Teacher protocol - High school 3D plant modeling

The Project

The Education Research and Outreach Lab at the Donald Danforth Plant Science Center offers opportunities to high school students to promote science education. This project addresses the disconnect between science, design, and technology. It explores how high school students can benefit from innovative learning experiences in plant science that integrate these disciplines while allowing them to gain the interest and skills needed for future STEM careers.

This project offers direct learning opportunities for high school students based on the innovative use of technologies such as virtual and augmented reality, that inspire creative learning, provide critical thinking and problem-solving benefits, support concepts of innovation and creativity, and allow students to connect to real-life situations impacting STEM career paths. Through the Augmented Virtual Reality (AVR) experiences, students will work in collaborative teams to create 3D models of plant objects. In doing so, they will be able to establish a connection between science, technology, and design. Teams will consist of self-identified science, technophile, and art students to generate the awareness that design and technology are a part of science, and that science is a part of design and technology. A STEAM (science, technology, engineering, art, and math) approach will be applied in which students' projects are focused not only on the final product but also on the artistic creative process. Strategic partnerships with scientists from the Donald Danforth Plant Science Center (DDPSC) and the zSpace AVR company will support the development of students' projects through training and mentoring. Students will have the opportunity to interact with researchers and present their projects at public and scientific events. Students will be trained in the use of AVR technologies and 3D design. This project will generate AVR plant science content that will be available to educators and students around the globe through zSpace. These experiences will be implemented, tested, and evaluated through the Plant and Agriculture Virtual Reality Learning Laboratory (PAVRLL) at the DDPSC. This learning experience will also contribute to the PAVRLL efforts to increase student awareness and improve knowledge about plants. Beyond plant-based content assessments, we will assess if these enriching experiences improve student attitudes towards STEAM subjects and interests in STEM careers.

Objectives

The overall and long-term goal of this project is to promote the connection betweeen science, technology, and design among high school students while providing direct learning opportunities that will guide them in choosing their future career paths. The STEAM goal will be accomplished through four major objectives:

1. Science: Inspire interest in STEM careers among students and provide them with skills for a future STEM career.
2. Science: Foster knowledge and appreciation of plant science among high school students.

3. Design: Integrate art and design into STEM plant science education (STEAM).
4. Technology: Apply AVR technology to advance plant science education through the use of novel tools and methodologies.

Learning outcomes

Students who participate in this project, are expected to be able to:

- Use AVR technology and its applications to create 3D plant models, thereby building useful technological skills for potential future STEM career paths.
- Identify and describe plant content and increase awareness of plants.
- Recognize the importance of art and design within STEM and appreciate science opportunities within art and design.
- Recognize the opportunities available for a future career in STEAM fields.
- Acknowledge the benefit of collaboration among peers, teachers, and scientists.

Education science and art standards

Below are the Next Generation Science Standards and the National Core Art Standards that apply to this project and that are expected to be used as a framework for the learning outcomes.

Next Generation Science Standards	
Performance Expectations	**Disciplinary Core Ideas**
Life Science	
HS-LS1 From Molecules to Organisms: Structures and Processes	
HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.	LS1.C: Organization for Matter and Energy Flow in Organisms
HS-LS2 Ecosystems: Interactions, Energy, and Dynamics	
HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.	LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.	LS2.A: Interdependent Relationships in Ecosystems
HS-LS4 Biological Evolution: Unity and Diversity	
HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations.	LS4.C: Adaptation

Engineering, technology, and applications of science
HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.	ETS1.B: Developing Possible Solutions
	ETS1.C: Optimizing the Design Solution

National Core Arts Standards	
Artistic Process	**Anchor Standard #**
Creating	**Conceiving and developing new artistic ideas and work** AS#1. Generate and conceptualize artistic ideas and work AS#2. Organize and develop artistic ideas and work AS#3. Refine and complete artistic work
Presenting	**Presenting (visual arts): Interpreting and sharing artistic work** AS#4. Select, analyze, and interpret artistic work for presentation AS#5. Develop and refine artistic techniques and work for presentation AS#6. Convey meaning through the presentation of artistic work
Responding	**Understanding and evaluating how the arts convey meaning** AS#7. Perceive and analyze artistic work AS#8. Interpret intent and meaning in artistic work AS#9. Apply criteria to evaluate artistic work
Connecting	**Relating artistic ideas and work with personal meaning and external context** AS#10. Synthesize and relate knowledge and personal experiences to make art AS#11. Relate artistic ideas and works with societal, cultural and historical context to deepen understanding

Materials

Provided by the DDPSC	Provided by the schools
8 zSpace AIOs with 8 3D and 16 2D glasses	Proper area and sturdy surfaces to display the zSpaces
5 Oculus Quest	Continuous electrical source
Manuals and protocols	Care and safe use of the zSpaces
Cleaning supplies	Cleaning of the equipment to prevent infectious diseases

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How to implement the project with your students

Overall project activities for teachers

- Guide your students to work in teams of self-identified science, technophile, and art students to create 3D models related to plant and agriculture.
- Collaborate with scientists from the Donald Danforth Plant Science Center (DDPSC) in the creation of the 3D models.
- Support students through the preparation of presentations of team projects in public and scientific events.
- Contribute to education research by sharing the artifacts (e.g. 3D models, photos, drawings, etc.) from the team projects and participating with your students in education assessments.
- Use augmented and virtual reality (AVR) technology in the classroom (e.g. zSpace and Oculus) to educate students about plants and agricultural science.
- Care for the AVR equipment.

Coordinate the implementation of the project

- Contact the Program Manager (PM), Sandra Arango-Caro (sarango-caro@danforthcenter.org), to coordinate a school visit, the delivery of the materials and equipment, and to have access to the project documents.
- Access your Google folder space using the link provided by e-mail. You need to have a Google account.
- Read and sign the photo release, acknowledgement of responsibility, and inventory forms and upload them in your Google folder or e-mail them to Sandra Arango-Caro, unless the school already has photo waivers of the students.

Preparations for project implementation

1. Teacher and PM meetings

The PM will discuss with you the needs and interests that this project can address for your class and a timeline for the project implementation (Table 1). Based on these discussions, the PM will provide a link to a Google folder with the information that is necessary to implement the project including forms, assessments, videos, assessments, articles, protocols, etc.

It would be your responsibility to get familiar with the material, complete the forms and assessments and attend the necessary training prior to the project implementation with the students.

2. Teacher training

It is recommended that you get familiar with the 3D modeling readings (page 7) and the software that the students will be using (Table 2), which are required for students.

Table 1. Timeline of project implementation (T-Teacher, S-Student, PM-Project Manager, M-Mentor).

Who	Activity	Time	Page
T/PM	Learn about the project and plan its implementation. Meetings with PM. Setup and access to a Google folder. Read protocols.	2 h	1-11
T	Teacher introduction to 3D modeling software (Tinkercad and Fusion 360).	1 h	7-8
T/PM	Project presentation to students by teacher and PM.	1 h	5
T/S	BEFORE starting the project, ask students to complete surveys, reflections, and photo waivers. Ask parents to complete consent forms.	30 min	5
	Set up teams, assign roles, inform about team etiquette.	15 min	6-7
S	Student training (3D modeling readings, Tinkercad and Fusion 360 videos, accounts creation).	3-4 h	7-8
T/S/ PM	Ask teams to discuss the potential 3D models to create based on Danforth needs and choose plant species to create their models.	30 min	9
S/M	Students develop the concept art of the 3D models, investigate the species biology and importance for research and society, consult with mentors.	3 h	9-10
S/M	Teams work on the creation of the 3D models.	~6 h	10
	Students interact with mentors for models' accuracy and to resolve questions about the biology and importance of the plants.	1 h	10
	Students work on the refinement of their models.	~6 h	10
T/S/ PM	Students have augmented and virtual reality experiences with zSpace and Oculus and learn about the use of 3D models in these environments.	1 h	10
T/S	Teams prepare posters, PowerPoint presentations and or videos of their projects.	4 h	10-11
T/S/ PM/M	Students present their projects virtually (15 minutes per team) during a school, scientific or public event.	1-2 h	10-11
T/S	Ask students to complete surveys and reflections and complete the teacher evaluation.	30 min	11

3. PM visit to the school

Meeting with teacher(s): The PM will review any questions that you may have about the implementation of the 3D modeling project.

Google folders: You will receive links to access Google folders where you and your students will be able to download (protocols, forms) and upload information (signed forms, photos, 3D models, presentations, etc.). You and your students will have also access to links to complete education research questionnaires.

Project presentation: The PM will introduce the project to students during an in-person or virtual school visit.

Intellectual property rights: Students and teachers will be informed in advance that the products (models) they generate through this project will be of open access. These products will be shared through the zSpace community, which will provide teachers and students across the world the opportunity to use them.

4. Education research pre-surveys

The Education Lab at the Danforth Center will work with you to help you administer surveys and written reflections (pre- and post- project) to students for education research. Student responses will contribute to STEAM (Science, Technology, Engineering, Arts and Mathematics), an emerging discipline with scant information on theory, best practices, and practical applications, by testing a STEAM teaching model in which student's design and create scientific products to use with AVR tools. The proposed project will contribute to the body of knowledge on teaching tools using AVR, from a different approach by giving opportunity to high school students to create their own AVR products. Surveys will assess changes in student perceptions about scientific disciplines and careers in STEAM and about awareness of plants and plant science.

Before the project starts, ask students to complete two pre-surveys (STEAM Semantics Survey and Plant Awareness Index) and reflection questions. To use the students answers in scientific publications, student consent is required (student personal information is not included in publications). Parental consent is also required for students that are minors (younger than 18 years of age). The links to access all the questionnaires and forms are below. Later in the protocol are the links to the surveys and reflections to complete after the project is over:

- Parent consent form for students younger than 18 years of age:
  https://survey.iad1.qualtrics.com/jfe/form/SV_bdCL901Up95Gyqi
- Pre-survey on student perceptions of scientific disciplines (STEM Semantic survey) with student consent/assent and demographic forms:
  https://survey.iad1.qualtrics.com/jfe/form/SV_eOKH836OTaLs9Lg
- Pre-survey on student plant awareness:
  https://survey.iad1.qualtrics.com/jfe/form/SV_8dFn8PWaTpiA3qe
- Pre-questionnaire for student written reflections:
  https://survey.iad1.qualtrics.com/jfe/form/SV_7Wo2pXIbFptN78i

Also, ask students to complete a photo waiver form:
https://drive.google.com/file/d/10Keh6YAj8k1H_dMRVWfwiFuhOD-9hoNP/view?usp=sharing

Implementation of the project with the students

1. Teams

Create teams of 3-6 students. In each team, try to have a representation of self-identified scientist, technophile, and art students. Ask the teams to discuss among themselves who will have the roles explain below. Based on the number of students in a team, students may have more than one role (small teams) or teams may have more than one student in a role (large teams). Make sure they understand that all members should participate in all phases of the project.

- Lead role: Maintains communication among members, makes sure everybody is participating in all phases of the project, checks that students complete the education research surveys, etc. Maintains contact with teacher.

- Scientist role: Coordinates the acquisition of information about the biological content and importance of the team's model(s). Maintains contact with mentor.
- Artist/Designer role: Coordinates the development of the concept art and ensures that the 3D model looks as accurate as possible. Supports the creation of the project presentations. Maintains contact with mentor.
- Technical role: Helps members with the training and use of the applications to design, create, and use the 3D models. Supports the creation of material for the presentations of the projects.
- Communication role: Coordinates the preparation and dissemination of the projects (Preparation of posters, PowerPoint presentations and or videos). Maintains contact with teacher and PM.

Promote teamwork etiquette among your students:
- Listen to each other's ideas
- Treat everybody respectfully
- Distribute the work fairly
- Do the work you committed to do
- Reflect on the benefits of collaboration

Emphasize to your students:
- To be patient, as they are learning by doing
- To be prepared for failing, as that is how we learn from our mistakes
- To be careful with the websites they access to prevent viewing inappropriate content
- To be responsible with the use of the equipment

Document the project progress through photos:
- Take photos of the teams and yourself during the different stages of the project.
- Encourage your students to take photos of themselves conducting the activity, as well as to take photos/screenshots of their sketches, on-line and in-person team meetings, and final products.
- These photos should be uploaded in your Google folder.

2. 3D model design and creation

What is 3D modeling?
Recommend students to visit the following links for readings on beginner steps on 3D modelling:
- Key processes of 3D modeling
  https://everisus.medium.com/key-processes-of-3d-modeling-49de59ed7a6
- 3D Modeling Basics
  https://all3dp.com/2/3d-modeling-basics-simply-explained/

- Beginner Steps to Start Designing 3D Models (Tinkercad example)
  https://home3dprintguide.com/beginner-steps-to-start-designing-3d-models/
- 3D Modeling Basics

https://www.instructables.com/Intro-to-3D-Modeling/

3. Student training

Students need to watch the training videos in Table 2. As they watch the videos, they should follow the steps to access Tinkercad and Fusion 360 (e.g. account creation), learn the basic controls and do the exercises to create 3D models.

Table 2. 3D modeling training videos (Watch videos in order)

3D modeling software	Description of videos and links (required to students)
Tinkercad **Overview:** https://www.tinkercad.com/	**Video 1: Welcome to Tinkercad!** (1:30 min) https://www.youtube.com/watch?v=LrU2zm_g7lE **Video 2: Tinkercad_Setup.** Account creation and basic controls (7:57 min)* https://drive.google.com/file/d/1ItYKeLWnCbtsM99cBmK4wgS2d5Ioud07/view?usp=share_link **Video 3: Tinkercad_Plant_Tutorial.** Creation of a plant (5:36 min) https://drive.google.com/file/d/1SybwtjYwurR1pyipYeU5yGvFIp-rJQWr/view?usp=share_link **Video 4: Tinkercad additional tutorial** (9:46 min) (Optional) https://www.youtube.com/watch?v=gOs6Mdj7y_4
Fusion 360 **Overview:** https://www.autodesk.com/products/fusion-360/overview	**Video 5: Fusion_Setup.** Account setup for Autodesk to access Fusion 360 in computer or Chromebook (3:11 min)* https://drive.google.com/file/d/1OFAXbePzihdSB5u7sj0YfWeZ6ijaWvIK/view?usp=share_link **Video 6: Fusion_Solids.** Basic controls and creation of a cup (7:35 min) https://drive.google.com/file/d/1SS6WkPa0AsxVRQXx6wRZH8M6Y2NsL07L/view?usp=share_link **Video 7: Fusion_Simple_Plant.** Creation of stem and leaves (8:35 min) https://drive.google.com/file/d/1Z5Y8V63qk-7bPzzWHz2Q3HLW_EhR-oDc/view?usp=share_link **Video 8: Fusion_Advanced Leaf.** Creation of a leaf (6:48 min) https://drive.google.com/file/d/1VK4jltUKkffkFIg8oogo9FdNCrnm8sFK/view?usp=share_link **Video 9: Fusion_Flower.** Creation of a flower (9:59 min) https://drive.google.com/file/d/19V_JFzrkw6rKv6k2JTKrexJ8-hdQ_A9L/view?usp=share_link

* Tinkercad and Fusion360 are software that belong to the Autodesk platform. If you have an Autodesk account, you can access both programs. Watch Video 1: Fusion_Setup to create this account.

4. Choosing the models to create

The program manager will discuss with you the potential models to create with the students based on the needs of the research labs at the Danforth Center. In Table 3 is a list of potential species to model that are under research at the Danforth Center.

Table 3. Information about potential plant species to choose for 3D modeling.

This table is available as a separate document since it is continuously updated.

5. Development of the concept art of the 3D models

The concept art is the visual concept of the 3D model that should be developed before starting to create the models. Students should start with the design of simple models of one object. As students' practice and get familiar with the 3D modeling software, they can develop more complex models made of different parts. Teams may create more than one 3D model related to the same species and or create models about plant-related process (e.g. pollination, germination, etc.).

To develop the concept art of the models, students can draw or sketch their designs with pen and paper, or use tablets to make the digital sketches of the 3D models using the following free software:
- Autodesk Sketchbook: https://sketchbook.com/
- Google AutoDraw: https://www.autodraw.com/
- Inkscape: https://inkscape.org/about/overview/

6. Work with scientists and mentors

Depending on the concept art, scientists and other mentors will work with the teams to advise on the biological aspect of the planned 3D models. For example, the mentor will suggest certain colors, shapes, or sizes that will make the models accurate when compared to real plant objects. The advisors will also help the students with the biological content and scientific importance of the models.

7. 3D model creation

Students should first watch the training videos to get familiar with the 3D modeling software Tinkercad and Fusion 360.

Requirements for 3D models to be used in the zSpace and Oculus platforms
- Vertice count should not be greater than 20,000
- Export your models in .obj format
- The .obj export will be a zipped file and this entire file is necessary for importing into VR.

When designing the 3D models, students should keep in mind the scientific accuracy, ease of use, and aesthetics of the product design.

8. Interaction with Augmented Reality (AR) and Virtual Reality (VR) tools

Students will have an in-person event when they will have the opportunity to learn to use zSpace computers for AR and Oculus Quest head mounted devices for VR experiences. They will learn how their 3D models could be used in AR and VR platforms.

9. Dissemination of the teams' projects

Students will prepare presentations of their projects with help and guidance from you and mentors. PowerPoint presentations, videos and or posters could be used by the students to share their results. The projects could be presented under different settings:
- Through your school during class or during another school event (STEAM day, science fair, etc.).
- Through the Danforth Center during public or scientific events (Scientific Retreat, PlantFest, etc.). The PM will coordinate with you the attendance of students to the Danforth events.

The PM will help coordinating the attendance of mentors to the presentation event, and mentors will evaluate the teams' products based on:
- the use of technology through the products they create
- the scientific accuracy, ease of use, and aesthetics of the product design

To prepare for the presentations, students should take into consideration to:
- Include the following content:
  - motivation for choosing the target species and particular objects
  - biological content describing the species and importance of the species for Danforth research and for society
  - design process
  - product: 3D plant model
  - challenges (positive and negative)
- Prepare slides that are visually appealing and look professional
- Practice the presentation in advance and test the timing of it
- (Optional) If your school has a 3D printer, consider creating a test print of the models to use during the presentation.

10. 3D model worksheet

Each team will prepare a one-page worksheet. These worksheets will support teachers' lesson plans related to the species and their 3D model(s). The worksheets should include the following elements, some of which already will be available from the presentations:

- Title: the name of the species (common and scientific name)
- Images: photo of the plant and the plant part modeled if applicable (e.g., seed, flower), and photo(s) of the 3D model(s)
- Biology of the plant and its importance to society and or plant science research (1-3 paragraphs)
- 3D model: Description of 3D model (1-2 paragraphs)

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- Questions: three to five questions formulated by the students (one per student) about what they will want to ask a student to learn about their model(s) and or science content.

Education research and evaluation

To continue with the education research goals of this project, teachers need to ask students **at the end** of the project, to complete post-surveys and post-reflections questions. In addition, teachers need to complete an evaluation questionnaire about the project experience. Use the following links to complete the questionnaires and forms:
- Post-survey on student perceptions of scientific disciplines (STEM Semantic survey).
  https://survey.iad1.qualtrics.com/jfe/form/SV_bK1wBTt5EjGqzau
- Post-survey on student plant awareness
  https://survey.iad1.qualtrics.com/jfe/form/SV_8A1qLdl8SSYxQ34
- Post-questionnaire on student reflections
  https://survey.iad1.qualtrics.com/jfe/form/SV_1Late3fRTxwOu46
- Teacher evaluation questionnaire
  https://survey.iad1.qualtrics.com/jfe/form/SV_5nnPVuiDlsruCyO

If you need help

Students may find challenges while developing the 3D models.
- For technical questions about the use of Tinkercad and Fusion 360, students should contact Nate Ly at NLy@danforthcenter.org.
- For questions about the biology and importance of the chosen species, contact the PM Sandra Arango-Caro (sarango-caro@danforthcenter.org) or the designated scientific advisors for each team.