

Building an Online Astronomy Research Student Team at Stanford Online High School

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Abstract

For high-school students that have never met in person, and that never *expect* to meet in person, some unique considerations arise in building a research team. Thoughtful strengthening of team member relationships is both more challenging and more vital than it is for an in-person collaboration. Furthermore, team members must possess a deeper understanding of the scientific process than typical students. The Stanford Online High School (SOHS) science curriculum fosters both the technical savvy and the scientific awareness that are advantageous in structuring an effective online collaborative research experience. This article describes an Stanford Online High School (SOHS) instructor's experience in cultivating the type of student for whom an online student research team experience is well-suited, and outlines some applications in the context of the Astronomy Research Seminar's broadening scope.

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Introduction

As internet and telescope technology has been growing, many people have attempted to bring this technology into the classroom to do authentic research (Fitzgerald et al., 2014) as well as education (Gomez and Fitzgerald, 2017). The Astronomy Research Seminar is one such example of introducing undergraduate and high school students to science in the context of a modest research project (Genet et al., 2010; Genet, 2007). Investigating an unknown binary star system (Genet et al., 2012) as part of a team and co-authoring a publication in an academic journal (the Journal of Double Star Observations, Clark, 2010) indoctrinates students into the way in which modern science is accomplished (Freed et al., 2017). Skills are honed that are useful not only within scientific practice, but also in many other fields where teamwork is valuable.

As the Astronomy Research Seminar continues to expand to other locations and topics (Genet et al.,

2017), schools and instructors are experimenting with new ways of making the approach relevant for their students. One increasingly common means of instruction for many programs is for some or all of the class meetings to occur online. In the context of an astronomy research course, coordinating the approach online introduces some unique advantages and constraints.

Stanford Online High School¹ (SOHS) has been conducting classes online since 2006. Although the students have opportunities to come together in person for meet-ups in their local regions and a few times per year at Stanford (for graduation, a 2-week residential summer program, and occasional gatherings), all of the academic-year courses happen completely online. This makes SOHS particularly well-suited as a proving ground of an online astronomy research seminar.

In this paper, I discuss some of the challenges and opportunities of online science instruction, many of

¹ see <http://ohs.stanford.edu>

which are relevant for SOHS science classes. Building community among young students who only see each other from the neck up over a webcam has some surprising similarities to and differences from the same process among students who meet face-to-face. Science instruction and the process of scientific teamwork also have several unique features for such a group. Here, I explore some of the lessons learned from taking astronomy research for students online in this context.

Online Team-Building

In this section, I outline some of the core concepts behind Online Team-Building that have been useful in running astronomy projects online.

Small Teams

One hallmark of a successful online learning community is that the teams / groups / classes are small. Although an online research team can include different *types* of students than an in-person one, it is a misconception that such a team will facilitate inclusion of a greater *number* of students. In an online team, as in an in-person team, it is important that each individual student will be specifically missed if they are not present. It is important to acknowledge and respect each team member's personality and life outside the classroom. A major reason for the success of SOHS is that class section sizes are capped at 16 students, and each student is assessed on his or her participation in the discussion.

Homegrown Curriculum

Another feature of a successful online seminar team is that the curriculum is homegrown, developed or at least significantly augmented by the individual instructor with the input of students where-ever possible. This is because the use of anonymously-produced curricula can be alienating in an online learning environment that already distances students from each other and the instructor. It is helpful to take every opportunity to bolster existing connections. One example is that the inclusion of the presenter's "talking head" in

instructional videos helps the instruction to feel more personal.

Text Chat

In synchronous online instruction, text chat can transform a lesson into something that is truly distinct from what is possible in a brick-and-mortar environment. It is hard to over-emphasize how profoundly text chat changes the culture of a classroom. Jokes get made that would be disruptive if stated verbally, community gets built, and students develop written personalities that complement their audio and video selves.

Instructors can give shy students a heads-up (via private message) that they are about to be called on, so that these students can ready themselves for the audio / video "spotlight". Often students who would stay quiet in spoken discussions become comfortable asking questions or adding comments in chat, where these can be expressed without interrupting the speaker.

At SOHS, it is expected that the speaker will track the chat during the discussion, responding to questions and comments as they arise or soliciting further input. This can be disorienting for guest lecturers, who often have difficulty multitasking to the necessary extent. When guest lecturers are not paying attention to chat, students will often take it upon themselves to respond to each other, posing answers to each others' questions, commenting on each others' connections, etc. Their level of engagement in the topic and the speaker increases because of this parallel discussion, whether or not the speaker actually responds to it.

Text chat provides a useful gauge of student enthusiasm: if chat is dead, it is a sign that students are not engaged and it might be time for the instructor to change course. On the other hand, if chat is really hopping, then a nerve has been struck, and the topic of such lively discussion is likely to be worth pursuing. As every teacher knows, it is through interaction that learning happens, and text chat provides a powerful medium for both gauging and for facilitating the interpersonal exchange that results in discovery.

In fact, some online programs use text chat exclusively for synchronous class sessions, without **any** supplementary audio or video. The Art of Problem Solving² (AoPS) is one such program, offering online math courses for middle and high school students. Each course of about 50 students meets once per week for about an hour. The classes are intense and fast-paced, with the instructor and a handful of TA's monitoring the classroom and deciding which questions and comments should be displayed for the group and which should be privately addressed. The instructor presents material, poses questions, and solicits answers, all without a single spoken word or visual aide. My sons took a few of these classes as students, and I was impressed with the thoughtful way in which their questions were triaged: sometimes, a TA would open a private chat window if the question was peripheral, other times, the question would be displayed for the group and the main instructor would address it for everyone. Students quickly learn to stay focused and take advantage of the opportunity to ask relevant questions; display of their query for the group is construed as high praise.

The efficacy of Art of Problem Solving is puzzling to many who ponder online education. With all of the features currently available in meeting software, why limit oneself to using only chat? By focusing students' attention down to that one window and providing no audio or video distraction, AoPS creates an environment from which students literally cannot look away while still pretending to themselves or others that they are paying attention. Such an environment emphasizes that it is the interaction that matters, and that students cannot be passive learners. Unresponsively watching classes or videos as if they were TV shows is a trap into which students tend to fall very easily, especially if these involve a lot of "eye candy".

At SOHS, text messaging is not limited to the classroom. Most classes and clubs have associated Skype groups. Students are constantly chatting with each other on Skype, so much so that

instructors have difficulty combating the distraction during class. Outside of class, however, Skype groups provide a powerful way for students to interact with each other, which can be particularly important for leveraging the "teachable moment". Students often do not internalize material presented in class sufficiently deeply that they can apply it in new situations. It is when they are wrestling with a new application that the theoretical material becomes pertinent. Creating a situation in which several sections worth of students have the same problem set due at the same time the next day gives students the opportunity to help each other when it is most relevant.

As an instructor, I often find that 90 seconds or less of my time, right when students are struggling to apply theoretical concepts in the context of a new problem, has the same or greater pedagogical value as much more of my time explaining the same concept in class or in my online office hours. The concepts take on their meaning not when they are being explained in class, but when students are actively working to apply the ideas to new situations, with their grade on the line and a deadline looming. The class Skype group makes this type of exchange possible right when it is valuable. If I am online, I'll answer a question, but if I am not, other students will often fill the gap, and spark fruitful discussions. These discussions are both useful for students to have and for me to be able to read when I eventually log in and see them. I remember one particularly productive one about whether a ball would have a greater acceleration thrown downward than it would have if dropped, which gave me good insight into an appropriate starting point for class the next day.

Technical Resilience

In order to engage in astronomical research of any flavor, students must be motivated to conquer technical problems. This is doubly true if the research team meets online, since all online meeting software is prone to disruptions due to lag and other issues. Technical difficulties must be re-framed as an opportunity for students and

²see <https://artofproblemsolving.com>

instructor to unite in battle. When the students and instructor know each other well, class can be conducted without audio, video, or even text chat.

At SOHS, the students already have this mindset, so the online astronomy research seminar is less of a stretch than it might be elsewhere. An email I sent after a particularly tech-error-ridden section for a course I taught a few years ago captures this:

“I had the most incredible section, despite not being there for most of it. 12 of the 18 students were able to get into my 8:30am Honors Chemistry section, but I and the other 6 students were shut out. I emailed everyone to follow along on Learning Catalytics, and emailed them solutions to each question after I had delivered it and given them a chance to respond. It was bizarre without audio or video. But, I noticed that I was getting a much higher percent correct than usual. Finally, about 15 minutes before the end of section, I was able to enter the session, along with the other 6 students who had been shut out. What I found was incredible: the 12 students in the session had been actively discussing the questions as I delivered them, and helping each other understand the solutions.”

Since that day, I’ve had several similar experiences of either being shut out from class myself or having students with limiting tech issues determined to participate regardless. The students never fail to come together to conquer the problem and make it work: it is a “learn or die trying” kind of mindset. Although tech issues are always nerve-wracking, I have now had the experience many times of getting back into a section meeting to find a class full of students engaged in scientific discussion and a text chat log full of evidence that students spent the time I was gone working their way through problems, explaining topics to each other, or involving each other in analysis of the concepts we

were tackling. In the last month, I’ve had a student attend class via screen-share, responding to polls and participating via the class Skype group. I’ve had another student in Puerto Rico, devastated by Hurricane Maria, attending class and answering questions via a unique combination of email and Skype. It is never fun, but it certainly prepares students for the myriad tech issues that can crop up in astronomical research.

Many different types of software are employed for modern research in astronomy, and their various functionalities and uses can be bewildering for instructors and students alike. SOHS students bring to the problem some of the same resilience that they bring to their online class meetings. Below are excerpts from the chat log of an astronomy research seminar meeting in which a student was wrestling with a formula on an Excel spreadsheet. Although the chat does not capture the audio or the screen-share for the session, it does capture the flavor of students determined to help each other conquer the technology. (Names have been changed.)

Anders: yes
 Kalee: =MOD(C2,1)
 Anders: for MJD in periods
 Ella: the formula’s not working for me for some reason
 Huang: I’m having excel problems, could someone else
 Ella: the first one lol
 Sergei: so this just gets rid of the one?
 Ella: yes
 Kalee: =A2-A2
 Ella: no it just leaves it as text
 Ella: ok one sec
 Huang : Artsy font
 Huang : Try clicking on the cell
 Huang : that you are referencing
 Sergei : did you click enter?
 Huang : instar of typing the value
 Huang : +(click on A2-(click on A2 and add dollar signs)
 Huang : *=
 Jaya: try typing it in the formula box

instead
 Huang : I GOT IT
 Sergei : try google doc maybe?
 Huang : Your A values are not number
 Huang : numbers
 Huang : they are on the left side I think
 Anders: try google sheets?
 Jaya: try using a lowercase a
 Ella: owow
 Sergei : trouble shooting in the 21st century
 Ella: yeh
 Ella: ok
 Jaya: your 2 looks weird like its subscripted or something
 Sergei : friday the 13th !
 Jaya: wait hlow about changing your font
 Huang : see, if it thought it was a number, it would have limited to 2 decimal places
 Jaya: its "corbel" which may not work
 Sergei : ^
 Anders: It should output as true or false if it works.
 Jaya: and off caps maybe
 Huang : It's tired on Friday after a long hard week
 Sergei : might be a missing plugin
 Ella: when you can relate to excel
 Ella: wow that grammar
 Ella: ill just try it
 Sergei : i got the same graph
 Sergei : is it inverted?
 Huang : I can help in Sheets if you screenshare
 Jaya: some of the values are negative
 Jaya: in ir
 Jaya: and not in b
 Huang : I can only view
 Sergei : how do you invert it?
 Anders: My V graph is ready. Should I put it into the group Sheets?
 Huang : I put it to scatter
 Anders: *Should
 Huang : But It looks like nothing

Huang : Better?
 Jaya: wait why are most of the values negative on the ip filter
 Ella: hey so i got the first column to work
 Ella: what formula should i use for the second and third?
 Ella: i used sheets
 Huang : You could try $A @ \text{mod } 0.55$
 Sergei : b^2/period
 Sergei : and then the next one is $\text{MOD}(C2, 1)$
 Jaya: if you look at the ip and b the numbers are almost completely different
 Kalee: $=\text{MOD}(((\text{MJD} - \text{firstobs})/\text{period}), 1)$
 Sergei : maybe it just emits more in the ip wavelength????
 Sergei : blackbody curve!
 Huang : yeah!
 Sergei : astronomy is the science of assumptions/approximations, lol

Cultivating Scientific Literacy in Online Students

Performing Experiments at Home

Performing science experiments at home, as is necessary at SOHS, can deepen appreciation for the scientific process in ways both obvious and subtle. First, the fact that everyone is working in a different lab space, using materials that are slightly different, necessitates more precise communication and clearer explanations of procedure than would typically be necessary. Also, students' results are necessarily different, and it is in trying to understand those differences that some of the most effective learning transpires. Students realize that science is all around them: scientific principles are not confined to a lab in a classroom at a school. It is, truly, what they make it, as shown in Figure 1.

For example, an experiment in the Foundations in Science course involves constructing a paper circuit using LED's. Every year, many of the students burn out their LEDS by hooking them up directly



Figure 1. *SOHS Students at Work*

to the 9V battery (despite multiple warnings not to do this). It is in this moment, when the LED is burned out and the students are scrambling around trying to find a way to do an experiment without the intended materials, that they stop being students and start being scientists. Moments like this simply cannot happen in a traditional classroom. The materials are all provided; if they break, the instructor will devise a substitute.

In SOHS science classes, on the other hand, science is in the hands of the students, and they can be incredibly creative. For example, for one experiment, students must use a T-connector to link two bubbles of different sizes at the ends of straws. Lacking a T-connector, one student rigged up a substitute out of PVC pipe and sheep lanolin from his farm, which he photographed and diagrammed in his lab notebook. (This is the sort of thing that makes SOHS students' lab notebooks significantly more interesting to read than the lab notebooks of students at a traditional school.) There are numerous examples of SOHS student creativity along similar lines. Dora's ketchup packet initially didn't float, so she added salt to the water . . . and

sparked a fruitful class discussion of why salt increases the density of water. Chloe discovered a new application of Bernoulli's principle when she blew across the top of a funnel rather than through the bottom to get the ping-pong ball out, which she described in her lab notebook as "a hopping effect". Helen's food-colored egg broke; she returned to her fortuitous photo documentation of that experiment during a later biology unit, because it illustrated of how the hydrophilic food coloring molecules colored everything except for the hydrophobic (fatty) egg yolk.

In addition to the creativity that can be unleashed in the context of online science experiments, there is significant value to taking science outside the classroom to emphasize its connection to students' daily lives. For example, the Honors Chemistry lab kit provided calcium acetate for an experiment, but students who were traveling without their kit that week discovered that they could stop at the nearest drugstore, buy a bottle of Tums antacid, and crush it up in some vinegar to make calcium acetate themselves. Doing it this way, they learned that calcium acetate is not some mysterious solution

found in a bottle in a chem lab, but rather is something that can be distilled from materials in their own environments. Their learning experience was deeper, not only because they got to do an extra-bonus calculation in order to get a calcium acetate solution of the correct concentration for the experiment, but also because they realized that chemistry is all around them, not confined to a science lab or even to their course lab kit.

Understanding the Nature of Science

Students always become frustrated when an experiment “doesn’t work”. At SOHS, because the instructor is not present when the experiment is being performed, experiments that “don’t work” are sometimes mysteries that persist, though careful photo and video documentation can occasionally resolve the anomaly. SOHS science instructors showcase incongruous results and highlight their importance, so that students eventually come to appreciate experiments that “don’t work” as containing more subtle and more interesting science than the systems that perform as expected.

In fact, understanding unexpected results is the only part of the classroom enterprise in which we are doing *real* science. This is often difficult for students to comprehend. For example, every year for a Foundations in Science circuit lab, I will know from corresponding with students that their circuit didn’t light up at first. They’ll bring it to my office hours to show on webcam so that we can work on debugging it together, and exchange emails with me describing various ways they tested its parts. Then, in their lab write-ups, I won’t see any of the tests they performed—just the perfect, finished circuit working as expected. I tell them, “You left out the science!” and they don’t understand because they think the “science” is their working circuit. They do not realize that the “science” is actually the part where they were testing its components. (I have come to insist that they document how they debugged a non-working circuit as part of this lab, regardless of whether they initially encounter difficulties.)

Once students truly understand that science is messy and indeterminate, and that the parts that are most significant are not the parts for which the answer can be looked up in the back of a textbook, they are ready for an endeavor like the Astronomy Research Seminar. Even so, it takes some adjustment for many students to realize that the outcome of the investigation is truly unknown at the outset, and it is unclear whether the research will even be scientifically interesting. For the right kind of student, this ambiguity is precisely what makes the enterprise so exciting.

Understanding the Limitations of Technology

Students often misunderstand the role of technology in science, as exemplified by this quote: “Because I used an app [to find the height of a Mentos geyser], measurement error does not apply.” The use of online tools to conduct and analyze experiments can strengthen students’ assumptions that any values output by software are not to be questioned, and should be reported to a maximum number of decimal places. For this reason, students might neglect to document possible sources of error for experiments that are conducted purely online, especially when robotic telescopes are used for data collection and software is employed for image analysis. It is especially important in an online environment to teach students where error is generated and how it propagates, and why results should not be reported to greater precision than can be justified by the particular conditions of the experiment.

Conclusions and Future Directions

Expanding the Astronomy Research Seminar to other types of students and schools will involve challenges both of technology and of acquainting students with the scientific process in an online setting. While neither of these is straightforward, Stanford Online High School science curriculum has some experience with both. Sharing the lessons learned in this context will hopefully assist with the cultivation of a new generation of tech-saavy and

science-literate learners, who are unhindered by distance in the building of collaborative research teams and the doing of science. Since modern scientific projects are increasingly accomplished by far-flung collaborations, the experience of participating in the Astronomy Research Seminar will be applicable on multiple levels for students who later pursue a career in science.

At SOHS, the Astronomy Research Seminar is currently an extracurricular venture, but as of January, 2018 it will be offered as an actual semester-long course. With the help of Michael Fitzgerald from Our Solar Siblings, we are hoping to expand from double-star papers to different types of research projects, including eclipsing binary systems and exoplanets. A small team of students is currently exploring an eclipsing binary system in preparation for the spring 2018 SOHS seminar.

Other seminar students-to-be have expressed interest in projects that touch upon gravitational microlensing and astrobiology. These would involve different kinds of analysis and may necessitate relaxing the requirement of publication in an academic journal. One central tenet of teaching, especially when the students are as highly-capable and self-directed as SOHS students, is the importance of nurturing and encouraging the intrinsic curiosity that students bring to the undertaking. Students are most genuinely and productively motivated to pursue projects of their own choosing. For example, one exceptional student project grew out of a student's curiosity about double star orbits, which inspired him to create a groundbreaking new tool for finding orbital solutions graphically (Hensley, 2018). Because projects such as this push my own boundaries as a mentor, I have come to rely heavily on the expertise of student-friendly astronomy researchers such as Richard Harshaw, Michael Fitzgerald, Russ Genet, Rachel Freed, and others.

As we experiment with schools, students, software, and modes of instruction for the Astronomy Research Seminar, the possibilities are both exciting and overwhelming. As a pioneer of online

education, Stanford Online High school provides an environment and a student body that is well-suited to exploring the ever-changing universe of feasible projects. With the help of robotic telescopes and a student-friendly research community, the empowerment of student astronomers is truly within our grasp. I am hopeful that my experience will be helpful to others in establishing their own interpretations of how students might meaningfully contribute to scientific research in this field.

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