the following variables to exhibit **significant correlation** (in decreasing order of correlation coefficient):

- **Course Attitude Index (Q48 in original survey; see Appendix):** measures a student's attitude to the course as a whole, based on an average of responses to 10 statements, scaled to -1 = strongly disagree to +1 = strongly agree. **Positively correlated.**
- **Grade Index (Q17):** what grade students *expected to receive* in the course at the time they took the survey. -1 = F, 0 = C, +1 = A. **Positively correlated.**
- **Career Index (Q12):** measures the degree to which a student's academic and career path is oriented towards STEM in general, and astronomy & physics in particular. -1 = planning a career in a non-STEM field; 0 = planning a career in a STEM field; 1 = Planning a career in a STEM field, and majoring or minoring in astronomy or physics. **Positively correlated.**
- **Instructor Index (Q64):** measures a student's attitude towards the primary course instructor, based on an average of responses to 11 statements (Q64), scaled to -1 = strongly disagree to +1 = strongly agree. **Positively correlated.**
- **Math Index (Q8):** measures a student's academic mathematics training background. Ranges from -1 = some algebra to +1 = beyond calculus. **Positively correlated.**
- **Institution Index (see Table 1):** measure of the type of institution the course was offered at: -1 = 2yr college, 0 = 4yr college, +1 = research I university. **Negatively correlated.**
- **Work Index (Q23):** based on the response to the statement "I worked harder than I thought I would in order to meet the instructor's standards or expectations." -1 = strongly disagree to +1 = strongly agree. **Negatively correlated.**

The following independent variables were found to exhibit **no significant correlation** with Attitude Index at the $p < 0.05$ level:

- **Skynet Index (see Table 2):** -1 = student was offered no Skynet-based labs; +1 = student was offered Skynet-based labs.
- **Lab Index (see Table 2):** -1 = no lab component to course at all; +1 = some lab component to course.
- **Online Index (see Table 2):** -1 = traditional lecture course; +1 = online course.
- **Engagement Index (Q35):** measures a student's level of engagement with the course, based on an average of their responses to 6 questions about how often they employed various study habits (doing readings, completing

assignments, engaging in classroom discussion, etc.).

- **Hours Index (Q15):** the number of hours the student spent per week on course-related work. Ranges from -1 = fewer than 3, to 0 = 7-9 hours, to +1 = 12 or more hours.
- **Credits Index (Q13):** how many credit hours the student was enrolled in while taking the intro astro course. Ranges from -1 = 6 or fewer credit hours to 0 = 7-9 credit hours to +1 = 19 or more credit hours.
- **Year Index (Q19):** the academic year of the student. Ranges from -1 = first year to +1 = 5th+ year.
- **Attendance Index (Q22):** based on the question "It is possible to do well in this course without attending class regularly", ranges from -1 = strongly disagree to +1 = strongly agree.
- **UNC HW Index (see Table 2):** measure of how many UNC-provided homework sets were assigned in the student's section. Ranges from -1 = none to +1 = all of the 9 available sets.

Baseline Model

As described above, we found that 7 of our independent variables were significantly correlated with the Attitude Index at the $p < 0.05$ level; the results are summarized in Table 4.

We consider each of these variables in turn, in descending order of correlation coefficient:

1. **Course Attitude Index:** It is not surprising that the Astronomy/Science Attitude Index's strongest and most significant correlation is that with the student's attitude towards and opinion about the course overall. The questions that comprise the Course Attitude index (Q48 in survey) focus on whether a student feels that the course and the work involved were effective in helping them learn, whether sufficient feedback was provided on a student's progress, and whether the student found the course inspiring and challenging. As with all of these correlations, we must speculate on causal relationships with caution. Does a positive experience in the course create a positive attitude towards science, or are students who were predisposed to view science favorably more likely to appreciate a course in introductory astronomy in the first place? It's not possible to disentangle these two with this analysis, but we can at least infer that the most impactful strategy for an institution to take, if its goal is to increase positive attitudes towards science in general, is to foster positive attitudes towards the student experience of an introductory course itself – its goals, pacing, feedback, and level of intellectual challenge.
2. **Grade Index:** It is also not surprising that a student's attitude towards science in general, after taking an introductory science course, would be correlated with the grade that they expect to receive. As with the previous index, it is not possible to say whether this is just correlation or causation. But by accounting for these strongly correlated Grade and Course Attitude Indices in the simultaneous multiple linear regression analysis, we can at least begin to unmask some of the subtler correlations that follow. We chose to explore the self-reported expected grade both because it is much easier, logistically and ethically, than attempting to assign actual grades to ostensibly anonymous surveys, and because, when it comes to attitudes, a student's self-perceived grade at the time of the survey is more likely to matter than what they actually end up getting.
3. **Career Index:** After Course Attitude Index, the STEM Career Index is the most significantly correlated independent variable. Again, as with the previous variables, it is not possible to say whether students who had already decided to pursue STEM careers are predisposed to have more positive attitudes towards science, or whether positive attitudes engendered by the course prompted some students to consider STEM careers for the first time. This is a case where giving the survey both

at the beginning and at the end of the course would be very helpful in interpreting the results. It is worth noting that 370 out of 749, or nearly 50% of the total respondents indicated that they did not intend to pursue STEM-related careers. As a group, these non-STEM students receive a less positive impact on science attitude than do their general STEM-major peers, who in turn are impacted less than those who specifically plan careers in astronomy or physics.

4. **Instructor Index:** While it makes sense that students who view their instructor positively might emerge from the course with a more positive attitude towards science, it is interesting that the correlation, while positive, is both relatively low and marginally significant. Also, as discussed in the following section, when we look only at the subsets of students who attended a lecture course, or who were exposed to Skynet during the course, and include their ratings of these components' helpfulness as independent variables in the regression analysis, the correlation of Attitude Index with Instructor Index disappears. The message seems to be that instructor quality helps to shape attitudes towards science, but not nearly as much as the perceived quality of the course curriculum and experience as a whole
5. **Math Index:** This is another correlation that is unsurprisingly positive but surprisingly weak. Having a more extensive mathematical coursework background corresponds to more positive science attitudes at the end of the course, but not by much. This would suggest that our Intro Astro curriculum (which requires only basic algebra) is relatively equally accessible and impactful to every student, regardless of mathematical background.
6. **Institution Index:** There is a weak but statistically significant negative correlation of Attitude Index with the type of institution the course is offered at, with 2-year community colleges doing better, in general, than 4-year colleges, and both doing better than Research I universities. This trend may reflect a dependence on class size and instructor availability, with the smaller, more personal environments typical of community college classrooms serving better to instill positive attitudes towards science than large auditorium-style lecture formats typical of major universities.
7. **Work Index:** Students who perceive the course to require more work than average emerge with more negative attitudes towards science. This would suggest that one straightforward way to boost science attitudes would be to reduce the workload in introductory science courses. It is important to keep in mind, however, that the very significantly positively correlated Course Attitude Index is partially a measure of how intellectually challenging and instructive the course is perceived to be. Make the course too easy, and you risk negatively impacting attitude towards the course, and so towards science in general.

Baseline Model + Helpfulness of Course Components

Students were asked to rate the Helpfulness Index of various components of their introductory astronomy courses, if present, which we scale from -1 = not helpful to +1 = extremely helpful (Q52). The students were given the option to indicate that any component was not applicable to their experience. The course components included:

- Attending class lectures
- Watching videos of lectures
- Supplementary notes (e.g., e-book on WebAssign)
- Homeworks
- In-class exercises/polling (e.g., clickers, polling cards, e-polling)
- Textbook
- Out-of-class exercises
- Office hours
- Online discussion forum (e.g., Sakai or Blackboard)

- Skynet-based telescope labs
- Other telescope labs (not part of UNC's curriculum, but employed at some participating institutions)
- Non-telescope labs (e.g., The Earth and the Seasons, or Hubble's Law)

We found that the mere *presence* of any of these individual course components (included in the linear regression analysis as binary independent variables where -1 = not used in course and +1 = used in course) did not significantly impact the students' attitudes about science. However, we did find that, for two components – attending in-class lectures, and Skynet-based labs – *how helpful* the students found these course components to be did matter. For the other course components, neither the existence of the component nor how helpful the students found it to be impacted the Attitude Index.

For each component, we analyzed the subset of non-N/A respondents and performed multiple linear regression on Attitude Index vs the same set of independent variables described earlier, but including the Helpfulness Index of that component, again iteratively eliminating independent variables for which the correlation significance was low. The Helpfulness Indices range from -1 = not helpful to my learning to +1 = extremely helpful to my learning.

Out of the 749 total student responses to the survey, 712 students attended in-classroom lectures. The distribution of Lecture Helpfulness Index ratings in this subsample is plotted in Figure 1,The results of multiple linear regression on this subset are presented in Table 5. We find a weak but statistically significant positive correlation between the Lecture Helpfulness Index and the Attitude Index: the more helpful a student finds attending class to be, the more positive their attitude towards science at the end of the course. However, note that the Instructor Attitude Index, which exhibited weak but significant positive correlation in the earlier baseline analysis (Table 4), is no longer significantly correlated in this subset ($p = 0.2$), when Lecture Helpfulness Index is included. Both are somewhat weak correlations, but this result would seem to indicate that students' attitudes towards their instructors and towards the effectiveness of the lectures are largely measures of the same thing. Instructors who wish to improve their students' attitudes towards science would thus be well served by investing more effort into polishing the lecture component of their course.

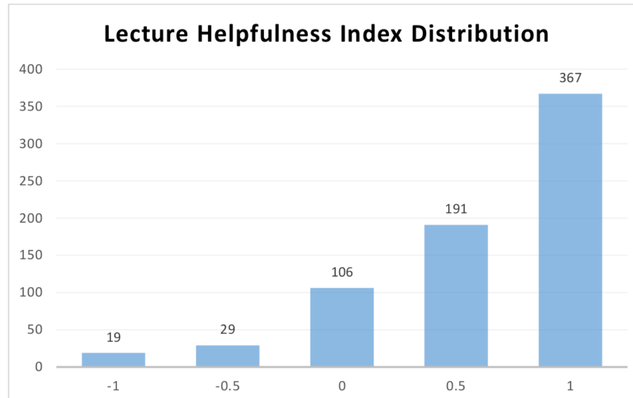

Figure 1. Distribution of our sample of 712 students who rated the helpfulness of in-class lectures. Those who found the lectures helpful left the course with more positive attitudes about astronomy and STEM fields in general. Other than our Skynet-based labs, no other course component had a similar effect. The Helpfulness Indices range from -1 = not helpful to my learning to +1 = extremely helpful to my learning.

Out of the 749 total student responses to the survey, 508 students participated in at least one Skynet-based lab during the semester. The distribution of Skynet Helpfulness Index ratings in this subsample is plotted in Figure 2, and the results of multiple linear regression on this subset are presented in Table 6. As with Lecture Helpfulness, we find a weak but statistically significant correlation between Science Attitude Index and Skynet Helpfulness Index for the subset of students who were exposed to Skynet-based labs. Those students who found the labs helpful, left the course with a more positive attitude towards science overall. Note that we performed this same analysis for the helpfulness of other lab components, including indoor labs and non-Skynet-based telescope labs, and found no significant impact. Adding at least one Skynet-based lab (and working to present it and integrate it in a way that is perceived as helpful to students' understanding of the course material) appears to be one way to significantly boost attitudes towards science for Intro Astro students.

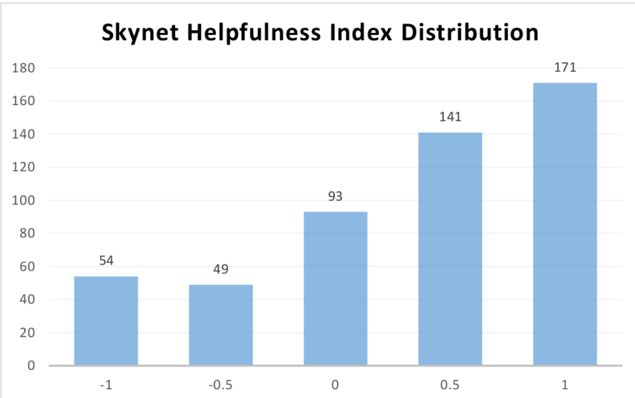

Figure 2. Distribution of our sample of 508 students who rated the helpfulness of Skynet-based telescope labs. Those who rated these labs as helpful left the course with more positive attitudes about astronomy and STEM fields in general. Other than in-class lectures, no other course component had a similar effect. The Helpfulness Indices range from -1 = not helpful to my learning to +1 = extremely helpful to my learning.

Conclusion

The majority of students do not enroll in Introductory Astronomy as part of their major; for many, it is the last science course they will ever take, and has the potential to shape their attitudes towards STEM fields for the rest of their life. It is less important, therefore, when assessing the effectiveness of Intro Astro courses to explore traditional curricular learning gains, than it is to explore the effects that various course components have on this attitude. We first arrived at a baseline model (Table 5) describing the correlation, for the entire sample, of Attitude Index with a variety of independent variables describing students' attitudes, backgrounds, and plans. We then analyzed, one at a time, subsets of the sample that reported engaging with various course components, and included as a new independent variable their rating of each component's helpfulness.

We found that the only course components whose helpfulness indices exhibit correlation with overall astronomy and STEM attitudes were in-class lectures and Skynet-based labs. While considerable effort has been expended to add new components to the Intro Astro curriculum, from in-class e-polling systems and questions, to providing videotapes of lectures to all students, to writing supplementary e-book materials, we cannot say at this time that they have had any effect one war or the other on attitudes. That is not to say that they have no effects at all – they very well may be found to improve traditional learning outcomes, for instance. But the results of this analysis suggest that an instructor's best bet for boosting attitudes with our Intro Astro curriculum is to concentrate on improving the quality of their lectures and of the Skynet-based telescope labs that they offer.

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Table 2. More detailed breakdown of student survey responses by section, including number of UNC labs and homeworks each instructor utilized, whether they used any of the Skynet-based telescope labs, whether the section was online, and whether any there was any lab component to the course at all.

Semest.	Institut.	Instructor	# Resp.	UNC Labs	UNC HWs	Skynet	Online	Labs
2014 S	ACTC	Riggs	7	8	0	Y	Y	Y
2014 S	FSU	Mattox	8	1	9	N	N	Y
2014 S	FSU	Mattox	4	0	9	N	N	Y
2014 S	GSC	O'Dell	5	5	0	Y	N	Y
2014 S	HPU	Barlow	10	2	0	Y	N	Y
2014 S	NCAT	Schuft	16	0	8	N	N	N
2014 S	WTCC	Chilton	18	0	0	N	N	Y
2014 S	WTCC	Converse	22	0	0	N	N	N
2014 S	WTCC	Wetli	11	5	0	Y	N	Y
2014 S	UNC	Law	46	8	9	Y	N	N
2014 S	UNC	Reichart	5	8	9	Y	Y	Y
2014 S	UNC	Reichart	22	8	9	Y	N	Y
2014 S	UVA	Murphy	24	0	0	N	N	Y
2014 S	ACTC	Riggs	1	8	0	Y	Y	N
2014 F	FSU	Mattox	7	1	9	N	N	N
2014 F	FSU	Mattox	8	0	9	N	N	Y
2014 F	FMU	Bryngelson	6	7	0	Y	N	Y
2014 F	NCAT	Schuft	12	0	5	N	N	Y
2014 F	WTCC	Converse	34	2	0	Y	N	Y
2014 F	WTCC	Wetli	8	4	0	Y	N	Y
2014 F	UNC	Reichart	193	8	9	Y	N	Y
2014 F	UNC	Reichart	11	8	9	Y	Y	Y
2015 S	UNC	Reichart	4	8	9	Y	Y	Y
2015 S	HPU	Barlow	5	2	0	Y	N	Y
2015 S	NCSU	Frohlich	4	8	0	Y	N	Y
2015 S	WTCC	Converse	16	2	0	Y	N	Y
2015 S	WTCC	Wetli	7	4	0	Y	N	Y
2015 S	NCAT	Kebede	1	8	9	Y	N	Y
2015 S	UNC	Reichart	21	8	9	Y	N	Y
2015 S	UVA	Murphy	4	7	0	Y	N	N
2015 S	WTCC	Chilton	32	2	0	Y	N	Y
2015 F	ACTC	Riggs	4	8	0	Y	N	N
2015 F	FSU	Mattox	5	1	9	N	N	N
2015 F	FSU	Mattox	2	0	9	N	N	Y
2015 F	WTCC	Converse	29	2	0	Y	N	Y
2015 F	NCSU	Frohlich	2	3	0	Y	N	Y
2015 F	UNC	Reichart	109	8	9	Y	N	Y
2015 F	UNC	Reichart	9	8	9	Y	Y	Y
2015 F	UNC	Reichart	7	8	9	Y	Y	Y
2015 F	WTCC	Sivayogan	10	4	0	Y	N	Y

Table 3. The questions that were used to compute the astronomy and science Attitude Index dependent variable. Student responses to each statement were scaled from -1 = strongly disagree to +1 = strongly agree. The sign of responses was flipped for those statements with a science-negative orientation, and then all were averaged to arrive at the Attitude Index.

Attitude Index Question	**Orientation**
Astronomy is a subject learned quickly by most people.	+
I have trouble understanding astronomy because of how I think.	-
Astronomy concepts are easy to understand.	+
Astronomy is irrelevant to my life.	-
I was under stress during astronomy class.	-
I understand how to apply analytical reasoning to astronomy.	+
Learning astronomy requires a great deal of discipline.	-
I have no idea of what's going on in astronomy.	-
I like astronomy.	+
What I learned in astronomy will not be useful in my career.	-
Most people have to learn a new way of thinking to do astronomy.	-
Astronomy is highly technical.	-
I felt insecure when I had to do astronomy homework.	-
I find it difficult to understand astronomy concepts.	-
I enjoyed taking this astronomy course.	+
I made a lot of errors applying concepts in astronomy.	-
Astronomy involves memorizing a massive collection of facts.	-
Astronomy is a complicated subject.	-
I can learn astronomy.	+
Astronomy is worthless.	-
I am scared of astronomy.	-
Science is a part of everyday life.	+
Scientific concepts are easy to understand.	+
Science is not useful to the typical professional.	-
The thought of taking a science course scares me.	-
I like science.	+
I find it difficult to understand scientific concepts.	-
I can learn science.	+
Scientific skills will make me more employable.	+
Science is a complicated subject.	-
I use science in my everyday life.	+
Scientific thinking is not applicable to my life outside my job.	-
Science should be a required part of my professional training.	+

Table 4. Multiple linear regression correlation coefficients for the entire survey data set ($N = 749$), after iterative elimination of independent variables for which $p > 0.05$.

Variable	**Coefficient**	***p*-value**
Course Attitude Index	0.25	2.5E-26
Grade Index	0.16	1.6E-12
Career Index	0.11	2.0E-21
Instructor Attitude Index	0.073	5.4E-03
Math Index	0.053	1.5E-04
Institution Index	-0.048	6.1E-06
Work Index	-0.10	7.8E-10

Table 5. Results of multiple linear regression on Attitude Index vs. significant variables, including Lecture Helpfulness Index, for the subset of $N = 712$ students who attended in-class lectures. *Top*: Fit with Instructor Attitude Index (which is not correlated with Attitude Index at the $p < 0.05$ level); *Bottom*: Fit with Instructor Attitude Index excluded.

Variable	**Coefficient**	**p-value**
Course Attitude Index	0.24	1.3E-21
Grade Index	0.14	4.2E-10
STEM Index	0.11	1.6E-18
Lecture Helpfulness Index	0.071	1.7E-04
Math Index	0.063	1.0E-05
Instructor Attitude Index	*0.036*	*2.0E-01*
Institution Index	-0.048	6.6E-06
Work Index	-0.11	1.0E-09

Variable	**Coefficient**	**p-value**
Course Attitude Index	0.26	2.2E-28
Grade Index	0.14	2.5E-10
STEM Index	0.11	2.6E-18
Lecture Helpfulness Index	0.077	2.1E-05
Math Index	0.064	7.7E-06
Institution Index	-0.046	1.2E-05
Work Index	-0.11	1.0E-09

Table 6. Results of multiple linear regression on Attitude Index vs. significant variables, including Skynet Helpfulness Index, for the subset of $N = 508$ students who participated in Skynet-based telescope labs. *Top*: Fit with Instructor Attitude Index (which is not correlated with Attitude Index at the $p < 0.05$ level); *Bottom*: Fit with Instructor Attitude Index excluded.

Variable	**Coefficient**	**p-value**
Grade Index	0.21	4.1E-13
Course Attitude Index	0.20	5.8E-11
Career Index	0.11	1.1E-13
Instructor Attitude Index	*0.057*	*6.5E-02*
Skynet Helpfulness Index	0.044	1.5E-02
Math Index	0.036	5.1E-02
Institution Index	-0.050	1.2E-04
Work Index	-0.095	1.2E-05

Variable	**Coefficient**	**p-value**
Course Attitude Index	0.22	1.4E-14
Grade Index	0.22	1.1E-13
Career Index	0.11	1.2E-13
Skynet Helpfulness Index	0.047	8.8E-03
Math Index	0.037	4.6E-02
Institution Index	-0.047	2.7E-04
Work Index	-0.095	1.4E-05