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Designing Effective Student-directed Research Experiences for High School Students (Work in Progress)

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INTRODUCTION

As global growth accelerates in science and technology (S&T) fields, the US is increasing its funding for extracurricular educational science, technology, engineering, and mathematics (STEM) programs at the K-12 level [1]. High school summer research programs are becoming more common as studies show the benefits these programs can have on high school students' interests in STEM fields and their eventual enrollment in STEM majors [2]–[7]. These programs involve bringing high school students to a university campus and providing them with a research experience, guided by a faculty member, over several weeks during the summer. However, the implementation of hands-on, research intensive programs for high school students can be difficult for several reasons.

One obstacle is the wide gap between high school students' current knowledge and the level of research being done at universities. This gap can create issues when scoping out a project and creating an opportunity for students to gain an authentic research experience (i.e., learn about the research process and obtain valuable research results) [8]–[10]. An additional obstacle is the amount of time university researchers need to commit to catching students up on a particular research topic. This creates less time for students be involved in the research project and may ultimately lead to students feeling left out of the research community and removing them from the STEM pipeline.

We contend that these highly motivated high school students can be exposed to ideas in a field and be engaged in meaningful research that serves the wider research community. Specifically, our approach involves having students work on research projects that focuses on the development of pre-college curriculum or STEM outreach activities that are relevant to the research mentors' work. Within this structure students gain valuable research and development skills, but at a level that is appropriate for their age level while reducing the projects costs and ensuring safety of students. This is of value to many federally funded researchers, as they are often looking for ways to add a broader impact component to their research projects. In a way this approach "kills two birds with one stone:" provides students an authentic research project and produces pre-college activities relevant to cutting edge research. Here we share several approaches used by the authors to create authentic high school research projects that meets the students at their current level of knowledge. Our last example provides initial data exploring the effectiveness of this approach in improving students' scientific identity, understanding how to ask and answer questions, confidence in pursing STEM degrees. The evaluation approach utilized in this study is Values-Engaged, Educative (VEE) evaluation approach [11].

APPROACH

Starting with a research topic being explored in an academic environment, we have identified three general strategies that can be used to design a high school research project, which can then be used to create formal, in classroom curriculum (Figure 1). The first involves simplifying a process or device used in a research laboratory using safe, classroom friendly materials. The second is exploring a recent advancement from the research laboratory such as investigating a new product or device. The third is distilling a complex principle used in a research environment to a fundamental phenomenon that can be replicated in the classroom. All three strategies pull from the field in different ways and provide examples of how inquiry-based high school research projects and curriculum can be designed.

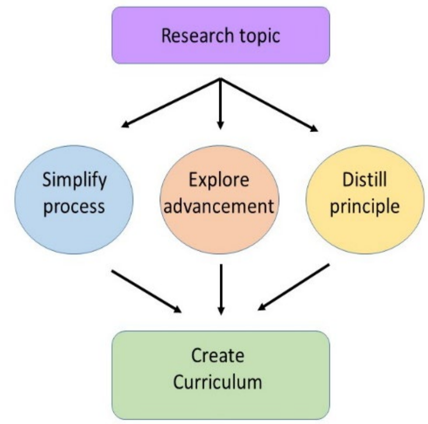

Figure 1. Approaches that can be used in student research

Redesigning or Simplifying a Process or Device

The first strategy is to take a research process or device and have the student researcher try to redesign it to be classroom friendly. Students are challenged to use inexpensive, off-the-shelf components, including replacing toxic or dangerous chemicals with safe alternatives. While research processes or devices often require expensive materials to maintain robust performance, the simplified, classroom version, does not require the same high fidelity or accuracy.

One example includes an effort by student researchers to simplify the stereolithography process for incorporation into a classroom setting [12]. Stereolithography is a 3D printing technology used to create small structures with submicron features using light to polymerizes monomers and oligomers [13]. These structures are so small, they are not visible to the naked eye. The student team's adaptation took the ideas from this process and made objects that were larger and could be held (Figure 2a). The first change was to replace the laser system with a data projector. This change allowed the light to easily display in two dimensions instead of using a laser and mirrors under precise control to trace a path. PowerPoint was used to create the images that were then displayed on the projector, where the color black represented areas where no polymerization was desired. Although the cost of a data projector is not insignificant, many schools have them available. Students were also challenged with not drastically modifying the projector, as it might be needed for regular classroom use. Because the project image needed to be modified to focus on a small area, roughly an inch by an inch, a student determined the focal length needed and location to place a magnifying glass in front of the lens that allowed the focus knobs on the projector to be rotated and produce the small in-focus image. A mirror was then placed to project the image down on the table instead of straight ahead onto a wall to enable polymerization of a thin layer of a solution onto a glass slide. Next, to create a 3D object, another student created a stage that could be lowered into a beaker of the polymer as each layer was made. They had to design the device to lower the stage a short distance. Students used a commercially available drawer slide attached to a threaded rod to allow the precise, fine movement of the stage (Figure

2b). After some trials, the students developed a very effective system to 3D print with classroom avaliable materials that was later finalized into curriculum [14], [15].

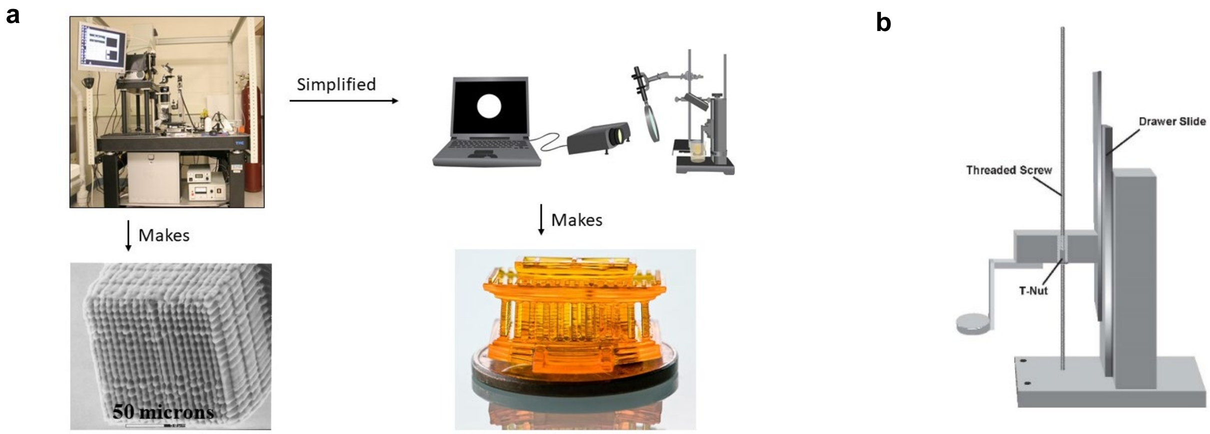

Figure 2. a) Stereolithography set up on top left corner makes submicron structures in a laboratory environment. Students simplified this process using a data projector to make a Lincoln memorial replica, sitting on a penny for scale. b) Stage device students created to allow a slide to lower into the polymer solution as the 3D object polymerized.

Explore an Advancement in a Field

A second strategy is to use an advancement in a field to expose students to a new development and generate interest. One example is the development of an easy and rapid technique to create silver nanoparticles. Several companies use silver nanoparticles in their manufacturing to confer antibacterial properties to products such as food containers that help preserve food or clothing that resists the unpleasant odors caused by microorganisms. The question the student investigated was: Is this marketing hype or do these products actually work? In turn, student researchers developed a straightforward procedure for testing the antibacterial properties of various commercially avaliable products. This eventually led to the development of a high school lab activity where students could test these particles and design a simple experiment to see if the silver nanoparticles suppressed bacterial growth compared to a control [16], [17].

Distill a Principle Used in a Device or Area of Research

The third strategy involves distilling a principle used in some device or area of research into a phenomenon that students can explore in the classroom, such as an atomic force microscope (AFM). AFM can capture images of objects smaller than the wavelength of light by using some imaging tricks to amplify the signal from the probe. If a small movement changes the angle a signal, such as from a laser, then that change can be amplified if the distance between the signal and detector is increased (Figure 3a). To teach this concept in the classroom in a more tangible manner, two students used this same trick to measure how much a wall deflects when it is pushed on. They taped a metal rod to a wall using strong double sided carpet tape. The rod was allowed to move freely on a table by being placed on small pins that would rotate as the rod moves relative to the table. To one of the pins, a mirror was attached, and a laser pointed at a mirror. As the rod moved, the pin with the mirror attached would rotate, and the laser light would be deflected. If the light struck a screen opposite the mirror, the small change due to the deflection can be measured by the amount of rotation of the pin, and therefore the amount the rod moved would be determined. A similar activity was subsequently developed for the classroom [18] (Figure 3b).

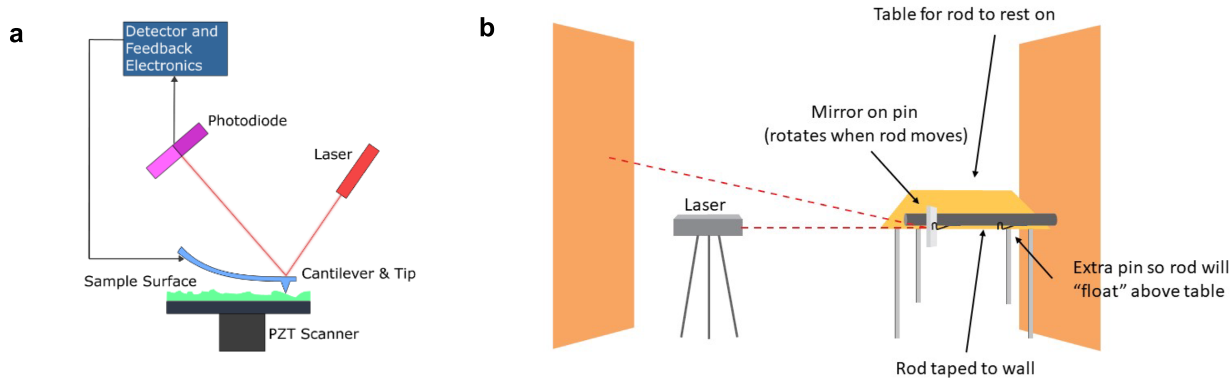

Figure 3. a) An AFM generates images by scanning a small cantilever over the surface of a sample. The cantilever bends as it moves over a surface, displacing the laser which can be measured to image the surface. b) Student-designed setup to determined movement of a wall using classroom avaliable equipment.

Create Curriculum

After a single summer, high school researchers are often able to create an activity that is ready with only a few minor modifications for classroom implementation. If this is not the case, a new team of student researchers can be brought in the following summer to pick up where the last group of students left off. To prepare the activity for implementation, pre-college teachers can be brought in to design appropriate curriculum around the activity and test it with their class. When curriculum does not strongly align with Next Generation Science Standards [19], the activities can be used in afterschool programs, summer camps, or other outreach efforts. These activities have helped deepen relationships between the university sponsoring the high school research program and the local schools, as the university is not only providing a research experience for students, but also helping teachers integrate cutting-edge, accessible research concepts into their curriculum.

RESULTS

One of these approaches, distill a principle in a device, has been evaluated over the last two years (2020 & 2021) in a remote work setting and the results are encouraging, although more participant data is needed to be statistically significant. For this study student teams worked with SunBuckets [20], a startup that uses parabolic dishes to concentrate solar energy into a box that contains phase change materials which in turn holds the internal temperature constant as a material changes phase. Students were tasked with using the stored heat to create a room heater for locations without access to reliable electricity. The societal implications of such an inexpensive product that held the potential to significantly improve the quality of life of many people is very motivating to many students. A pre-program and post-program survey were given to student researchers. The survey found slight increases in students’ attitudes toward STEM and their scientific identity on several measures (Figure 4). More data is needed to make conclusions on this approaches ability to increase students understanding of the nature of scientific inquiry [21].

DISCUSSION

These approaches allow for several advantages for the researcher and the high school student. From the researcher side, projects created using these approaches can serve as a basis for pre-college curriculum development and outreach activities. This is of value to many federally

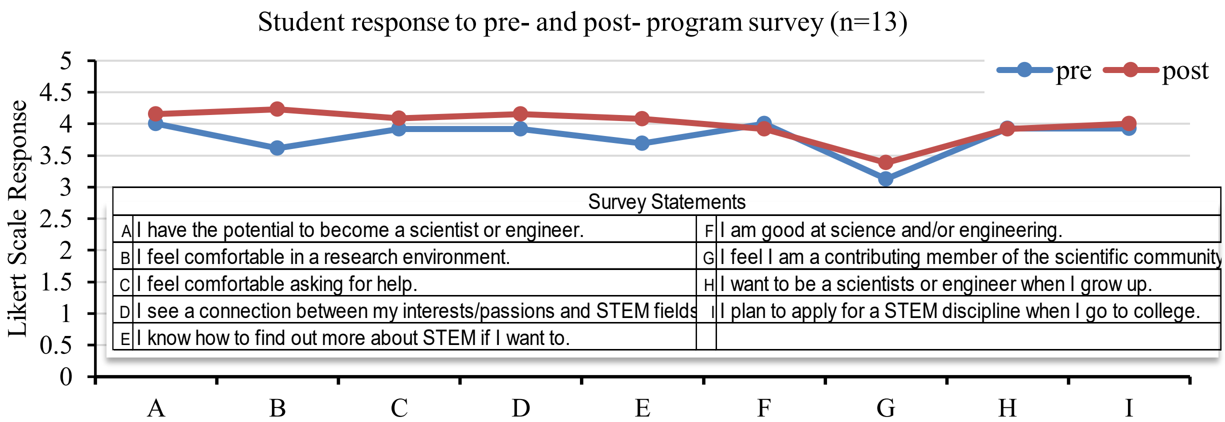

Figure 4. Program participants' responses to pre- and post-program survey.

funded researchers, as they are often looking for ways to add a broader impact component to their research projects. The cost of these projects is as low to the host research group, as the projects use relatively inexpensive and commonly available equipment and materials. This means that there is less concern that the high school student researcher will damage a laboratory device or use up expensive materials. The supplies and chemicals being used for projects are designed to be safe for pre-college students. Last, due to the nature of these projects, precision and reliability of materials or final product is less demanding, moving the focus to student learning outcomes vs. research outcomes.

Developing a pre-college curriculum or outreach activity within a context of a research project also has many advantages for pre-college students. The approaches to creating high school research projects here are not creating merely "toy" research projects but, instead, real research that directly feeds into the important goal broadening the engineering education pipeline. Reliability of research-led outreach activities increase with this approach as students are actively testing their use among their student team. In addition, pre-college students are excited and motivated by the thought that what they are doing will help their peers in the years to come.

These types of research projects also allow students to do meaningful research as they work remotely, and programs can reach many students who do not have access to universities locally. Through virtual meeting spaces such as Zoom, students can collaborate with a research team while working from home. Supplies can be dropped off and products can be collected by car or be mailed. Students can design structures to be 3D printed and these can be fabricated and then delivered to the students. These logistics allowed us to widen the geographic area from which we pulled pre-college researchers from, allowing a state-wide reach in our case. But each research group can decide where they want to find pre-college researchers.

CONCLUSIONS

The possibilities are vast for involving pre-college students in meaningful research that they can be conducted safely and effectively. The results are useful if the researchers pass the results on to teachers and other pre-college educators to engage the general public. The students understand how a research problem is attacked and can see how results can build on previous work as they solve the next step in a process. This approach also effectively introduces students to STEM and prepares them for more focused and extensive research in the future.

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