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Full STEAM Ahead with the NASA Opportunities in Visualization, Art, and Science (NOVAS) Program

Daniel Zevin,[1] Steve Croft,[2] Leitha Thrall,[1] Matthew Fillingim,[1] and Lynette R. Cook[3]

[1]*Multiverse, Space Sciences Laboratory, U.C. Berkeley, Berkeley, California, USA;* `dzevin@ssl.berkeley.edu`

[2]*Astronomy Department,U.C. Berkeley, Berkeley, California, USA*

[3]*Fine Artist/Illustrator, Daly City, California, USA;*
`http://extrasolar.spaceart.org`

Abstract. There has been increasing interest in the use of art as a new tool in the teaching of Science, Technology, Engineering, and Mathematics (STEM). The concept has received major consideration by our federal government, design colleges, art institutes, and leading universities. Many have, in fact, fully embraced this concept, and it's not unusual today to see "Art" added to STEM to get STEAM. On August 5, 2014, the NASA-funded NASA Opportunities in Visualization, Art, and Science (NOVAS) program team provided a professional development workshop at the Astronomical Society of the Pacific's 2014 Annual Meeting. In this two-hour workshop, participants learned about the rise of STEAM and were shown valuable skills and techniques used by the NOVAS program for the application of STEAM in a variety of out-of-school time (OST) settings. The workshop highlighted how OST and other informal educators can use art and digital media to help teach about current, cutting-edge STEM investigations, and why scientists need artists to help visualize and communicate their research. Although NASA science and project outcomes from the NOVAS program were emphasized, participants also discussed how NOVAS' methodologies could be applied to other STEM subjects and OST formats.

1. The Rise of STEAM Education in the United States

Practically all purveyors of Science, Technology, Engineering, and Mathematics (STEM) education in the United States have by now seen the word "Art" added to the STEM acronym to get STEAM. At its core, the idea is that doing art helps spark creativity and innovation, two of the most vital ingredients for advancing STEM research to new levels of both discovery and economic progress. And by using art to investigate STEM in the classroom (which also includes a focus on design and the use of digital technology), we can give our children an advantage when it comes to becoming the next leaders of the emerging STEM-centered workforce. Two of the most prominent education institutions that first promoted a STEAM approach nationally include the Rhode Island School of Design (Maeda 2012) and the National Science Teachers Association (Shapiro 2010). The National Science Foundation propelled the national STEAM movement even further and helped consolidate much of the research on STEAM education to date when in 2011 it launched "The Art of Science Learning" initiative.[1] The STEAM trend has even reached our universities, where research scientists, artists, and their students are now being urged to collaborate in the lab, field, and studio, and to look at and benefit from commonalities in their practice (Wong 2014).

2. The NASA Opportunities in Visualization, Art, and Science Program

2.1. Program Design and Objectives

Led by members of the University of California, Berkeley's Multiverse team at the Space Sciences Laboratory,[2] in partnership with UC Berkeley Astronomy, NASA Opportunities in Visualization, Art, and Science (NOVAS) is a NASA-funded STEAM-based program mainly for high school students that explores NASA science through art. NOVAS started in June 2012 and is expected to continue fully funded at least through May 2015. The project's overall aim is to motivate more diverse young people, especially African Americans (who make up to 30% of the populations in the communities surrounding the UC Berkeley campus, but less than 2% of the UC Berkeley STEM student body), to consider STEM majors and careers. However, unlike many other STEAM efforts that go no further than using art projects as a means to explore and learn more about STEM topics, NOVAS is somewhat unusual in that it also highlights the need for and uses of art and visualizations in science. Scientists, engineers, and others in STEM fields have long understood that data and scientific concepts can often be more easily communicated through images, illustrations, models, simulations, and other artistic representations. Thus, when discussing potential STEM futures with participating youth, the NOVAS program team is always sure to point out the truly vast array of possible careers in STEM, including those that are available to artists and/or graphic designers who help scientists and others visualize and communicate their work, in addition to jobs that are focused on conducting research and/or solving engineering challenges.

2.2. Program Offerings

The NOVAS program engages high school students and others in the following ways:

- **Summer Workshops:** These workshops take place each summer for six to seven hours a day, three days a week, for three weeks. NOVAS summer workshops are held at local youth centers such as the YMCA-PG&E Teen Center in Berkeley, California,[3] and more recently, at the RYSE Youth Center in Richmond, California.[4] Each workshop session focuses on one science and/or engineering design concept, then explores that concept through art and/or multimedia projects and real-world examples of visualizations on the topic. There is also often a continuity of science themes throughout sessions; for example, from supernovae to

[1] `http://www.artofsciencelearning.org`

[2] `http://multiverse.ssl.berkeley.edu/`

[3] `http://ymca-cba.org/locations/ymca-pge-teen-center`

[4] `http://www.rysecenter.org`

elements to planet formation to the search for life. Art and visualization techniques and tools used by students span a wide spectrum and include: painting, sculpture, drawing, CAD images, 3D printing, green screen filming, stop-motion animation, video editing, and sound recording. Students always have a chance to present their artworks and digital creations at the end of each session. Each summer workshop also includes at least two daylong field trips, which have thus far included visits to UC Berkeley, the Exploratorium,[5] NASA Ames Research Center, and the Chabot Space & Science Center.[6]

- **Afterschool Workshops:** Each spring for about 40 hours total (plus an additional 8–16 hours of optional field trip time), NOVAS offers afterschool programs through partnerships with community centers and high schools. More recently, we've been offering these workshops at REALM Charter School in Berkeley, California.[7] These sessions are far less intensive than our summer workshop offerings, but allow us to pilot test new program ideas. For example, in May 2014, we incorporated aspects of the Maker Movement (Bajarin 2014) into a project at REALM that had all students working together to launch a high altitude balloon to the edge of space. Students were assigned to three main teams for the project: building and launching; public relations and 3D mission patch design and printing; and documentary filming and video editing.

- **Internship and Community Outreach**: After participating in one of our workshops, participating youth are invited to become NOVAS interns. Interns assist the NOVAS team with running our summer and afterschool workshops, and during the school year meet on the UC Berkeley campus for approximately two and a half hours each week (and for occasional field trips) to get more in-depth scientific illustration and other STEM visualization training. NOVAS interns also assist with community outreach programming. For these efforts, we train our interns how to operate telescopes and run hands-on activities, including many of the arts- and digital media-based activities we offer during our workshops. Interns thus far have helped us with three star parties, a special family day event at the California Academy of Sciences,[8] three "Teen Science Nights" at local science museums, and presented their artworks at two UC Berkeley "Art and Science" gallery exhibitions.

- **Educator Professional Development**: We have been summarizing the NOVAS model and what we have learned through NOVAS to date and presenting this information to other OST educators and middle and high school teachers. Our educator professional development (PD) workshops usually take place over a two-day period, in part, to provide educators with hands-on, in-depth training on how to use certain art techniques and multimedia tools in the teaching of STEM. But we are also learning more about the emergence and expansion of STEAM

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[5] `http://www.exploratorium.edu`

[6] `http://www.chabotspace.org`

[7] `http://www.realmcharterschool.org`

[8] `http://www.calacademy.org`

education in our communities through these experiences as well, as most educators who come to our workshops have at least some STEAM knowledge and skills of their own to share. For example, one of our recent PD participants operates his own 3D printing service for schools and OST programs. Partly through him, we learned about a great surge in 3D printers being used for STEM education purposes. We also had this particular educator come to one of our NOVAS intern meetings to teach our interns new skills for designing 3D models, and print out their own 3D creations. Thus, the NOVAS PD workshops are also providing new networking and collaboration opportunities in the San Francisco Bay Area. To keep the communication and momentum going, we launched a new STEAM listserv for educators.[9]

2.3. Program Website

The NOVAS website[10] is used mainly to showcase the program and our participants' artwork, including their digital media creations. A web tool called RebelMouse also allows participating youth, or anyone else who wants to connect with NOVAS for that matter, to contribute content to the site via social media as often as they wish. RebelMouse constantly seeks out the `#nasanovas` and other key hashtags from posts through applications such Instagram[11] and Twitter[12] and then stores them for the NOVAS team to review. Once approved, these social media posts go directly to our website's home page. RebelMouse is free to use, and the NOVAS team encourages other STEM/STEAM education organizations, programs, and individuals to try it on their own websites.[13]

2.4. Program Evaluation and Participant Response

Formative evaluation results of NOVAS to date, provided by the Research Group at the Lawrence Hall of Science,[14] have been exceedingly positive. Overall, summer and afterschool workshop participants have enjoyed the workshops and field trips and have felt that their expectations for the program were met. Even participants who started the program with a strong interest and self-confidence in science and/or science visualization indicated that their knowledge, interests, and abilities increased in many ways as a result of participating in NOVAS. Interns have also largely enjoyed the internship experience, though many asked for even more in-depth training in scientific illustration and/or visualization skills and techniques (something that the team is concentrating on during the 2014–2015 school year). Emerging themes from the program evaluation in general are as follows:

- Participants report that they really enjoy the art projects;

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[9]If you are in the Bay Area and would like to sign up, go to `http://tinyurl.com/baysteam`.

[10]`http://www.nasanovas.org`

[11]`http://www.instagram.com`

[12]`htttp://www.twitter.com`

[13]More information can be found at `http://www.RebelMouse.com`.

[14]`http://www.lawrencehallofscience.org/services_and_expertise/research_group`

- Participants report increased positive attitudes towards science or science visualization;
- Participants report increased interest in science or science visualization;
- In general, it appears that students who may not have an affinity for STEM subject matter can be better engaged in STEM through art and have fun while learning STEM concepts; and
- Teens who disliked or struggled with STEM subjects had a better attitude towards and interest in STEM fields after participating in NOVAS.

Comments about NOVAS captured on youth surveys and sent to us via emails from parents and partner educators have also helped to demonstrate the impact of the NOVAS program. The remarks have included the following statements:

> "The whole summer session explained the whole universe more clearly to me than the average school portrayal of the solar system and milky way."—NOVAS summer youth participant

> "Just wanted to thank... the whole [NOVAS team] for a fantastic program. [My son] had an amazing time, learned so much and made friends with a bunch of great kids. We, as parents, were at the receiving end of all the positive energy that you have generated these past few weeks. Thank you for this great experience. Can't wait for more."—parent of a NOVAS summer youth participant

> "... I wanted to let you know that some of the students who are coming to [the workshops] have improved in their classroom grades since starting the program! I think the experience they are having is encouraging them that science and art can be fun, interesting, and educational!"—high school teacher of NOVAS afterschool participants

3. NOVAS PD Workshop at the ASP 2014 Annual Meeting

On August 5, 2014, the NOVAS program team provided a PD workshop at the Astronomical Society of the Pacific's (ASP) 2014 Annual Meeting. Although in this particular case we were only able to offer a two-hour workshop rather than our regular two-day PD experience, and much of the usual hands-on experience was eliminated, participants still learned much about the NOVAS program's particular STEAM approach, the program's offerings, and how to make similar use of the methodologies used by the NOVAS program for the application of STEAM in a variety of out-of-school time (OST) settings. The remainder of this paper will focus on the learning activities highlighted during the August workshop. These particular activities were chosen because they have consistently proven to be enjoyed and highly valued by high school students participating in NOVAS summer and afterschool workshops.

3.1. Working with Scientific Illustrators and Other Visualization Experts

By collaborating with professional scientific illustrators and other STEM visualization experts and having them present and work directly with students in your classroom or OST program, you'll have someone speaking and demonstrating from firsthand experience with your students what it means to be a professional artist working in STEM and with STEM researchers. Reaching out to local universities or media outlets that cover STEM in the news may be one way to find these professionals in your area. You can also search scientific illustrator networks online, such as the Guild Of Natural Science Illustrators[15] or Science-Art.com.[16] Always spend some time, at least one or two meetings, with the artist you plan to work with before inviting him or her to meet with your students. You'll want to develop a detailed agenda of who's doing what and when during the time spent with your students, and gather all necessary supplies beforehand. NOVAS has been partnering with such experts since the program's inception, most notably with renowned scientific illustrator Lynette Cook, who is known mainly for her illustrations of newly discovered exoplanets.[17] Working with Lynette, we developed a simple, yet extremely successful structure for her visits with our students. These sessions have lasted up to six hours, and normally proceed as follows:

1. First, students are introduced to the concept of exoplanets and their detection. For NOVAS, we have the luxury of having professional astronomers and astronomy educators on our team to tackle this part. If possible, especially if session time is a factor, you should try to do this introduction (or at least part of it) a session beforehand, just prior to your illustrator's visit, especially so that you can have your students explore exoplanet science through hands-on activities. The ASP[18] and NASA[19] websites provide good resources for such lessons and activities. For other STEM topics, be sure your students have some familiarity with the concept(s) before the illustrator's visit.

2. Next, your students will create their own illustrations in the same manner as demonstrated. Be sure each student workstation is set up ahead of time, or that supplies are in a central place and easy to gather. If you are concerned about keeping your tables, desks, and floors clean, cover them with plastic wrap, butcher paper, or some other protective material. Provide aprons for students who want them (though tell them ahead of time to wear old clothes they don't mind getting dirty for this session). If possible, have students illustrate something from actual scientific data, or at least a scientific description of the object in question, just like the illustrator did. For example, we have each NOVAS student draw from a hat a short 1–2 paragraph description of a different exoplanet (though there are only four to five exoplanet descriptions for about 25 students). The students then create small thumbnail sketches to visualize their planet in relationship to its parent star or stars, trying different arrangements so they can decide which one they

[15] http://www.gnsi.org

[16] http://www.science-art.com

[17] See http://extrasolar.spaceart.org

[18] http://www.astrosociety.org/edu/publications/tnl/76/76.html

[19] http://kepler.nasa.gov/education/activities

want to actually paint (which happens on canvas board). The invited artist may roam around the room at this time to offer advice or help when needed. The artist can also continue to work on an example illustration in a central location, but invite students to come up with their artworks to ask questions.

3. Give students at least two hours to create detailed illustrations. In NOVAS, we have found that most students will take the time needed to paint their exoplanets as well as they possibly can, and they will spend time with the illustrator and other members of the team to get all the details correct (such as apparent distance to star, and the day and night sides of the planet). If they finish early, suggest additional features they can add to their illustrations. For exoplanets, such additions can include moons, evidence of intelligent life, or the galactic plane further out in space (i.e., the Milky Way). Alternatively, they can start painting another planet (or let them know they will need to start cleaning their area, which might also keep them motivated to continue painting as long as possible).

4. When students complete their illustration, have them sign and date their work, and if possible, attach their printed scientific description on the back of their illustration for reference (especially for when they share their work with friends and family). At the end of the session, have all students come up and present their artwork. Encourage them to talk about their particular assignment and how they decided to tackle it. For NOVAS, we bring students up in groups based upon which exoplanet they were assigned. The class will see how each student used a different approach in their illustration and were able to use their own artistic license to be different, yet still scientifically accurate.

3.2. Stop-Motion Animation

Stop-motion animation can be a fun way for students to explore any STEM topic. In NOVAS, we have students work in teams of three or four, and each team animates the main stages of a different NASA space mission (e.g., launch, instrument deployment, data collection, and discovery). Stop-motion animation comes in many forms (e.g., clay, paper, drawing, etc., or any combination of these forms), and it's a good idea to provide your students with an overview of the different formats ahead of time. A simple search on YouTube[20] will bring up many examples. Let your students know exactly what it is you want animated, but allow enough flexibility for creativity and self-guided topic exploration. They also need to know what supplies you have available for them and how they will gain the knowledge necessary to complete their animations. In NOVAS, we give our students access to the Internet to research their assignments in more detail. Have students storyboard their animations before they begin filming. Show them some examples of simple storyboarding, and how storyboards are very similar to comic books. Make sure they include a title frame and some type of end/credits/date made frame(s).

The key to a successful stop-motion animation activity is easy to use hardware /software and a simple, flexible setup. For software, we prefer the freeware Frame-By-Frame for Mac computers, which is available for download.[21] Alternatively, for PC

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[20] `http://www.youtube.com`

[21] `http://sourceforge.net/projects/framebyframe/`

computers, you can use MonkeyJam.[22] For each program, follow the simple online instructions and give your students a quick demonstration before they begin. [Tip: Every time you record a new animation frame in these programs, a file will be saved on your computer. Have your students setup a separate folder for this purpose so that the program being used saves each frame there. Students will also have to manually save their entire projects. Encourage your students to save their projects as often as possible!]

A camera is also needed to create stop-motion animations, and a webcam is what most stop-motion animation software programs will search for to use. External webcams are the easiest to use, especially because it's most likely the supplies your students will manipulate to create their animations (e.g., clay, paper, etc.) will be set on tables or desks. Thus, having an external webcam that can easily be setup above the animation "stage" (i.e., the total area captured by the camera) is best. In NOVAS, our webcam setup consists of a tabletop stand (Figure 1). Start with a 36" wooden dowel with three to four small nails randomly hammered in on the lowest section of the rod just above one end. The nail end is placed in a bucket ¾ full of plaster. The nails act as an anchor for the dowel, in the event you lift the stand by the dowel and not the bucket handle. Next, create a moveable arm that can be attached to the other end of the dowel. Start with hobby board (4" × ¼" × 24–30") with a hole drilled that is the same diameter as the dowel, centered at approximately 3" from the end of the board. This allows the arm to slide up and down the dowel and remain stationary when at rest. The webcam can now be attached to the end of the board and point down to the background or "stage" area on the table. Try to find a webcam with lights and a manual focusing feature. We chose the Kinobo B3 USB Webcam with 6.0 megapixels, mic, LED lights, and small metal stand for Xp/Vista/Windows 7. This particular webcam can be removed from its stand and can easily clip to the end of the hobby board. If you have a different webcam model, you may use masking tape or other creative ways to attach it securely to the board, but make sure there is a clear, unimpeded view looking down on the workspace. Having the hobby board arm move up and down the dowel also helps focus the webcam for either close ups or a wider view.

3.3. Simulation Videos Using Green Screen

Creating videos using green screen technology is a great way to engage your students artistically at many levels. Also known as chroma keying, it consists of filming video in front of a colored backdrop (usually green, although blue screens are sometimes used instead). Professional chroma keying is used in broadcast television (for example, in weather reports where the presenter appears in front of a computer map), but inexpensive green screen setups are also available for educational use. In NOVAS, we used a green screen kit purchased online for around $150. This consists of a green cloth backdrop which hangs from extendable stands, as well as two bright lights on stands with lighting umbrellas attached to soften the light (Figure 2). Some educators are using even simpler and cheaper setups such as green construction paper and spotlights. More expensive kits are available too, and with a studio setup, a whole wall could be painted green and professional stage lighting used.

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[22] available at `http://monkeyjam.org`

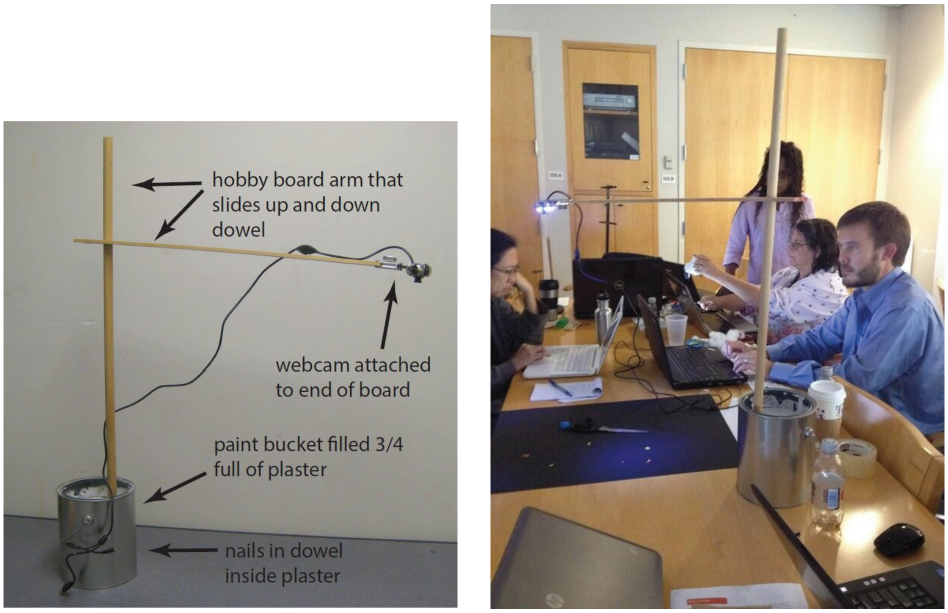

Figure 1. NOVAS stop-motion webcam stand setup and example of use.

We have used our setup in two main ways. Firstly, we have set it up like a photo booth at outreach events. The Photo Booth software on a Mac computer includes a number of special effects, from distorting the image from the camera to adding photo backdrops. A green screen is not strictly necessary for this; the user steps out of the frame and the computer identifies the stationary background and replaces it with a photo. Then when the user steps in front of the camera again, they appear in front of the chosen backdrop. Having proper lighting is important though, and using our green screen setup has produced good results, as well as appearing more enticing to visitors to our booth than just a laptop and webcam. By linking Photo Booth to Mac Mail, we send our booth visitors a photograph of themselves apparently on the surface of Mars (or some other location in space) including a link to the NOVAS webpage for further information about our program. Visitors can pose with a selection of props including space suits and other items.

In our youth workshops, we use the green screen kit for a longer video activity. Here the backdrop is applied afterwards rather than in real time. Live green screen video software is available but expensive, although there are some apps for iOS and Android that provide a quicker and cheaper alternative. For our setup, participants create their own props, storyboard, and script, and then act out their scenes in front of the green screen. The screen itself is illuminated by the umbrella lights, which are placed to the side, out of the shot, facing the screen. The actors are illuminated by a third light overhead. You may need to experiment with lighting positions for best results, as eliminating shadows is important for accurate background subtraction. The video can be filmed with a built-in laptop camera or webcam, but you may get better results with a digital SLR set to video mode or a video camera. Once you have your digital video files, import them into your video editing software. On a Mac, iMovie has a green screen option. This is not enabled by default but requires you to switch on “Advanced Tools” in

Figure 2. Typical NOVAS green screen setup.

preferences. The green backdrop in your clip can then be replaced with a still image, a second video, or an animated backdrop. Detailed instructions are available in a number of locations online, and a number of other programs, including Adobe Premiere, can also perform chroma keying. The green screen assignment we give our youth is to imagine a human colony on Mars and produce a promotional video set at a time in the future when mass colonization of Mars has begun. After learning about conditions on Mars, as well as Martian landscapes and "visitor attractions" such as Olympus Mons and Valles Marineris, they produce a short video commercial encouraging their peers to join them in leaving Earth to colonize the Solar System. Teens have a lot of fun with this project, designing props such as a "Marserati" car, as well as reassuring their peers that Wi-Fi service on Mars is fast and easily available, as are their favorite fast food restaurants. However, they also learn a lot about Mars and the challenges humans will face to survive there, including extracting water from the Martian ice caps and dealing with the thin atmosphere and low temperatures.

3.4. Tinkercad

Tinkercad[23] is a free, online prototyping tool for designing just about any object one can imagine. It also allows you to save your object as a .stl file that can be printed on a 3D printer. It's a great way to get students to be creative and approach design projects like real engineers. It is easy to learn and there are tutorials that will help you with

[23] `https://tinkercad.com`

the design process. The tutorials are geared toward beginners and teach the necessary application basics before moving on to more complex modeling techniques. However, it is advisable to go through the tutorials and use the application yourself before you have your students take on the Tinkercad challenge. We have found a few minor bugs and unclear sections in some of these tutorials that you'll want to be familiar with ahead of time. Once you are comfortable with the workings of Tinkercad, you can give your students a simple demonstration while they follow along at their own computers. Afterward, let them loose to simply play and experiment with the application first for at least a half hour.

Once you feel your students are getting a good sense for how to use Tinkercad, you can give them a design assignment. For NOVAS, we've had our students tackle a number of different projects with Tinkercad. One such assignment was to design a 3D "mission patch" for a high altitude balloon launch (Figure 3). We then printed their patches on a 3D printer at our laboratory. Such printers are becoming more and more common, and thus to find one for your own use, you might start by checking with your local science center, museum, or university for possible access. There are also numerous 3D printing services that can be found online. Some provide local support while others offer online file uploading and mailing of your printed objects. Because Tinkercad is a web-based application, you can also easily share your projects just by copying the link. In addition, Tinkercad users can access each other's designs and develop them further, thus allowing your students to work on projects collaboratively and easily share projects.

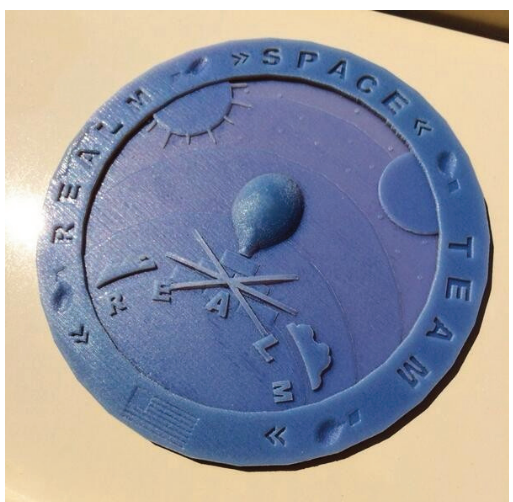

Figure 3. Mission patch created by a NOVAS student using Tinkercad.

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