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Designing an Iterative Research Kit Exchange Program for Remote High School Science (Evaluation)

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Karl Ernsberger began developing novel learning experiences as an undergraduate at Embry Riddle Aeronautical University, setting up his own Senior Thesis program with the GSIS department chair to manage a nonprofit office in Iraq during the 2007-2008 invasion. Since that experience in creating his own learning environment, he has spent 12 years in Secondary education on two continents, developing and testing learning systems in STEM classrooms. Karl holds a Master's in Education from Trevecca Nazarene University focusing on Mathematics and Physics (2015) and a Bachelor's in Global Security and Intelligence from Embry Riddle Aeronautical University (2009)

Iterative Research Kit Exchange Program for Remote High School Science (Evaluation)
Managing a Montessori-inspired Collaborative Off-campus Secondary Program

Abstract

Student engagement in science curriculum is dependent on hands-on live labs, rigorous collaboration and student ownership of learning goals. However, remote labs are often over-scripted, restrict student choice, and do not foster collaboration or exploration of evidence like a true development project does. Moreover, most lab kits available to remote students are single-use to be shelved or discarded when complete, which is neither sustainable for schools nor rewarding for students.

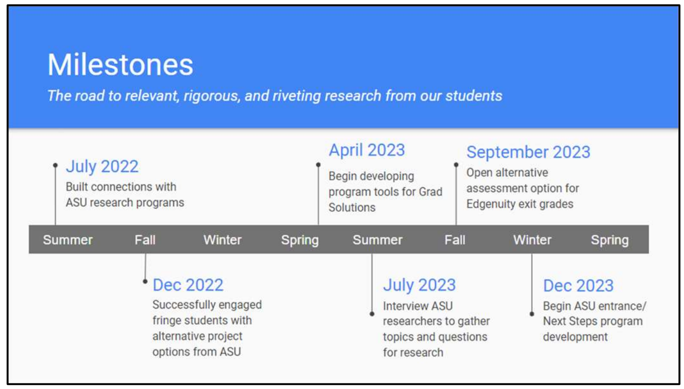


Fig.1 Timeline slide from startup presentation. Presented to Graduation Solutions March 2023

Conversely, prevalent online educational platforms like Khan Academy or IXL, often rely on a video-to-quiz content format without live lab experience or collaboration.

To address this gap, I developed a remote-accessible program focused on student-driven STEM development exchange kits, guided by State Standards as research topic guides, which aims to provide remote students with engaging, collaborative, and challenging engineering tasks.

A pilot initiative was formulated based on prior experience in two separate ASU Research Experience for Teachers (RET) programs in 2022 and 2023. The pilot program began on campus, designing and testing initial kits and exchange procedures (Fig.1). The primary result was a naturally rigorous standard of communication and reporting between students. The first iteration of project reports were rudimentary and poorly reported, as students hadn't traded


Coral team 2

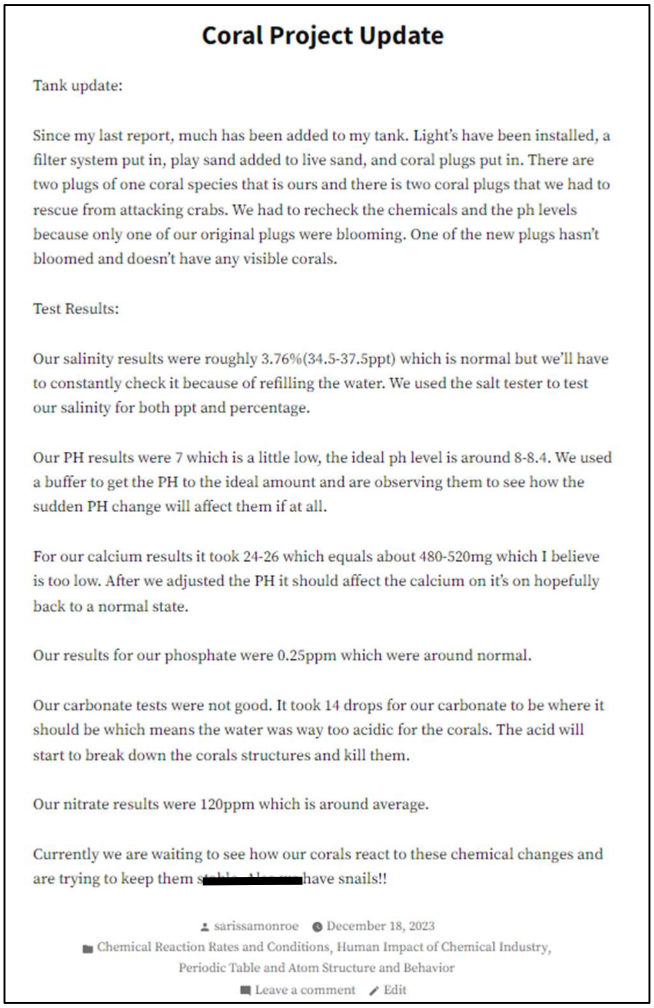
Progress Update

So far, we have cleaned our tank, filled it with water, treated the water, mixed in salt, and tested for the different chemicals. Our levels for all of them were good except for carbonate hardness. Our carbonate hardness was so high that we don't even know the number.

minionman3353 September 5, 2023
Chemical Reaction Rates and Conditions, Electron Bonding Types and Behaviors, Human Impact of Chemical Industry
Leave a comment Edit

Fig. 2; First student report on an ASU sourced project. Note the limited reporting and lack of detail. This is before students began exchanging information for collaborative development cycles. Compare to Figure 4.

Fig. 3; First stage of ASU-sourced Coral project.


Coral Project Update

Tank update:

Since my last report, much has been added to my tank. Light's have been installed, a filter system put in, play sand added to live sand, and coral plugs put in. There are two plugs of one coral species that is ours and there is two coral plugs that we had to rescue from attacking crabs. We had to recheck the chemicals and the ph levels because only one of our original plugs were blooming. One of the new plugs hasn't bloomed and doesn't have any visible corals.

Test Results:

Our salinity results were roughly 3.76%(34.5-37.5ppt) which is normal but we'll have to constantly check it because of refilling the water. We used the salt tester to test our salinity for both ppt and percentage.

Our PH results were 7 which is a little low, the ideal ph level is around 8-8.4. We used a buffer to get the PH to the ideal amount and are observing them to see how the sudden PH change will affect them if at all.

For our calcium results it took 24-26 which equals about 480-520mg which I believe is too low. After we adjusted the PH it should affect the calcium on it's on hopefully back to a normal state.

Our results for our phosphate were 0.25ppm which were around normal.

Our carbonate tests were not good. It took 14 drops for our carbonate to be where it should be which means the water was way too acidic for the corals. The acid will start to break down the corals structures and kill them.

Our nitrate results were 120ppm which is around average.

Currently we are waiting to see how our corals react to these chemical changes and are trying to keep them [redacted] have snails!!

sarissamonroe December 18, 2023
Chemical Reaction Rates and Conditions, Human Impact of Chemical Industry, Periodic Table and Atom Structure and Behavior
Leave a comment Edit

Fig. 4; End of semester update for the same project as Figure 2. Note the difference in measurement accuracy, analysis, detail, and sections in this reporting iteration.


Fig. 5; Tank 2, under maintenance the day the update in Figure 4 was posted.

projects yet (Fig.2,3). Subsequent iterations of each project strand rapidly gained complexity and reporting rigor, as groups regularly relied on prior teams for clarification to ensure their own success (Fig.4,5). A side-by-side comparison of reports from the first iteration to later iterations in the same thread and per student shows a growing sophistication and rigor of reporting.

This iterative engineering kit exchange pilot program not only addresses the limitations of remote learning but also highlights the substantial growth in student communication and reporting proficiency through collaborative learning experiences [1].

Index Terms: Remote Learning, STEM kits, Montessori, Research Experience, Sustainable Learning

I. Background

STEM (Science Technology Engineering Math) education can take multiple forms. Common methods include lecture, prescribed readings, preset labs, discussion, quizzes and vocabulary lists, demonstration, and project based learning. Each of these methods fail to include at least one critical piece of student learning, though project based learning gets the closest to genuine research. Several of these methods don't require students to experiment, communicate findings, or make use of scientific information in context. A few of these methods don't include checks for understanding, and instead trains the student into rote memorization, which is less relevant than research experience if the student decides to join the research community. While project based learning includes most of these valuable skills, and can make authentic use of vocabulary lists, prescribed learning, and lecture, it does not necessarily allow the student to pursue personal

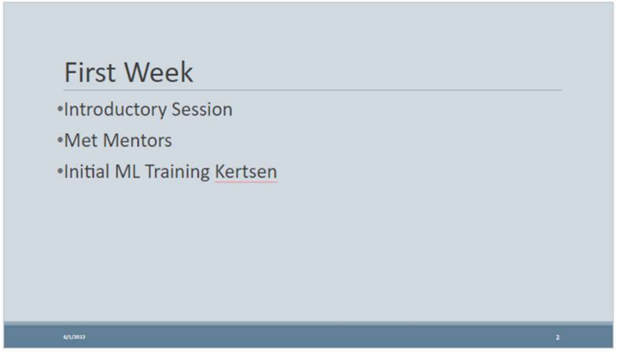


Fig. 6; Slide 2 of SenSIP RET Progress Report. Spent the first week learning Python, the anticipated codebase for the research project. Mentor meetings happened at the end of the week, when project goals were set.

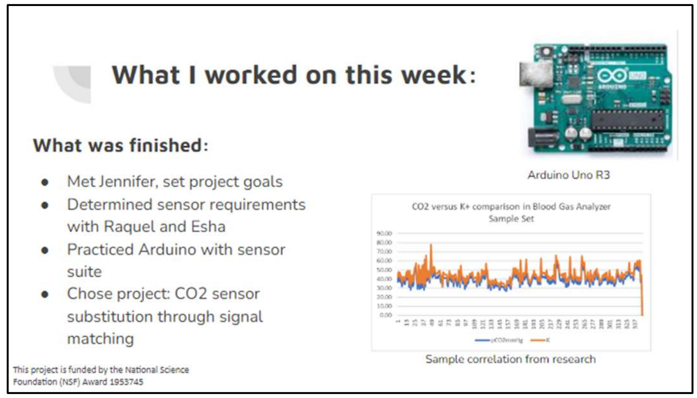


Fig. 7; SenSIP RET week 2 progress report. The prior week was dedicated to study in Python code, which became irrelevant once the project goal was set, and lost a week of progress.

research interests, intrinsically reward the student for achieving their set goal, or model the communication requirements of an authentic research community.

Remote learning is even more restricted. Generally, remote STEM learning is provided by a combination of single-use STEM kits designed to introduce or demonstrate a specific set of concepts and skills, or online learning systems with lecture, prebuilt virtual labs and quizzes as the most common methods of content delivery [2],[3][1]. All of these, unless specifically prescribed, don't encourage the remote learner to connect with or collaborate with other students. When communication is a required component of a course, it often consists of shallow, teacher-mandated standards of communication with little student benefit other than attempting to help students connect or provide unmotivated peer review, which doesn't often lead to genuine discussion. When learning is checked through standardized quizzing and lists, there is also a high risk of cheating, where students can share answers or find them online during a testing session, which further reduces the authenticity of the learning and promotes poor learning habits. Remote students, especially, struggle with disconnection from peers, and a lack of opportunity to communicate in an educational setting. Some have been taken out of the public school system because of learning differences, unsafe environments, poor peer interactions, distance, or lack of access to resources. Others have opted for remote learning because of a preference for online platforms, or the freedom to pursue personal academic goals.

The scientific method is a system of both experimentation and communication, which means the ideal learning pathway will naturally incorporate and prioritize both. The modern scientific research community is a widespread, interconnected community of experimenters, who collaborate broadly and closely to pursue shared goals of discovery. Researchers must be able to communicate effectively with investors, peer researchers, interns, students, and industry partners about their work. They must be able to provide and receive insight and feedback on their work, and discuss and clarify concepts in use in their experiments.

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[1] As of January 2024, the number of available remote Montessori style teacher jobs is 34 in Mesa, Arizona versus 411 remote teachers of other methods in Mesa, Arizona. These Montessori jobs are >80% elementary positions. [3]

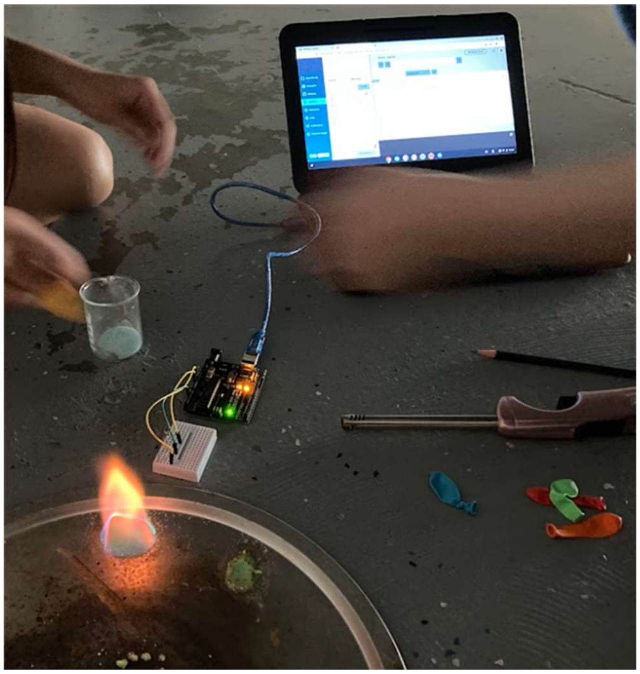


Fig. 8; Student PBL project to develop an Arduino-based digital flame spectrometer. One of the more successful learning experiences for the 2022-2023 Chemistry class.

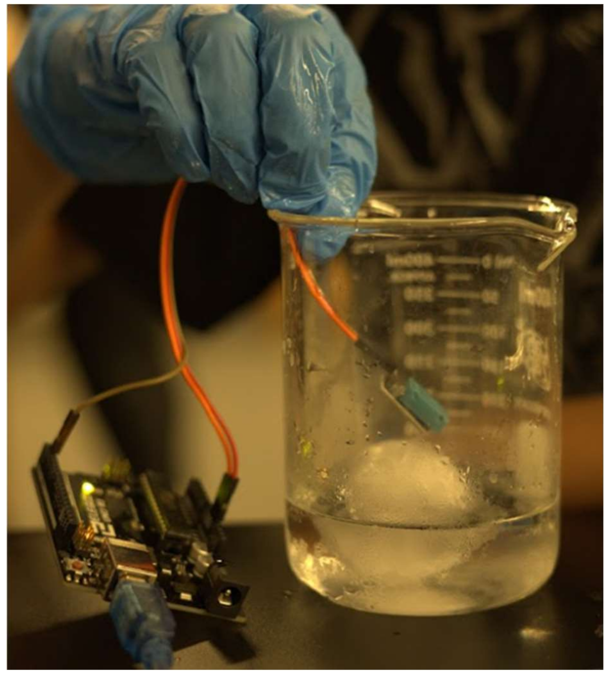


Fig. 9; The Arduino Dewpoint lab that sparked one student's interest in a two-month self-directed community health screening.

The most common method of remote STEM teaching, introducing a concept and then quizzing the concept does not train a student to connect or consider the usefulness of a concept. Even providing a prebuilt lab, grading the results and then discarding the student work does not habituate a student to the need for rigorous and thoughtful communication in their reports. In short, focusing on the topics in a STEM course does not provide valuable practice in the skills of scientific inquiry, and that is a misalignment of priorities. Students should be habituated and familiar with the methods of inquiry, and through that study the content of any field of Science. In this way, if any concept is forgotten, misunderstood or skipped because of time, the student will still and always know how to relearn it correctly and on their own, and how to use or teach it as well.

Montessori classrooms are built around the belief that the context and function of a skill are the best means to teach it [4]. For example, a functioning farm is the best place to learn farming, and a functioning economy in the classroom is the best way to learn money, marketing, business, and entrepreneurship [5][6]. Likewise, young students, whether in Montessori schools or otherwise, already know how to be curious, how to try something new, and then how to talk to someone else about joining them in a new, rewarding activity [7][8]. Those natural inclinations are unused in a lecture-to-quiz platform, and too resource intensive in a PBL format, where the core skill being learned should be following the student's curiosity through to the achievement of bringing others into the discovery and the joy of learning. Therefore, the STEM classroom needs to function like and have the impact of actual STEM institutions, in order to revive and reward that natural curiosity and drive to learn so often found in elementary students, and so often lost in secondary students, only to be found again much later in the professional field [9]. That gap in

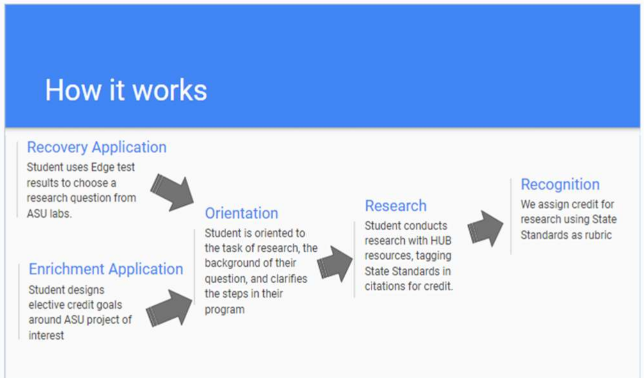


Fig. 10; Slide 8 from RES+C powerpoint pitch. Presented to Graduation Solutions March 2023.

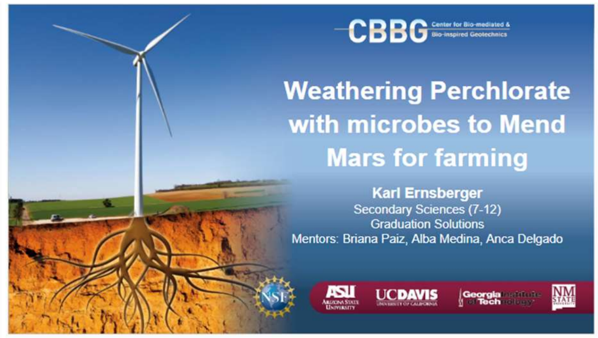


Fig. 11; CBBG RET final presentation, front slide. This program provided the initial connections and project thrusts for the early versions of student exchange kits.

the joy of learning is unnecessary. Elementary students love play rotations, show and tell, Simon says, and career days. Those are the same skills employed with sophistication and training in Scientific research. Play rotations become lab experiments, show and tell becomes conferences, Simon Says becomes the lab method, Career Days becomes internships and residencies. These core skills should be developed, then, in a coherent and functional STEM environment where the student learns to do science, not just about science [10].

II. Program Development

Program development began as a series of experiences and discoveries that changed the perspective on what to teach, and how. In 2022, the Sensor Signal and Information Processing center at Arizona State University hosted a Research Experience for Teachers (SenSIP RET). The program was centered around the goal of exposing Secondary and College educators to current research, and introducing them to research practices, with the expectation that they would bring back new lesson plans to share that experience in their own classrooms.

The SenSIP program's first week was overwhelming, for two reasons. There was an incredible amount of technical material given, with the expectation that the teachers would be able to absorb it, and the research projects were not determined (Fig.6). Trying to sift through and select what material to learn, plan with, and retain without an end goal or learning criteria made it difficult to know what to focus on. After meeting with our project mentors and figuring out a specific research project, however, it became clear what learning materials would be useful, and what would be useless (Fig. 7). This relieved a lot of the tension around what to study and how, because the project goal was the selection criteria and study became much easier, and sifting through high level research and technical journals was no longer overwhelming. That first lesson, that a research goal helps organize and prioritize vast collections of technical material, set the stage for developing a new kind of High School science program.

Over the winter of 2022, two directions of development were followed. After the RET finished, the Sensor development project continued under the guidance of the summer RET mentor, Daniel Gulick, in order to become more familiar with the nature of university research. At the same time, at the high school, research-style enrichment lessons were introduced alongside the existing lectures and project based learning, in order to determine the best fit between them. It was found, both through the at-home research and with students in the classroom, that the learning was much richer and more compelling with larger, more thorough and complex projects that are chosen and developed with the student's input, rather than short, temporary or disconnected labs that bring no long-term investment or impact (Fig.8). Continuity between lessons, and connections with outside interested parties serves to elevate interest in the material, and through the interest, content retention. Often, over the course of that school year, groups of students would prefer to continue a course of inquiry and find even deeper concepts through continuing research than the students who left the project in order to follow along with lectures or the next small-scale scheduled lab.

For example, one student decided to continue sampling breaths of classmates with a CO2 sensor after an initial dew point experiment involving Arduino circuits and dry ice concluded (Fig. 9). Through her continuing research, she made connections between the weather-focused content of the class to carbon cycles, human physiology, and metabolic disorders in humans. She even discovered undiagnosed cases of anemia in the student body, which were later confirmed in doctor's visits. This was a student who, prior to taking on this independent research, struggled academically for a number of reasons. There were eight or nine similar cases of student driven continuing research that resulted in students learning core content out of sequence, but learning it in a more real, thorough, and impactful manner than lectures and labs could achieve. It was a challenge, then, to keep shifting between independent student driven research and scheduled curriculum in the classroom.

Around spring of 2023, it started to become clear that a classroom that makes best use of student-driven inquiry would be one that provided room for students to pursue recursive inquiry as

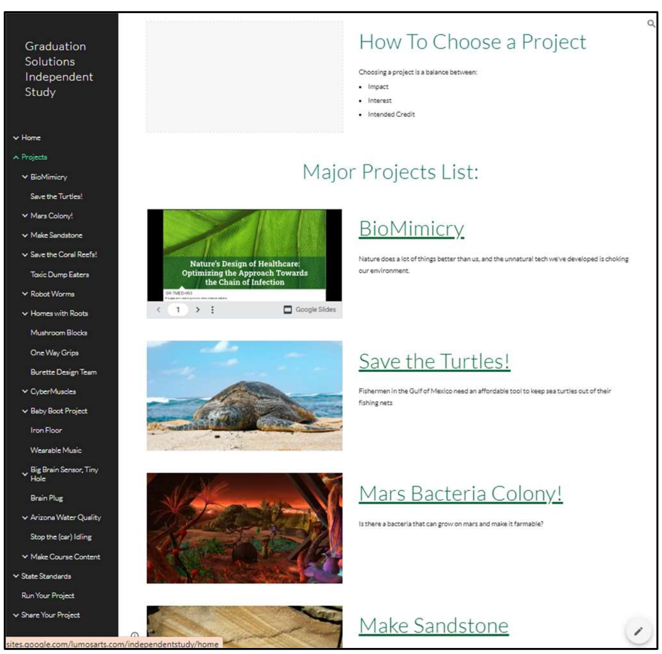


Fig. 12; Project Portal for research exchange program. This site has been under constant development since inception in 2022.

Fig. 13; Mars kits in the classroom for fall 2023 curiosity led them, trusting that they would discover concepts and connections to content that could not be planned for. In April a formal plan for a student research program was drafted and presented to school administrators as a powerpoint (Fig.10). The presentation was very well received, with two initial concerns. The concerns presented by administrators at the time were the amount of time and effort it would require of the teacher to build and provide such a program, and the methods that would be employed to ensure students learned required content. Those concerns were discussed, and safeguards were put in place for a pilot year, to achieve a specific set of goals: develop a set of kits, confirm conceptual depth for participants through a comparison with students who continued on traditional learning platforms, determine the change in teacher's workload, and develop a curriculum around the program that can be shared.

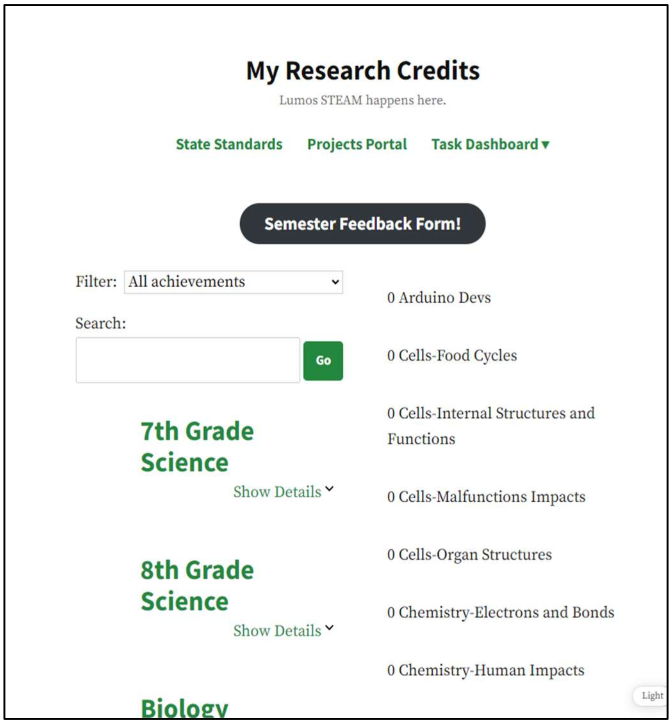


Fig. 14; Student portal to standards and points tracking system. This view is from a dummy account with no points awarded, for student anonymity

The administration agreed on the goal to develop a student-driven collaborative research kit exchange program, whose project kits would be carefully developed by the students under the teacher's guidance. The kits would be focused on current research goals of nearby universities, and be reusable and expansible in nature. To gather reasonable projects for inquiry it was necessary to attend another RET program provided by the Center for Bio-Inspired and Bio-Mediated Geotechnics (Fig. 11).

The CBBG Summer RET program began with a project meeting with mentors, instead of content. Having the meeting in advance, and not being frontloaded with content, made it much easier to accurately pay attention to and retain important content. This confirmed the earlier lesson learned that beginning with a project or a goal will help students prioritize, anchor and organize content as they learn it.

The CBBG Program ran concurrently and on the same campus as the SenSIP program, which provided an opportunity to orient another teacher to the sensor development project from the prior year. The chance to hand off a project and see the next person run with and excel at the same goal was incredibly rewarding for both, and served to confirm the value and the volume of learning through the SenSIP research program. The experience of handing off a project to a peer that valued and appreciated the mentorship was extremely rewarding and motivating.
At the same time as the CBBG RET, a simple student project portal was outlined, specifically for introducing students to the college research projects, and giving them a forum for posting their

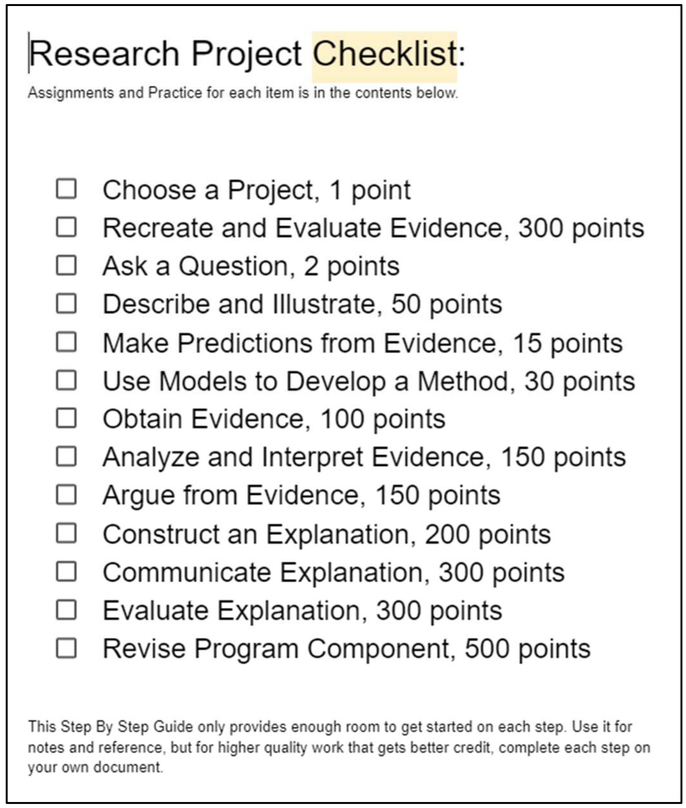
own additions to each. To assist with the design, several students from the prior year were recruited to review, test, and develop the website (Fig.12). Students were also recruited to design early versions of the exchange kits being assembled for the program.

One of the first kits built was the Mars Farming kit, since Mars farming was the CBBG project assigned for the RET program (Fig.13). The kit included an airtight transparent luggage tub, Arduino irrigation and sensor kit, a clamp-mounted LED lamp, a set of sieves, a sample bag of Urea, a chemical Cold Pack (ammonium nitrate), coffee filters, a tea light, Chia seeds, a USCS Soil Classification chart and a soil test kit. This kit was the first prototype of the pilot kit program, and incorporated student learning in programming, circuitry, biology, geology, astronomy, chemistry, physical science, statistics, and with the appropriate standard of reporting, ELA content.

As the pilot year launched at Lumos Arts Academy, the program structure was further developed, including a custom standards based grading system (Fig. 14), a collaborative research process (Fig. 15), additional kits, project binders for each kit and background content delivery systems for each project and State Standard.

III. Program Structure

The program has several unique features, owing to the dynamic nature of research and development. These are: the Project and Standards Portal(Fig. 12), the Development Cycle workflow assignments(Fig. 15), the Student Points tracking system(Fig. 14), and the iterative kits with their binders (Fig.16).



Research Project Checklist:

Assignments and Practice for each item is in the contents below.

- ☐ Choose a Project, 1 point
- ☐ Recreate and Evaluate Evidence, 300 points
- ☐ Ask a Question, 2 points
- ☐ Describe and Illustrate, 50 points
- ☐ Make Predictions from Evidence, 15 points
- ☐ Use Models to Develop a Method, 30 points
- ☐ Obtain Evidence, 100 points
- ☐ Analyze and Interpret Evidence, 150 points
- ☐ Argue from Evidence, 150 points
- ☐ Construct an Explanation, 200 points
- ☐ Communicate Explanation, 300 points
- ☐ Evaluate Explanation, 300 points
- ☐ Revise Program Component, 500 points

This Step By Step Guide only provides enough room to get started on each step. Use it for notes and reference, but for higher quality work that gets better credit, complete each step on your own document.

Fig. 15; Checklist/table of contents for student workflow guide. These tasks are taken from the NGSS State Standards and the Arizona Core Skills lists.

Fig. 16; Sample kit in use on the table. The classroom Chromebooks are not included, on the assumption most remote students will have their own devices.

The first web portal, built over summer 2023, is a Project and Standards Portal (Fig. 17). The website was originally intended to house the entire set of assignments that represents a development cycle (Fig.13), but those have since been ported to a second linked site that runs the points system (Fig. 12). The Project part of the portal houses descriptions of several research projects available to students. Each project page highlights the current goals, problems, and achievements in that project (Fig. 18). They also include links to contact the primary investigator, recent achievements and publications, and relevant topics. Several of those topics are crosslinked to the Standards portion of the portal, where topics are arranged by State Standard. Further student development of the site will incorporate and link all content between the Standards and Projects sides of the site, by topic. This dual arrangement of content is intended for the student to be able to choose a project to work on either by interest area, or by required standards. As students develop and complete portions of research, their results and publications are also added to either the Standards or Project sides of the site, and any affected goals, problems, or achievements are updated as well, in order to assist successive teams to understand the development of the project over iterations and the state of the kits they will receive.

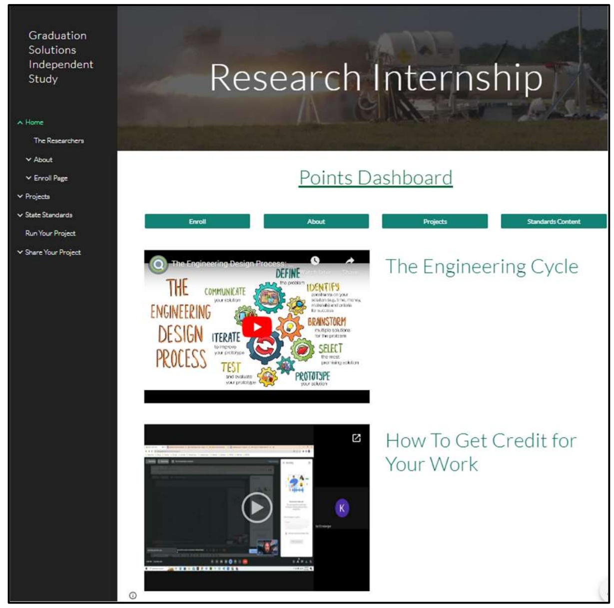


Fig. 17; Front page of Projects Portal.

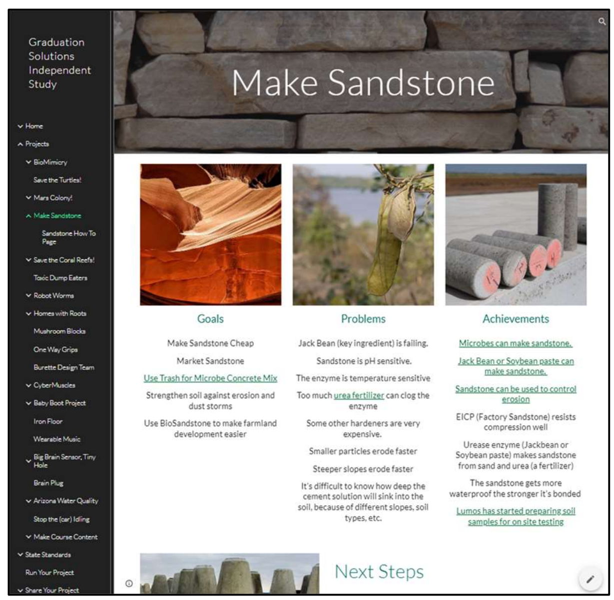


Fig. 18; Sample Project Page with introduction content and research links

The second web portal, currently housed in a Wordpress account, includes the research phase guides, which are like assignment options, and a points tracking system (Fig.12). These pages needed to be housed in a Wordpress account to integrate the points system capability with some auto-grading techniques, and for the possibility of creating and managing student accounts where their points are logged. The points are grouped and awarded by State Standard, and earned by completing phases of a project with relevant topics included in the illustrations, descriptions, and analysis of the experiment. The research phase guides follow three closely matching systems: the NGSS Core Competencies list, the Scientific Method, and the Engineering Cycle. These phases are currently being formatted into a flowchart to be hosted on the main page of the Wordpress site, so students can navigate their project and access guides via the workflow diagram.

In order to meet students at their level, and also encourage them to develop their research skills at a challenging pace, the grading used is not assessed per assignment, but as an overall productivity and rigor metric over a time period. The students are awarded points in a topic based on the amount and quality of work done in the assignment, and points are awarded against a professionalism rubric that multiplies the base points for any phase based on sophistication of the work (Fig. 19). The levels are divided into Elementary, High School, College, Research and Industrial standards, with appropriate requirements for each. As such, there is no required number of points for an assignment. Students are not compared against an expected level of achievement for any research assignment, and points are compiled continuously from any assignment in a standard until the required total points are earned. Only achieved points are tallied, and total achieved points are used to pass a course. Students are thus rewarded for participation at any level, and are encouraged to progress up the professionalism ladder in order to obtain points for graduation faster. This also makes the grading system flexible enough to allow for the unpredictability of research, and the possibilities of breakthroughs or delays in research for any student, without penalizing or unduly rewarding either.

Students are introduced to the program through an Orientation module, where they review the Arizona State Science Standards for Science, are introduced to the various available projects, and then work out a self-pacing guide based on the points they need to earn for their course credit (Fig.20), their expected course completion date, and a few other metrics to determine how often

Science Points Guide

Here's how you know what points you'll get for your work

1. **Elementary (x1 points)**
- Pick research projects based on interests and curiosity.
- Simplicity and practicality are crucial for better understanding and engagement.
- Teachers or other adults suggest suitable projects.

2. **Middle (x1 points)**
- Consider research projects systematically, exploring various subjects and topics of interest with available research resources.
- May align projects with school curriculum or personal goals.
- Seeks guidance from teachers or peers for a project idea that is challenging yet achievable.

3. **High (x2 points)**
- Research projects align with career aspirations or college applications.
- Explore complex and in-depth subjects, utilizing advanced research methods.
- Collaborate with experts to enhance the quality and depth of the project.

4. **College (x3 points)**
- Independently choose research projects aligned with the course.
- Seek research opportunities under faculty mentors or join ongoing projects within their college.
- Conduct extensive literature reviews, data analysis, and advance larger research initiatives.

5. **Teacher (x5 points)**
- Choose research projects driving for improving educational practices and outcomes.
- Focus on effective teaching, student assessment, or innovative classroom approaches.
- Help design and implement studies for meaningful insights and education enhancements.

6. **Professional (x10 points)**
- Research to contribute to industry knowledge, solve real-world problems, and drive innovation.
- Projects aligned with their expertise and career goals, such as market research, scientific studies, or data analyses.
- Influenced by industry trends, aiming to stay at the forefront of their field and improve processes within their organization.

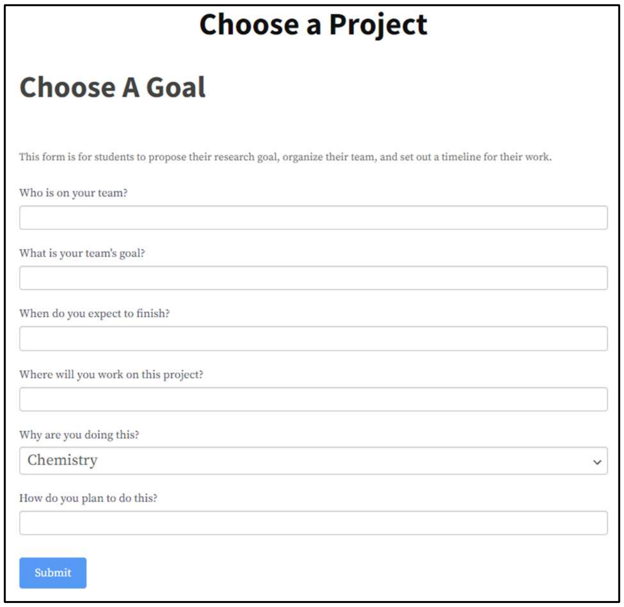
Each of these individuals has unique motivations, goals, and resources that influence their choice of a research project. Whether driven by curiosity, academic requirements, career aspirations, or professional development, selecting the right research project is crucial to fostering learning, growth, and meaningful contributions to their respective fields.

Fig. 19; Performance Rubric. These criteria function as points multipliers for student work. Students are not held to a percentage system, but a productivity and professionalism points multiplier system.

Arizona Core Science Goals:

Course Points	Category Points	Standards	Base Points
Earth And Space	**Earth**	Sun and Weather	1000 Stones
8000 Points	4000 Stones	Cycles and Patterns	1000 Stones
		Chapters and Timeline	300 Stones
		Resources, Hazards and Impacts	1000 Stones
	Space	Stars	200 Stars
	1500 Stars	Planets, Orbits and Gravity	300 Stars
		The Universe	300 Stars
Life Science	**Cells**	Parts and Functions	1000 Cell Count
15000 Points	3000 Cell Count	Growth and Organs	500 Cell Count
		Diseases	500 Cell Count
	Ecology	Metabolism and Nutrient Cycles	1000 Eco Credits
	6000 Eco Credits	Disruptions	2000 Eco Credits
		Human Impact	2000 Eco Credits
	Genetics	Variation and Reproduction	500 Upgrade Points
	1500 Upgrade Points	Impact of Technology	750 Upgrade Points
	Evolution	DNA and Mutations	300 EXP
	2000 EXP	Mechanisms of Evolution	300 EXP
		Inheritance and Diversity	500 EXP
Physical Science	**Particle Theory**	Periodic Table and Atoms	2000 Vials
20,000 Points	10,000 Vials	Electrons and Bonds	2000 Vials
		Reactions	2000 Vials
		Industrial Chemistry	3000 Vials
	Forces and Fields	Force Fields	1500 Hit Points
	4000 Hit Points	Charting Newton's Laws	500 Hit Points
		Using Newton's Laws	1000 Hit Points
	Energy	Exchange in a System	1000 Energy
	5000 Energy	Use and Impacts	1000 Energy
		Waves	2000 Energy

Fig. 20; Student Science graduation guide, first page. Further pages outline learning goals per grade or course. The Standards titles tie directly to the Points Portal and the project guides.


Choose a Project

Choose A Goal

This form is for students to propose their research goal, organize their team, and set out a timeline for their work.

Who is on your team?

What is your team's goal?

When do you expect to finish?

Where will you work on this project?

Why are you doing this?

Chemistry

How do you plan to do this?

Submit

Fig. 21; The starting point for student work. This form will develop as logistics for offsite users is refined, to include pickup options, tuition fees, etc.

they should try to submit assignments in order to keep pace. Students then use the State Standards they want to achieve and their personal interests to select an appropriate project. That is the first step in the orientation cycle, called "Choose a Project." This goal is completed on a simple worksheet or online form (Fig. 21). They are then walked through their first research cycle as a cohort, where the teacher focuses on explicitly guiding the group through each research phase in the NGSS Standards, earning base points for each phase (Fig. 13).

Every phase in the cycle is a core skill listed in the Arizona State Science Standards, except for Choose a Project, and Revise a Program Component, both of which were deemed necessary for the healthy function and development of the program.

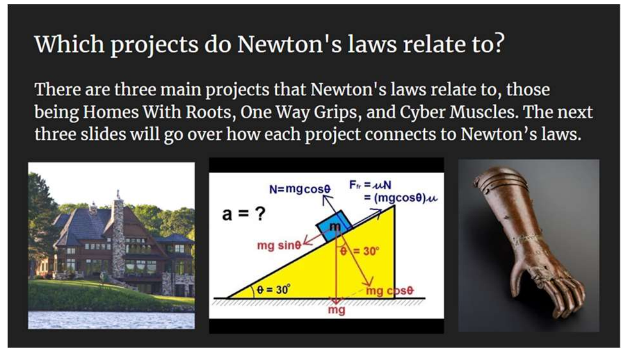
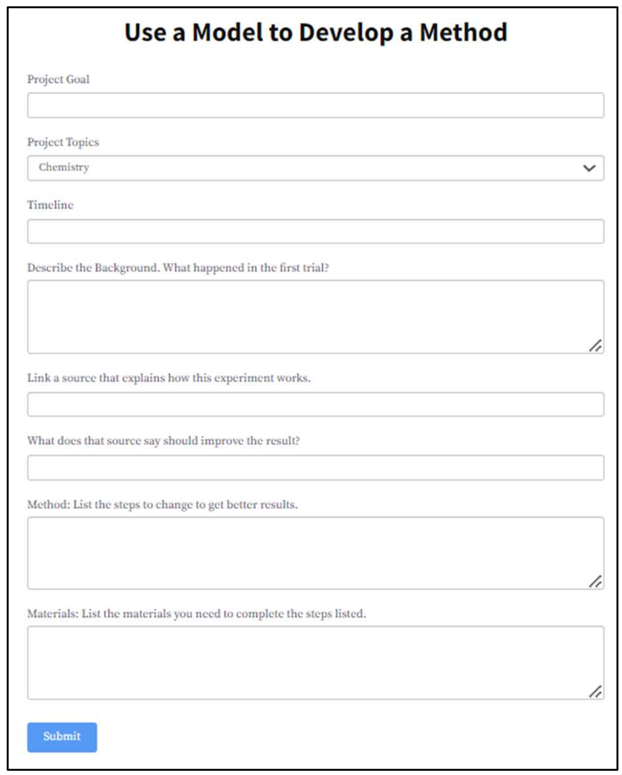


Fig. 22; Student presentation on Newton's Laws and their applicability to specific projects. This is the transition slide between his overview of the three laws, and the slides explaining their application to the projects listed.


Use a Model to Develop a Method

Project Goal

Project Topics

Chemistry

Timeline

Describe the Background. What happened in the first trial?

Link a source that explains how this experiment works.

What does that source say should improve the result?

Method: List the steps to change to get better results.

Materials: List the materials you need to complete the steps listed.

Submit

Fig. 23; Students are encouraged to look up modifications and improvements to the lab. This is the core step of the development cycle, and the most genuine indicator of analytical thinking during the course

When a student has chosen a project, their next step is Recreate and Evaluate Evidence. After the student has obtained the lab kit and binder, they select the most recent version of the lab out of the binder, and attempt to reproduce the results posted by the previous team. Results are either posted to the blog or added to the binder,

Fig. 24; Image of a student's second trial on the Homes With Roots project. This trial integrated lessons learned from the Sandstone project as well.

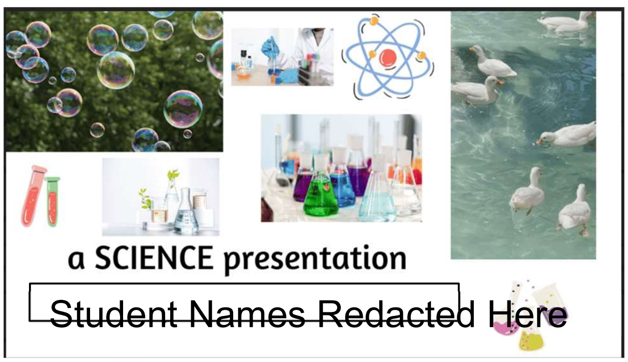


Fig. 25; Title page of a student presentation. Students presented to each other, and between classes regularly, to recruit project partners, present results, and pass on projects, especially when a problem changed focus, like a Biology problem changing into a Chemistry problem.

as a comparison study to the earlier team. This serves as the introductory round for any project, and the starting point for the next task, Asking Questions.

In this step, the student begins to investigate options for their revision. They check that their project goal is complete and relevant, and that they understand the phenomena relevant to the lab they just ran. These elements are then submitted for credit when they Describe and Illustrate, in their own words and graphics, how the experiment works, using analysis tools provided in the State Standards content. For example, a student takes on a project developing burrowing robots, and they demonstrate proper understanding of Newton's Laws by drawing a Force Vector diagram of the prior experiment's results, or of a proposed next iteration of the design (Fig. 22). They are graded on proper use of Newton's Laws in their diagram and experimental prediction.

A diagram of an upgraded design then constitutes a Prediction from Evidence, or a Method from a Model, which are the next stages in the assignment flow, depending on the details that are included (Fig. 23). Once an experimental design has been proposed by the student, they use the kit again, and are allowed to request, order, or make any additional items that are needed in order to run an upgraded trial and record the relevant data (Fig. 24). This stage is where the kits become reusable, iterative, and expansive. Each time a kit is exchanged, it is added to with a marginal expense or adaptation to the original design. Their analysis, argument, and explanations are then completed by the student, in preparation to receive credit for their complete project, and to hand off their project to the next team. All these pieces, the analysis, argument and explanation are vetted by prospective receiving teams in the next stage, Communicate Explanation. The points earned by the presenting team can be determined either by the receiving team or by the teacher, depending on whether the project is adopted immediately by peers.

When students get to the Construct and Communicate Explanation stages, they present their project and results either to peers or to the outside mentor (Fig. 25). Through viewing and responding to peer work, they are able to complete the Evaluate Explanation portions of their

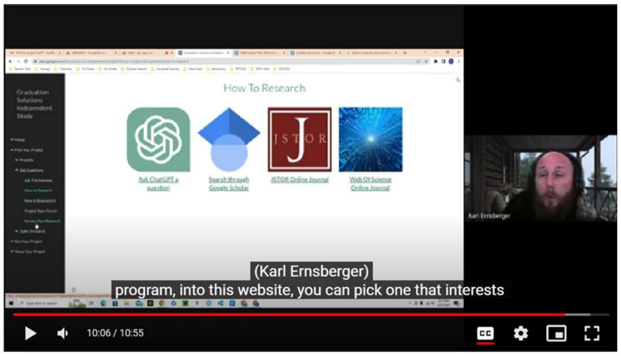


Fig. 26; Snapshot of an overview video on how to conduct research. These orientation videos are under development to familiarize new cohorts to the research process.

orientation as well. This evaluation stage is critical for the recyclability of the kits, as it is during this presentation and evaluation stage that students are reviewing prospective projects to take on for their next research cycle. Students that presented to each other, then exchange projects, and use each other's recommended next steps to design their follow-up experiments. The receiving team also reviews the material linked and produced by their predecessors to help them begin making their own descriptions, illustrations and predictions for the outcome of the next experiment in the project thread.

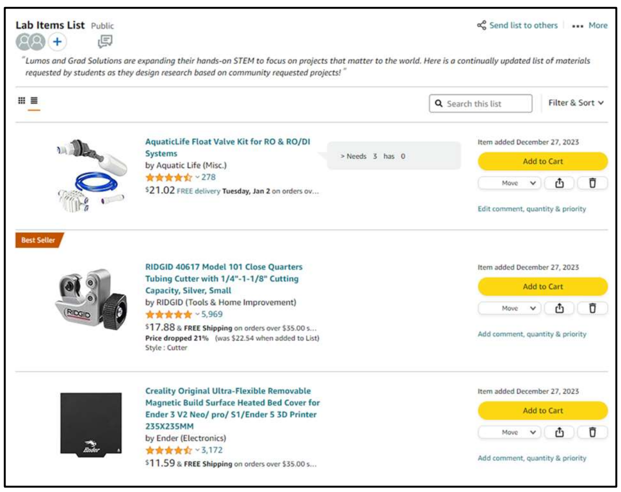


Fig. 27; Amazon Wishlist. This list is continuously updated with student materials requests, and then, in order, presented to community investors, then parents, then if parts are still needed, paid for out of the class budget.

Using this project workflow, several benefits are gained. Students are always, and at every stage, in charge of identifying useful information from peers and public sources, and apply it directly to a live scenario. Students are also motivated to review each other thoroughly and effectively, because the quality of their own project is dependent on them being honest and thorough in their review of peer work that they will immediately adopt. Students are also rewarded for growth regardless of their prior achievement, because they are assessed based on productivity, and not achievement level, but are still awarded credit for applying the course topics. Students are also in charge of identifying and understanding the course goals, because they are constantly referring back to course standards throughout the program as the basis for choosing project threads, designing experiments, and analyzing results. The more often they refer to and use State Standards concepts, the more points they earn for their work. Students are also rewarded for their work because they are able to present and hand off their work to a group that cares about and will use their results.

The lab also benefits from a reduced cost for lab equipment, because the lab no longer requires a 1:1 or even group-matched quantity of tools to be able to perform a project. Kits for each project rotate through the class, gaining complexity with each iteration, so that student mastery of content also spirals up naturally through the year. The way this project flow looks in class depends on whether the class is in Orientation or open project flow.

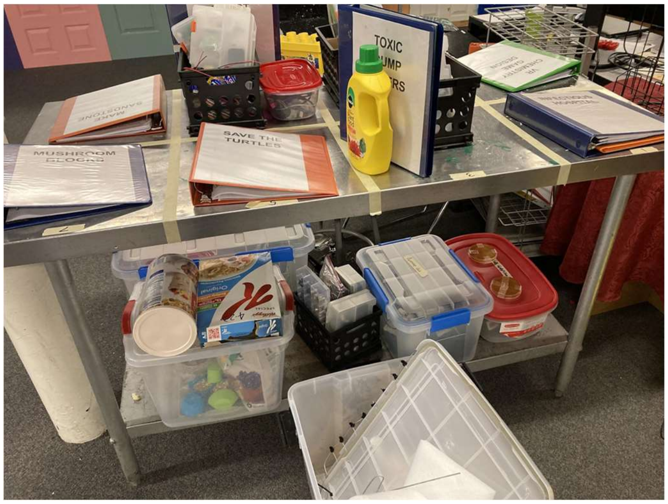


Fig. 28; Kits being stored. Project folders help students log progress and communicate between teams. These kits are being used in a rotation in the 7th and 8th grade classes. Every three or so weeks, the teams rotate projects, presenting progress to the receiving team, so that the next team can choose the most achievable next goal in the project outline.

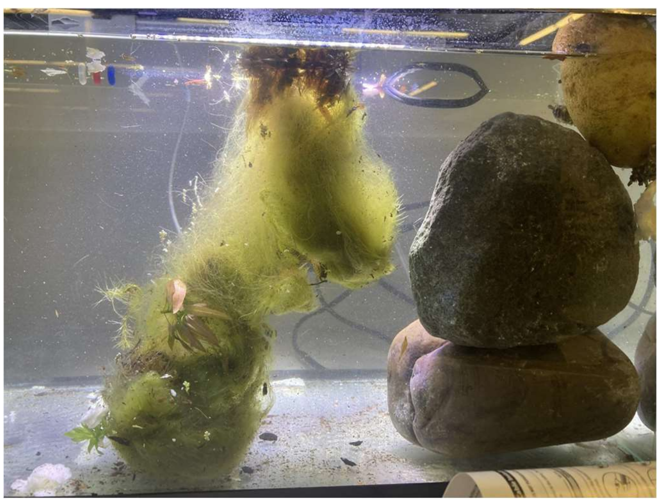
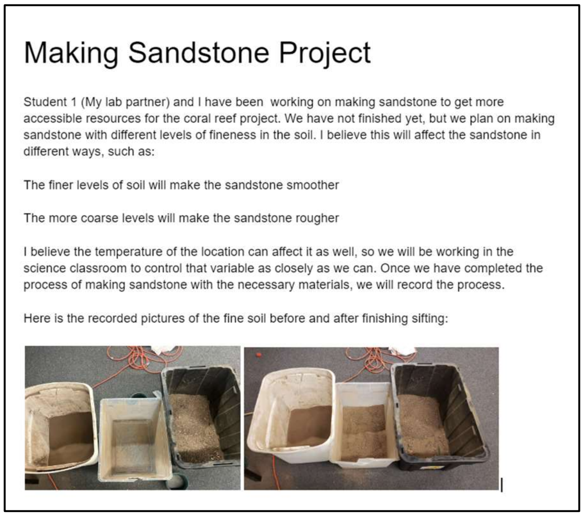


Fig. 29; Student-designed Bioclogging experiment. Following investigation of multiple groundwater bioremediation projects, students identified bioclogging as a central problem, and are using this tank to replicate and experiment on the problem in a visibly accessible scenario.

During Orientation, students are walked through each stage of their chosen project in lock step, and deadlines are discussed and set as a whole class for each phase (Fig.26). Students use the phase guides (Fig.15) all together, and each assignment is completed as a group, with the teacher demonstrating, including using a kit. Students complete each stage together, working on separate projects, both so that they can be better oriented to the projects as a class through collective discussion of challenges associated with each project, but also so students can identify and abstract the skill being taught at each phase, like how to ask questions, or how to analyze a result, or how to communicate a finding effectively.

Once Orientation is complete, teams, pairs or individual students arrange with the teacher to choose, design, and schedule separate projects, chosen first out of the projects completed during Orientation, but can also be new projects at the teacher's discretion. This open research phase is the easiest to let a Substitute teacher run, because the instructions are identical regardless of whether a teacher or substitute is present, and the classroom behavior should be self-sustaining.

For most of the course time, students begin class by checking their project checklist or process flow location (depending on program version) to determine which part of the classroom to join. Students with active labs to set up, run or gather data from take their kits out and continue their trial. Students who are choosing a project or asking questions are either reviewing posted content on open projects, or are evaluating presentations from others on their completed project. They are gathered at the presentation screen. Students who are analyzing results, stuck on a phase, or evaluating a program component are with the teacher, in discussion. This makes three specific areas in the lab for an in-person setting, or three possible methods of interaction for remote learning. There's the Kit space, where labs are running. There's the Presenter space, where students are relating and discussing projects



Making Sandstone Project

Student 1 (My lab partner) and I have been working on making sandstone to get more accessible resources for the coral reef project. We have not finished yet, but we plan on making sandstone with different levels of fineness in the soil. I believe this will affect the sandstone in different ways, such as:

The finer levels of soil will make the sandstone smoother

The more coarse levels will make the sandstone rougher

I believe the temperature of the location can affect it as well, so we will be working in the science classroom to control that variable as closely as we can. Once we have completed the process of making sandstone with the necessary materials, we will record the process.

Here is the recorded pictures of the fine soil before and after finishing sifting:

Fig. 30; First iteration student reporting on the CBBG Sandstone project. Note that materials, procedures, measurement data, and thorough analysis are missing from this first update.

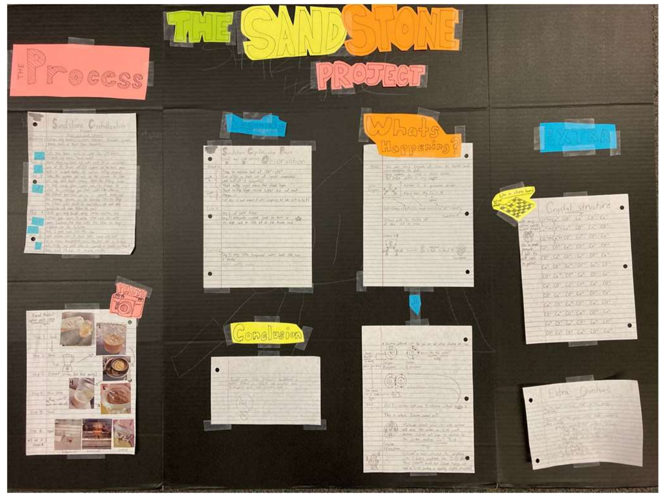


Fig. 31; Student poster on the Sandstone Project. This second generation report includes much more detail than the first generation.

with each other, ideally with a camera and microphone to both record the presentation and also for remote students to join live. There's also the Mentor space, where the teacher assists students with any challenges or difficulties they run into through their project. Stations with low attendance can be shut down for the day, so the teacher can attend more fully to the other two stations.

Substitute teachers are integrated into the learning system as well. The instructions typically given to substitutes are one of two options. It's either "Students are in this phase of orientation, here are the forms for them to fill out, and teacher notes for guiding them through the stage" or an explanation of the stations, possibly with some detail relevant to the students and their projects or if there are special events like a visiting speaker. These basic details can all be printed out in an Emergency Substitute folder, and remain relevant the entire year, without losing classroom momentum.

IV. Kits Overview

As students design an experiment around a research goal, they turn in materials requests as part of the Methods section of their research paper. Those requests are either already in the kit provided for the project thread, added to an Amazon Wishlist (Fig. 27) for parents or other investors to purchase, or provided by the project source such as CBBG, SenSIP, or other professional groups.

So far, kits have been designed around CBBG, SenSIP, and AZDEQ research. Multiple rounds of development have occurred on these projects (Fig.28):

- Probiotic ICU
- Mars Farming
- Make Sandstone

- Coral Reefs
- Homes with Roots
- Mushroom Blocks
- VR Chem Class
- Scoby Leather
- Robot Worms
- Comfortable Body Armor

Kits have also been designed for these projects, but have not gone through more than one development cycle yet (Fig. 29):

- Save the Turtles
- Toxic Dump Eaters
- Robot Worms
- One Way Grips
- Cyber Muscles
- Baby Boot Project
- Iron Floor
- Wearable Music
- Stop the Seize
- Brain Plug
- Arizona Water Quality
- Arizona Air Quality

Students have intentionally been key to the development of research kits from the beginning. During summer of 2023, before the pilot program launched, four students were offered early credit for the course for beginning development. Current kits cost about $4.25 per use for replacing materials used to replicate the most recent version of the project. Total setup cost for purchasing currently designed kits is around $2000, including all 22 kits in their current form.

As kits get used, and lab versions and instructions are refined, these setup estimates and per use estimates are fluid, as students are constantly updating materials lists for each project. Students report on the materials they used for successive versions of the project, and put any new materials used in their revision of the kit back in the kit and add them to the materials list when the kit is returned. Each kit's startup price is expected to slowly grow as student contributions add to the

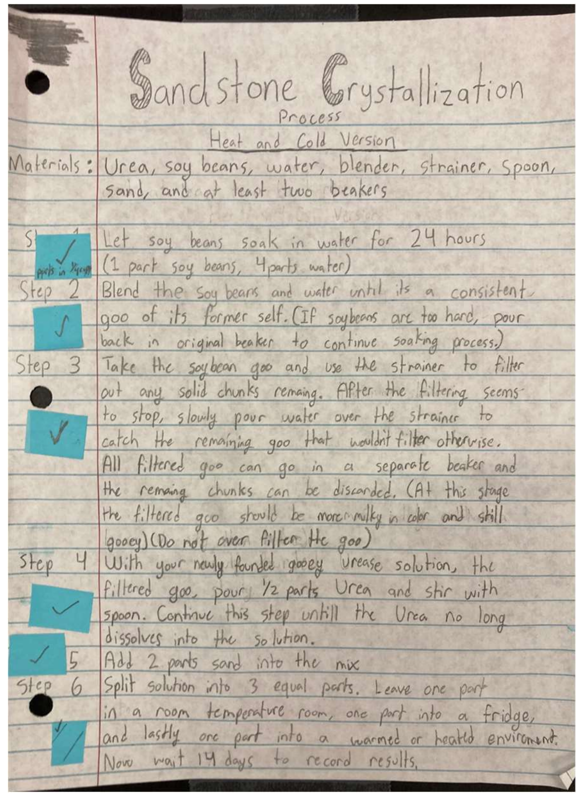


Fig. 31a. Introduction section of report poster.

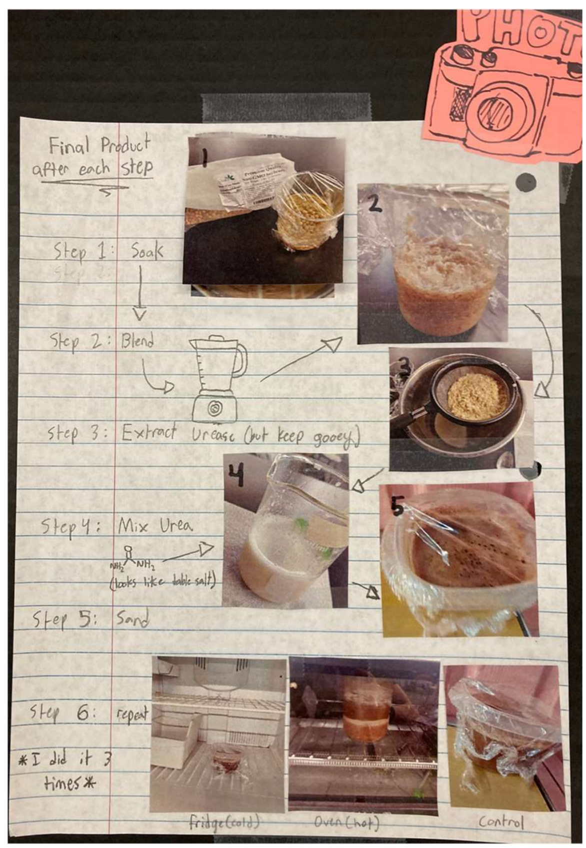


Fig. 31b; Results section

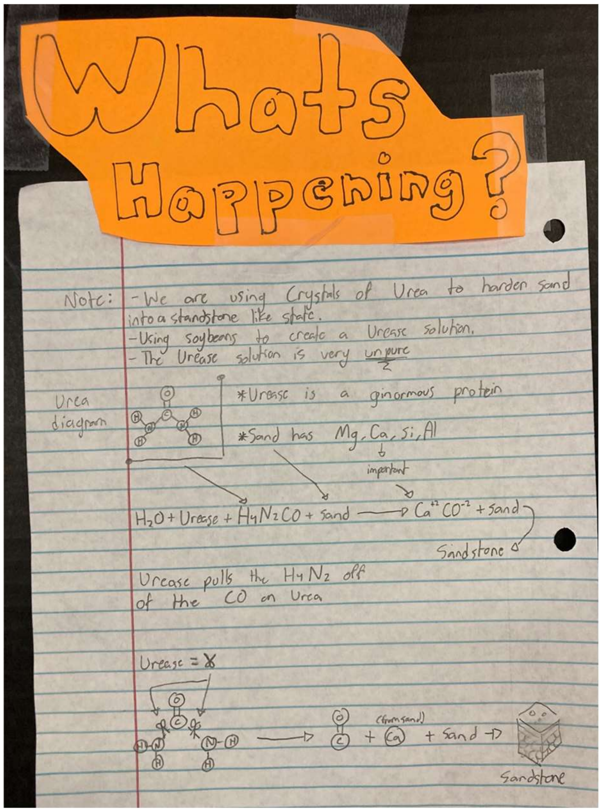


Fig. 31c; Analysis section

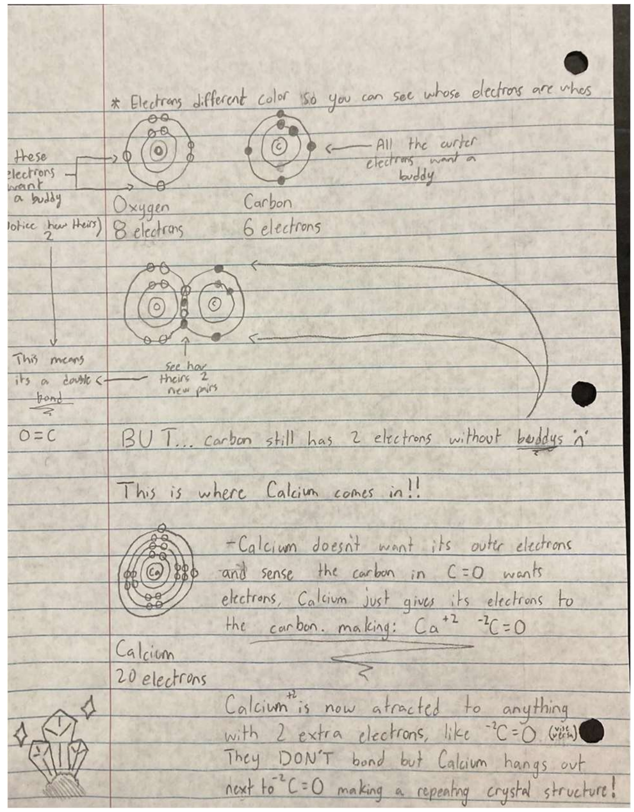


Fig. 31d. Additional Analysis

equipment used in the thread until a complete solution is realized, at which point the project could be revised or retired, to make room for a new starter kit. Their report then becomes the instructions for the next group to replicate and then build from. As the most mature projects retire and new projects are added in, the overall price per project is expected to remain roughly stable, since new projects have fewer associated materials than a mature project is expected to have.

V. Early Outcomes

The pilot year of the project yielded numerous lessons and refinements, as both teacher and student adjusted and added to the new workflow. The most salient lesson for both student and teacher is that professional communication is absolutely essential to the progress of iterative, multi-team projects. Students quickly discovered the importance of thorough, complete communication and reporting on their project, because of the frequent requests for clarification on early versions of project instructions and reports.

Figure 30 is a sample of a first-generation report by a student, edited for anonymization. This report includes an update on work that was completed, and a basic prediction on the effects of use of various materials on an outcome, but it doesn't produce valuable direction or information for the next team to build on.

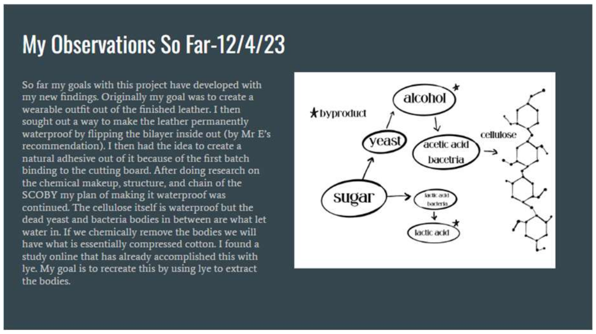


Fig. 32; Main analysis diagram of Scoby Leather project.

Fig. 33; Timeline from Scoby Leather project.

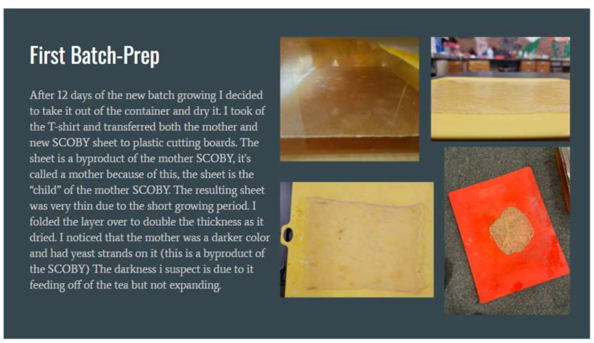


Fig. 34; Initial setup of the Scoby Leather project.

Fig. 35; Student presenting at CBBG NSF Conference at ASU.

Fig. 36; Students engaged at a project station. These three are preparing to set up a new trial in the freshly setup One Way Grips project.

The second generation of instructions on this project are much more thoroughly researched, cited, and the instructions are far clearer for the third team to use in their follow-on project (Fig. 31).

As can be seen, not only were the background of the project much more thoroughly investigated, but analysis of the core reaction are included, and the project concludes with clear and actionable recommendations for next steps.

The team that produced the first report changed projects, and produced this secondary project: SCOBY Leather Gen 1 Project (Figures 32-34)

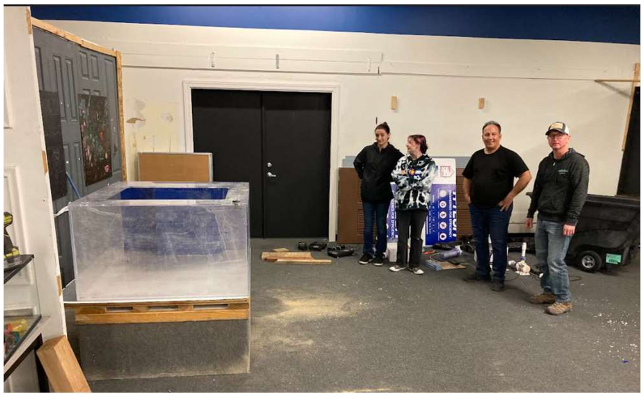


Fig. 37; Parents and students visiting over Christmas break to install the estimated $3000 Coral Tank they donated since the program started.

Fig. 38; ASU visitors came in every few weeks to mentor students, present new projects, and collaborate on shared projects.

The level of detail for this second project is much more thorough, clear and actionable. The project specifies a valuable next step for the project, and a good reason for doing so. It includes references, tutorial materials, and thorough documentation of the experiment's results.

Both branches from the first project, one following the project and the other following the team, indicates a quickly rising level of rigor in reporting and analysis. Successive generations on a project thread provide much more actionable instructions, and more valuable background information for assessing the value of the project for the audience.

Those lessons were learned through trial, by students exchanging projects and finding that they needed much more information from their predecessors for the second or third generations than the first report provided, and from that knowledge recognizing more easily how and when to record details for their projects. Students realized quickly how to edit and refine their reports because they were simultaneously asking for clarification on a project they were taking on, writing their own updates to it, and providing clarification to another team that had taken up their previous project. Students do occasionally comment about the constant flow of writing and analysis required in the class, but when given the alternative to return to other systems of learning classwide, students consistently vote to continue with the program. As the rigor has naturally risen, the demand for content to use in analysis has risen as well, resulting in more productive use of instruction.

One particularly salient event that demonstrates the quality of student work and interest was a field trip to a National Science Foundation review of the CBBG program. Students who were featured in the Mars project poster were invited to share their work during the poster session. Out of the posters available in the room, ours was the most engaged by NSF members, who spoke primarily with the students about their parts in the projects with great interest (Fig. 35).

In a confirming counter-example, at one point, several concerns led the teacher to pull the 7th and 8th grade classes out of the research program temporarily, opting for a teacher-led, classwide project on astronomy. The concerns included student maturity to approach a complex problem in teams and rigorously communicate progress, the compatibility of available projects to

Astronomy standards, and the lack of materials and time available to set up and run more projects. This occurred after the 7th and 8th graders were already introduced to the program, and had gone through one round of research projects with the teacher. This shift away from exchange based research led to several undesired outcomes. Student engagement with the material dropped. Writing and reporting rigor were supported only by teacher feedback, not by natural factors in the student body, and therefore writing quality declined sharply and the work required of the teacher increased. Student interest and retention of the material also declined. Partway through this project, these effects were noticed, and the project was cut short. In its place, completed projects from other grades were set up for 7th and 8th grade in a round robin development challenge format, where teams of students would rotate through a unique STEM challenge at each table for one to two weeks, attempting to revise and improve on a prior team's result, based on their reporting. This immediately restored student interest, collaboration, student-led demands for increased clarity, rigor, and relevance in written and recorded information, and a return to student retention of information (Fig. 36). 7th and 8th graders independently invited upper grade students to their class time to collaborate on projects and collectively revise and update instructions and data, for example.

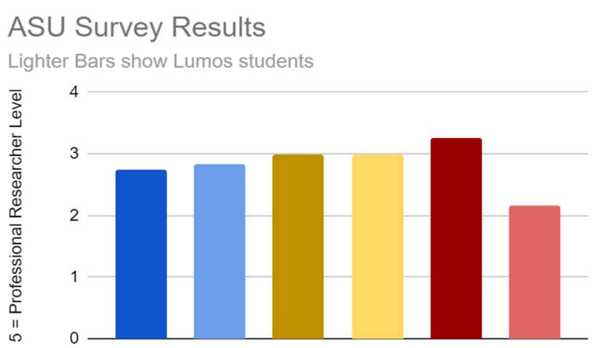
Demand continues for clear, thorough content in all grade levels. Students often comment that they need more thorough instructions from each other, and then willingly admit to providing incomplete instructions as well.

Parents and other community members were generally enthusiastic about the new program (Fig. 37). The first parent-teacher conference in September passed without complaints, some significant praise about students who had found a new passion for learning, and a few questions from parents about the grading system, or how to help their student navigate the project phases and points. The Amazon Wishlist was frequently fully emptied by parents of students, and a few parents donated significant personal equipment to specific projects. As the second quarter progressed, parent investment in the Amazon Wishlist slowed down, but investment and equipment donations from ASU and other sources picked up significantly. This might be because parents' interest was worn down by frequent updates to the list, while ASU began responding more favorably as consistent follow through gave credibility to the initial request.
Project and department leaders from ASU were also very active and available to visit the school and participate in orienting students to their projects. Visitors from ASU and other places were in the classroom every other week on average, to either present a new project to students, advise students on their current projects, or to establish plans to initiate programs with the Science department (Fig. 38). ASU collaborators who visited, or who received Lumos students for field trips were also commonly impressed with the engagement, rigor and sophistication students show in their projects.

Students were initially anxious about the program. Reports of discomfort and unfamiliarity filtered back from other teachers, as well as uncertainty about how to earn the required number of points to pass the course. Unfamiliarity with the kits, workflow, points system and web portal contributed to that anxiety. The expectation of communicating with and working on projects from ASU also gave a sense of unusually high expectations. The orientation phase did calm some of that discomfort, because students were walked through the workflow step by step and awarded points for turning in individual phases. Not all students became comfortable with the style of learning, however, and one opted out during the walkthrough. Students who are homebound are starting to access and participate in the program as of the end of the first semester, though most of the remote students have been through the in-person orientation. As the program progressed, the remaining students became more comfortable with the learning process, and many were able to offer meaningful feedback and assistance developing the learning portal, support content for projects, and workflow. That feedback and student support was used to rapidly arrange and launch the student points management system, and revamp the project portal. Some students were frustrated by the frequent updates, but by the end of the first quarter the major revisions to the learning platform were complete, and student frustration over changes to the online portals subsided. Students who had little motivation to engage in other classes would often stay after, come outside of class hours, or come in early to work on projects. This was especially the case in 9th grade Biology and 10th grade Physical Science classes, and for students who had more thoroughly developed starting points for their projects.

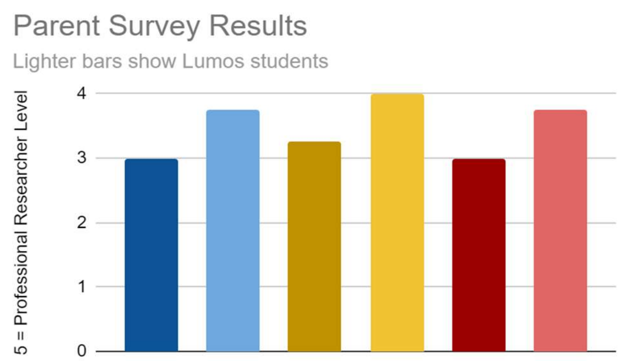
One area of student dissatisfaction at the end of the first semester was that the kits for most projects were not prebuilt, and did not include a starter scenario that reproduces the problem. Some recent feedback from students is that it would be easier for them to get invested in a project if the initial experiment was thoroughly equipped, with clear instructions for setup so that the student can see and interact with the problem from the outset, rather than trying to understand and recreate the problem and then solve it.

By the end of the first semester, two students had opted out of the program. The first opted out by the second week, preferring specifically to continue with the online video and quiz style learning system, because of the uncertainty of working in a changing, developing system. The other opted out at the beginning of the second quarter, out of frustration at the lack of conceptual content available to introduce each project with.



Blue: Science Knowledge Rating
Yellow: Experimental Skill Rating
Red: Communication Skill Rating

Fig. 39; Visitors from ASU believe Lumos students performed similarly to their own students in areas of Scientific Knowledge and Experimental Skill, but are somewhat behind in Communication Skill.



Blue: Knowledge Rating
Yellow: Experimental Skill Rating
Red: Communication Skill Rating

Fig. 40; Notice the parents agree with the ASU counterparts on two out of three categories; they believe their students are excelling in Communication Skill.

Others occasionally express frustration, but ultimately prefer to stay with the program as long as underlying concerns are addressed. Student concerns range from confusion over the points system, frustration over changing online platforms and web locations due to live development, a lack of clearly defined instructions for the start of a project, the inconvenience of not having a kit or resources when homebound, or the writing required to communicate effectively with an upcoming team. A few also expressed discomfort working with a specific team or teammate, or a dislike for the mess or overstimulation of specific labs. Aside from the two that opted out, however, all of these concerns were amenable to the system by discussing alternative team roles, projects, work phases or work methods available within the program, or through continued development of program content and resources.

VI. Public Assessment

At the end of the third quarter, a public Showcase event was held to display student projects to the school community and parents and to survey their opinion of the student work.. Several researchers and coordinators from ASU were invited to attend, and fill out the survey. The survey asked two questions about the nature of Science as a discipline, two pieces of advice for the Lumos teacher and students for their final quarter, and two ratings questions. The ratings questions produced the most unexpected results, so they will be discussed here. The questions were: "If you're a teacher, what level do your students possess of these factors (Scientific Knowledge, Experimental Skills, Communication Skills)?", and "What level do my students seem to possess (of Scientific Knowledge, Experimental Skills, Communication Skills), based on their displays?" Responses were formatted on a Likert scale of 0 to 5, with 0 being "None" and 5 being "Professional Researcher" ASU Visitor survey responses are shown in Fig. 39. Parent responses to the same survey are shown in Figure 40. In total, four parents and six ASU visitors completed the survey.

Of the ASU visitors, only three had met the students previously. The expected outcome was for ASU students to be appraised to outperform Lumos students in each category except for Communication, and for parents to agree with ASU visitors generally. However, the average response from the ASU visitors is that Lumos students are already competitive with their own college students in Science Knowledge and Experimental Skill, while lacking somewhat in Communication Skill. The parents did not agree on the communication piece, and generally rated Lumos students higher than other students they were familiar with, including in the Communication Skill category. This difference in rating between ASU visitors and Lumos parents might exist for several reasons. Lumos students have a higher prevalence of IEP and 504 documentation than the general populace, and the parents might be adjusting their rating out of consideration for student anxiety in public interaction. They might also be rating their students higher out of a personal desire to honor their own children. They might also be pleasantly surprised at the rate of improvement, and bias their opinion of achievement because of the rate of improvement.

Conversely, ASU visitors might have rated Lumos student communication skills lower by comparison because Lumos students were more anxious or awkward in their communication, as documented in their IEP's or 504's, and their level of achievement was disproportionately affected in that category due to those challenges.

One missing piece that could have clarified this survey result more, would be to determine what students the ASU visitors and parents were comparing the Lumos students to. The assumption that the ASU visitors would compare Lumos students to ASU students was not verified in the questionnaire, nor is it clear from the survey who the parents are comparing Lumos students to. However, the generally favorable response from parents, and the near-competitive appraisal versus what is likely ASU students, is admirable for the work of 7th to 11th grade students. The impact on the teacher's workload and job satisfaction were both positive. Teacher grading time has decreased, and the teacher has been able to maintain a consistently earlier quitting time than prior years, even while developing new materials and organizing events with outside groups. Parent relationships with the teacher have improved, and prospects for parallel material benefits have emerged, both for the teacher and for the classroom.

VII. Next Steps

The lessons learned drive the next steps in development for the program. While anecdotal evidence like parent material support and feedback at parent teacher conferences, student votes to return to the program, student requests to stay late to complete labs and growing ASU material support does paint a positive picture of the impact of the program, it is still just anecdotal and needs a more thorough data collection, especially of student reviews and a valid comparison of student skills versus traditionally trained students.

The strongest felt need for on-campus students is the need for content introductions in project binders, specifically in the areas of using State Standards concepts to describe the opening problem in each project, and in clear, thorough and specific instructions to set up the current lab state in each project. This would be solved by providing a ready lab kit with a report binder for each project, both as a writing sample and as an introduction to the program, where students can use the sample report's instructions to set up the first experiment from their kit, and use the results from that lab to plan out their modification, predictions, and reports for the second trial. This means when the program opens in new locations the kits must have a complete set of initial materials and instructions, with logistics available for students to order materials for modifying the kit in their modification round. This strongest felt need is the recommended next step in development for the program.

Teachers also need a more automatic, fluid system for scoring sections of a report, importing scores into the traditional letter grade format, then forwarding completed reports to the next project team. This can be solved by digitizing and centralizing all paper-based communication between students, so that AI based scoring systems, and peer review processes can be captured by the same system and used to augment the teacher's grading efforts. Specifically:

1. The Wordpress points labels need to be updated to a consistent format, and relate more intuitively to State Standards labels.
2. The points awards for each phase needs to be rebalanced to award more points for early planning portions of a project, as students tend to struggle with the planning and content search portions more than anticipated.

3. AI grading prompts need to be designed and vetted to provide valuable feedback to students when work is submitted.
4. An automatic award system needs to be built for awarding additional points to students when their work is referenced or used by a peer.
5. The orientation needs to finish by specifically clarifying the variety of roles available to students in a research environment. Many students specifically asked to become literature reviewers for projects, without knowing it was an option in the program, or how to use their background research to lead into a set of instructions for other students.

Kit containers and contents documentation needs to be standardized, so that kit exchanges, storage and content checks can be swifter and more student-led. Kits need to be ready with materials checklists when given to students, with room for students to add items to the materials checklist.

Kits also need to be provided in an initial state with clear instructions to reproduce the problem to be solved, so that students have a functional introduction to the stage that the project is at, and a starting point for their investigation and modifications to the kit. The ideal case is that kits would be returned with an updated binder as is, without disassembly, by the prior researcher, so that the exact condition the prior student achieved is represented to the next student accurately.

The orientation phase of the program needs to be made more robust, including a teacher demonstration of how to complete each phase of a project. Specifically:

1. The orientation needs to include more specific training in how to write lab instructions for peers.
2. The orientation needs to include teacher demonstrations of how to research, describe and illustrate phenomena active in a kit, and explicitly assign the same observation, research and description activities to students before they are allowed to pursue modification.
3. The orientation needs to include more specific examples of well-written reports, with an explanation of how the reports fulfill needs of peers and of State Standards content.
4. The orientation needs to clearly specify the differences between traditional learning and working in a research environment, and the goal of getting your work noticed and used by others.

The user guide also needs to be edited for clarity and effectiveness. There are portions of the guides that students still don’t find relevant, and there are categories of writing that peers frequently require from each other that are not addressed in the evaluation guides.

The program, as it is laid out, seems to be inherently most compatible with homeschool groups, remote learners, credit recovery programs, and other venues that do not monitor seat time or manage strict deadlines. The open discovery nature of true research, and the ebb and flow of experiment timelines makes this program a strong fit for students who already know how to manage their own learning, or struggle to maintain a bell schedule. This means a distributed logistics system for the kits is key for developing and scaling the program sustainably.

The strongest felt need for online students is a dedicated instructor for online collaboration, and a more robustly developed online content and kit access system. As of January 2024, there is no orientation system or logistics available for engaging online students in the kit exchange system. Inquiries have been made to libraries and community centers, as well as Graduation Solutions hubs, and the majority of locations contacted have expressed interest in hosting kits for the program, but the system has not been set up yet to provide consistent, convenient access to remote students.

Local libraries that were canvassed have expressed interest in storing and distributing STEM kits, and many already have STEM programs built into their budget, as it is a known area of interest for communities that frequent libraries. This future expansion to distributed community learning means that the kits will need to be transported between hubs regularly for students to pick up and drop off, and the most successful student modifications to kits will need to be updated in every hub's kits through a version control system.

Lastly, the scalability of the program is dependent on the continued development of well-designed STEM kits with binders and exchange websites, and the logistics required to stock and maintain the kits in multiple locations. For early stage development, offering the kits through local exchanges around Arizona is the most effective next step, and then establishing chapters in other states to run local exchanges.

For any process or tool to perform well, it needs to be designed with the end in mind. The end goal of any Science class, from Elementary to Professional, could be aimed at creating highly trained, professional researchers. If that is the foundation for choosing how to design a course, it becomes readily apparent what skills, and in what context and sequence, a student should learn, at any age or in any setting, whether remote or in-person. This first attempt at building a Science curriculum from inspiration like CBBG and SenSIP RET's for Secondary students, produced results that shows there are several major gains possible in student achievement, engagement and satisfaction when the goal of the course is clear, and doesn't change. As Rick Stiggins said, "Students can hit any target that they know about and that stands still for them."

VIII. References

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