Northeastern University College of Engineering

College of Engineering

Boston, MA 02115

GE 1501/1502 Cornerstone of Engineering 1 & 2

Instructor: Professor Bala Maheswaran

Course Description: (Cornerstone of Engineering 1) Introduces students to the engineering design process and algorithmic thinking using a combination of lectures and hands-on projects and labs while encouraging critical thinking. Offers students an opportunity to develop creative problem-solving skills used in engineering design, to structure software, and to cultivate effective written and oral communication skills. Topics include the use of design and graphics communication software, spreadsheets, a high-level programming language, programmable microcontrollers as well as various electronic components, and 3-D printing. Requires students to develop an original design solution to a technical problem as a final term project. Requires students to have a laptop computer that meets the specifications of the College of Engineering.

(Cornerstone of Engineering 2) Continues GE 1501 using a project-based approach under a unifying theme. Covers topics that introduce students to engineering analysis and design. Uses a math application package for matrix applications along with various real-life engineering problems solved using programming. Considers ethical reasoning in design and analysis, including ethical theories, professional codes, and emerging micro/macro issues in engineering. Introduces quantitative tools and ethical topics separately and weaves them into all design and problem-solving stages of the student projects. Covers 3-D assembly drawings and modeling, along with review and further work in design. Students work on open-ended design problems, developing working models, and prototypes to demonstrate and present their designs. Requires students to have a laptop computer that meets the specifications of the College of Engineering.

Concentrated Solar Thermal Course Material:

Concentrated Solar Thermal Power (CSTP) Heliostat Model Assembly

Objective: This hands-on activity will provide participants with an understanding of solar concentration principles and showcase the potential of heliostat technology for renewable energy generation. By engaging in this activity, you will explore how heliostats can enhance solar power systems.

Activity: Build a paper prototype of a heliostat that tracks the sun's movement and reflects sunlight onto a specific target, simulating the functionality of a heliostat-based solar power plant.

Project: Construct a miniature heliostat model using mirrors, 3D-printed and laser-cut materials, motors, and a pivot mechanism. Utilize 3D printing, laser cutting, Arduino, sensors, and programming to demonstrate how these models can effectively track the sun and direct sunlight to a designated target, mimicking the operation of a real heliostat system.

Presentation Requirements

Prepare a 10-minute oral presentation for the class using PowerPoint, websites, film clips, images, or other multimedia tools. Your presentation should cover the following points:

- Summary of the Heliostat Model
- Insights gained about engineering design
- Identified inefficiencies in the model
- Suggested improvements
- SolidWorks Simulation tutorial and design

Submission Guidelines

Submit your team report via Canvas with the following components:

- Title and team member names
- Detailed procedure from concept to prototype and 3D model
- Design details
- Results
- Analysis
- Save your file as da3_teamID.docx

Reference:

An Overview of Heliostats and Concentrating Solar Power Tower Plants, Mackenzie Dennis, National Renewable Energy Laboratory, March 2022

2025 ASEE Northeast Section Conference, March 22, 2025, University of Bridgeport, Bridgeport, CT, USA.

Developing a Sustainable Engineering Mindset Through Heliostat Activities in Project-Based Learning

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Abstract

The "heliostat mindset" emphasizes the harnessing of solar energy through heliostats—devices designed to track the sun and reflect its light to specific targets, commonly utilized in concentrated solar power systems. This mindset is vital for engineering students as it fosters sustainability awareness, encouraging them to incorporate renewable energy solutions into their designs. Engaging with heliostat technology stimulates innovation and creativity, requiring students to think critically about efficiency and effectiveness in their problem-solving approaches. Moreover, the interdisciplinary nature of heliostat energy—encompassing fields such as optics, thermodynamics, design process, use of sensor, rapid prototyping, and basic materials science—promotes a comprehensive educational experience. This focus enables students to bridge theoretical concepts with practical applications, better preparing them for careers in the sustainability sector. As the demand for renewable energy solutions continues to rise, expertise in solar technologies, including heliostats, will enhance students' competitiveness in the job market. This paper presents project details, student involvement, learning objectives, outcomes, and feedback, illustrating how adopting a heliostat energy mindset equips engineering students to tackle future challenges in sustainable energy.

Introduction

In recent years, engineering education has increasingly focused on developing students' competencies in sustainability, especially in renewable energy technologies. Among these, solar power holds significant potential, with heliostats playing a critical role in concentrated solar Thermal power (CSTP) systems [1- 7]. Heliostats track the sun's movement and reflect sunlight to a specific target, often a solar receiver or a central tower, where the reflected sunlight is used to generate energy. A heliostat system requires a blend of engineering principles—optics, control systems, materials science, and mechanical design—that challenges students to consider both technical and environmental impacts in their projects. This paper presents a heliostat model assembly project, conducted as part of a project-based learning (PBL) curriculum [8-9], aimed at fostering a sustainable engineering mindset in students. A sustainable engineering mindset involves not only designing efficient systems but also considering their environmental impact and potential for long-term sustainability [10].

Through the heliostat project, students are encouraged to think critically about the intersection of technology and the environment, gaining insights into the complexities and challenges of renewable energy systems. The project involved the construction of a miniature heliostat using 3D-printed components, laser-cut materials, motors, sensors, and Arduino programming to replicate the operational mechanics of real heliostat systems. The primary goal of the heliostat model assembly project was to provide students with a hands-on understanding of solar concentration principles and to demonstrate the potential of heliostat technology in renewable energy generation. Through the project, students explored how heliostats can optimize solar power systems by reflecting sunlight effectively to designated targets.

This paper focuses on how this concentrated solar Thermal power (CSTP) heliostat system Project-Based Learning approach fostered a Sustainable Engineering Mindset, rather than on the specifics of project design, prototype development, or data collection and analysis, which will be discussed in a separate publication. The heliostat project required students to draw on knowledge from multiple engineering disciplines, offering opportunities for independent and self-directed learning. The key educational values learned through these activities include a deep understanding of optics, where students explore light reflection, concentration, and sun-tracking systems. In addition, they apply thermodynamics principles to optimize energy efficiency and improve sunlight collection. The design and prototyping process involves the use of rapid prototyping techniques, such as 3D printing and laser cutting, to create components for the project. Lastly, students engage in control systems by programming Arduino-based sensors and motors to adjust the positioning of the heliostat, gaining hands-on experience with these essential technologies. This interdisciplinary approach reflects the real-world complexity of energy systems, where effective solutions require collaboration across various areas of expertise.

Additionally, the heliostat model assembly encouraged innovation and problem-solving. The iterative process of design and optimization presented challenges like improving sun-tracking accuracy, enhancing light reflection efficiency, and ensuring mechanical stability. These obstacles pushed students to critically assess potential inefficiencies and come up with creative solutions, cultivating the problem-solving mindset needed to tackle future energy challenges.

Method and Approach

The project description and details can be found in Appendix 1. Thirty one students, organized into seven groups, participated in this activity over the span of three weeks. Students were encouraged to complete the project using available resources, while making use of the makerspace, 3D printing, laser cutting, mirrors, Arduino, sensors, and other freely available materials. Each team adopted different design approaches, independent of one another. Upon completion of the project and its presentation, students were asked to respond to several project-based survey questions, which included both Likert Scale and Open-Response Survey Questions, as detailed in Appendix 2.

As mentioned earlier, this paper focuses on how the project contributed to developing a sustainable engineering mindset in students. To provide further insight for the readers, we have included samples of the prototypes in Appendix 3.

Results and Analysis

A survey was conducted after the completion of the heliostat project to evaluate student experiences and assess the effectiveness of the activity in fostering a sustainable engineering mindset, as well as to examine how participation in the project has motivated individuals to address future challenges in sustainable energy. Twenty-six students responded to the survey, sharing how their involvement in the heliostat project has inspired them to tackle future sustainable energy challenges, particularly through concentrated solar thermal power. This paper primarily focuses on questions 1, 5, 6, 10, and 11 from Appendix 2, but the results from all responses are presented in Figures 1-10.

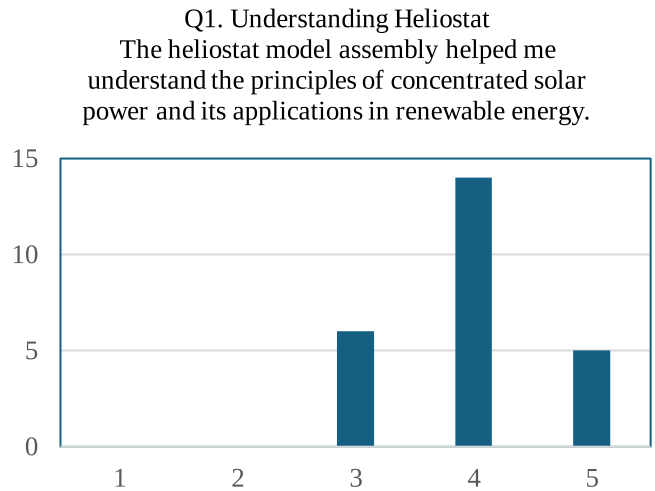

Figure 1: Understanding Solar Technology

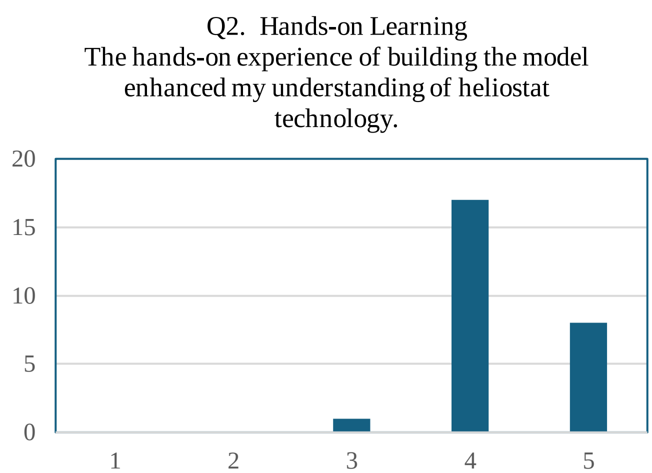

Figure 2: Value of Hands-on Learning

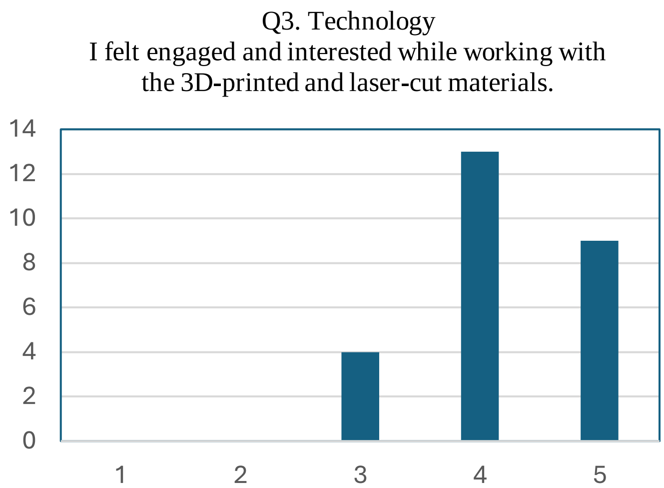

Figure 3: Engagement with Technology

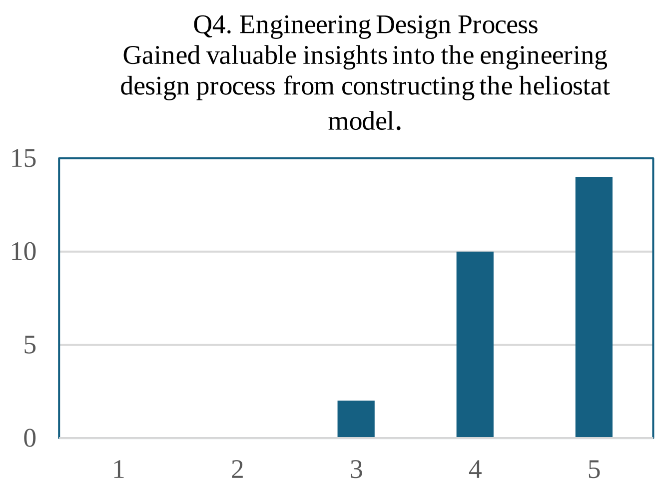

Figure 4: Engineering Design Insights

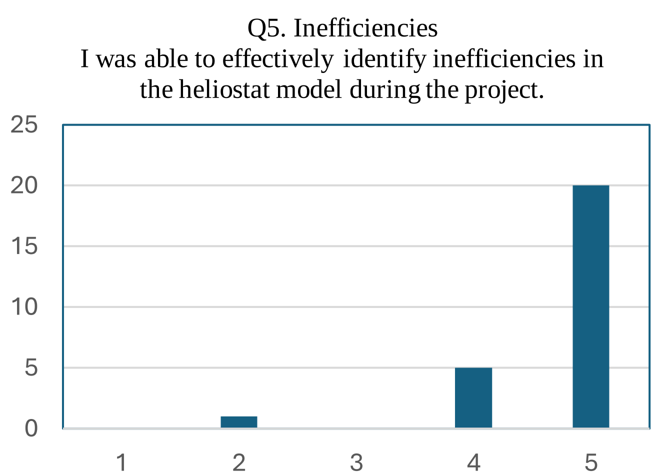

Figure 5: Identifying Inefficiencies

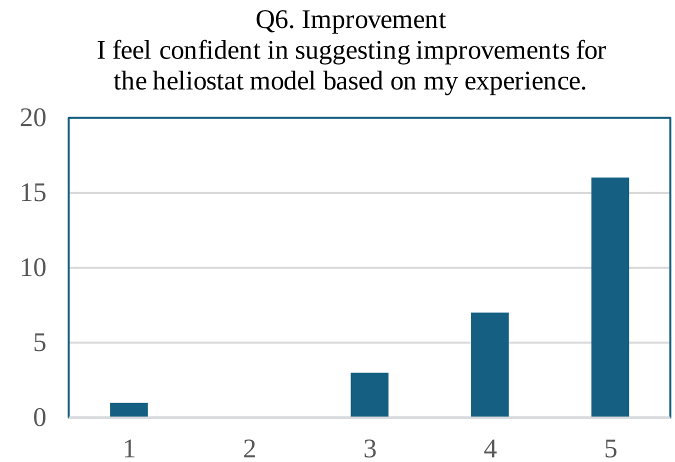

Figure 6: Suggestions for Improvement

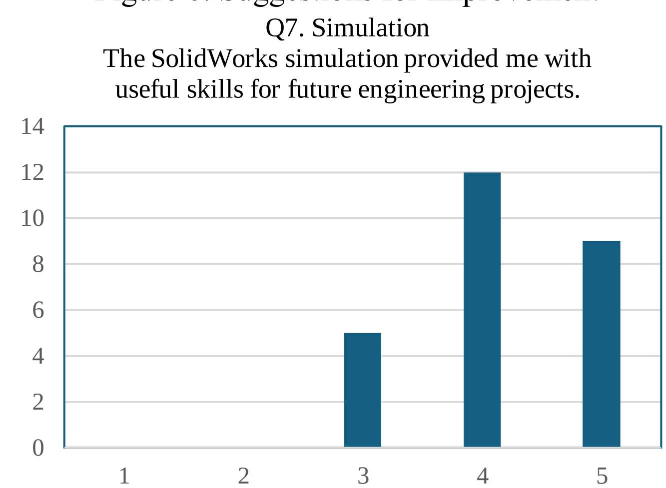

Figure 7: Simulation and Design Tools

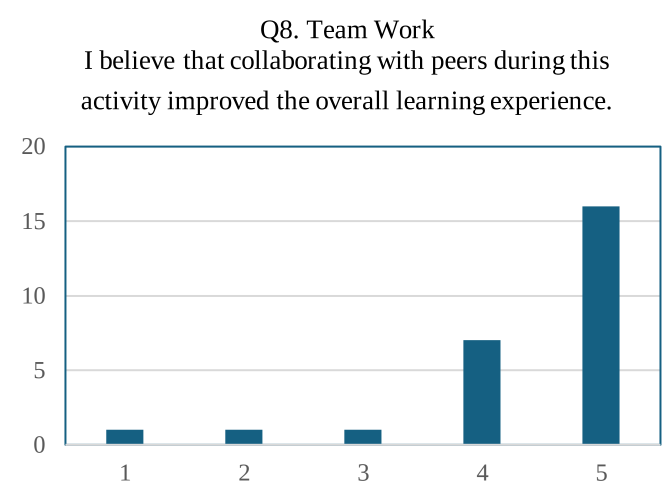

Figure 8: Team Collaboration

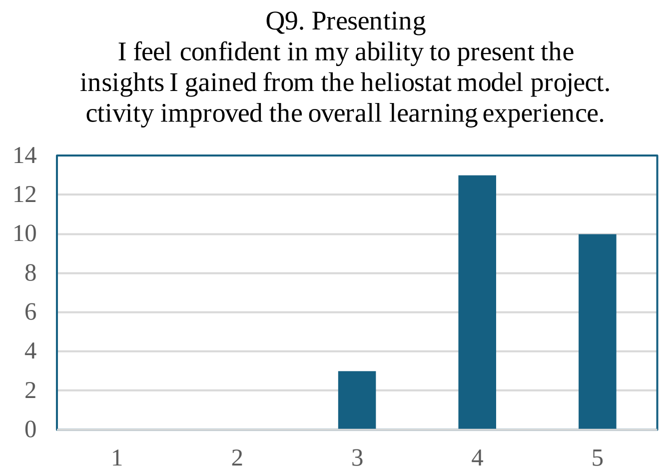

Figure 9: Confidence in Presenting Insights

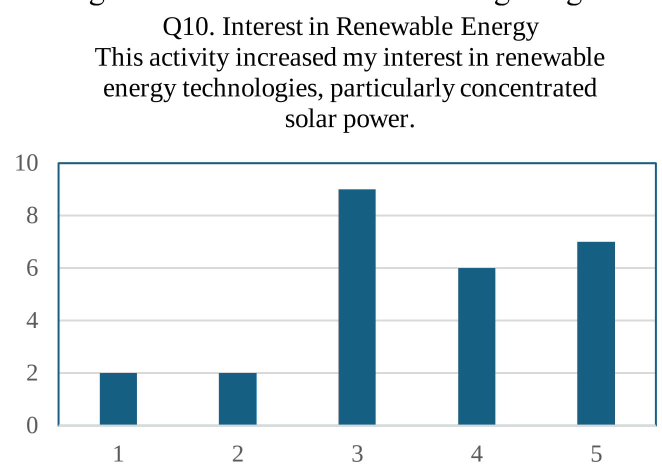

Figure 10: Interest in Renewable Energy

Many respondents noted that the project sparked or deepened their interest in sustainable energy and renewable technologies, particularly solar energy. Several expressed a greater desire to pursue careers in renewable energy engineering or related fields. The hands-on experience of building the heliostat was highlighted as a valuable opportunity, helping participants appreciate the complexities and challenges of sustainable energy systems. This practical exposure motivated many to explore ways to contribute to innovative solutions. Additionally, a significant number of respondents mentioned that the project increased their awareness of the broader environmental impact of sustainable energy, encouraging them to consider environmental concerns and potential solutions in future projects.

While facing challenges, such as inefficiencies in their designs and the complexities of solar-thermal technology, several participants acknowledged that these obstacles led them to seek ways to improve sustainability and energy efficiency. Some respondents also gained a better understanding of alternative solar technologies, such as heliostats and solar-thermal energy, sparking a greater interest in how these technologies can be applied to real-world energy systems. For a few, the project reinforced their belief that engineering can provide solutions to real-world problems, particularly those related to energy and sustainability, motivating them to further explore sustainable energy in their engineering work. However, a small number of responses indicated that the project did not significantly alter their career goals or interests, with one individual mentioning a greater interest in health and medicine.

In summary, most participants expressed that the heliostat project motivated them to pursue a future in sustainable energy, either by deepening their understanding of solar technologies, encouraging them to work on real-world solutions, or inspiring them to integrate sustainability into their future engineering projects.

Discussion

A majority of students (88%) reported a significant increase in their understanding of solar technology, particularly concentrated solar thermal power systems. The hands-on assembly of the heliostat model provided practical knowledge that reinforced theoretical concepts related to solar energy. Nearly 90% of respondents strongly agreed that the experience enhanced their comprehension of heliostat technology. Many students noted that building the model helped them appreciate the complexities of concentrated solar thermal power systems and the crucial importance of precision in renewable energy technologies.

Collaboration with peers was highly beneficial, as reported by 85% of participants. This teamwork facilitated knowledge sharing, problem-solving discussions, and improved communication skills—essential elements of real-world engineering projects. Most students identified design inefficiencies, such as challenges with mirror alignment, motor precision, and sensor calibration. These insights deepened their understanding of the technical limitations of solar tracking systems, which are key to improving the efficiency of future designs.

Additionally, many students developed a greater interest in renewable energy, especially solar energy. Several expressed that the project motivated them to pursue careers in sustainable energy engineering, while others became more aware of environmental issues and the potential for engineering solutions to tackle global energy challenges.

Conclusion

The heliostat model assembly project successfully nurtured a sustainable engineering mindset by combining technical education with practical applications in renewable energy. The hands-on nature of the project, along with its interdisciplinary approach, allowed students to deepen their knowledge of solar technologies and gain valuable insights into the complexities of designing and optimizing energy systems. Participant feedback indicated an increased interest in sustainable energy, with many expressing a desire to pursue careers in the field. The project also highlighted the importance of collaboration, problem-solving, and innovation in addressing the global challenge of transitioning to renewable energy. By incorporating activities like the heliostat model assembly into engineering curricula, educational institutions can better prepare students to contribute to sustainable energy solutions.

The responses to the heliostat project reflect its significant impact on participants' perceptions of sustainable energy and their career aspirations. For most students, the project sparked or strengthened their interest in renewable energy, particularly solar technologies, motivating them to explore careers in sustainable energy engineering. The hands-on experience provided valuable insights into solar-thermal systems and underscored the challenges and opportunities for innovation in energy efficiency.

Moreover, many students developed a heightened awareness of the environmental importance of renewable energy, leading them to consider sustainability more critically in their future work. While some did not experience a substantial shift in their interests, the overall trend suggests that the project fostered a greater appreciation for solar technology and its potential to address global energy challenges. Ultimately, the heliostat project inspired students to explore and contribute to sustainable energy solutions, reinforcing the vital role of engineering in addressing pressing environmental issues.

Acknowledgment

We would like to express our sincere appreciation to the Cornerstone Engineering students from Professor Maheswaran's section for their creative efforts and valuable feedback. Our thanks also go to the First-Year Learning and Innovation Center for their assistance and support. We are grateful to the members of the National Renewable Energy Laboratory (NREL) for their encouragement. This work is supported by the National Renewable Energy Laboratory (NREL) under grant SUB-2024-10424.

References.

1. Mackenzie Dennis, *An Overview of Heliostats and Concentrating Solar Power Tower Plants,* National Renewable Energy Laboratory, March 2022
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5. Zhao, Y., & Li, X. (2020). "Progress and challenges of concentrated solar thermal power (CSP) technologies." *Energy Reports*, 6, 128-140.
6. Ghasempour, R., & Aslani, F. (2018). "Techno-economic evaluation of concentrated solar power systems: A case study for Iran." *Renewable Energy*, 116, 137-150.
7. Alavi, M. A., & Keshavarz, A. (2021). "Design and performance analysis of concentrated solar power plants: A case study of CSP systems in desert climates." *Renewable Energy*, 163, 1789-1801.
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9. Maheswaran, B., & Criollo, A., & Reghupathi, A., & Shah, A., & Lee, R. (2022, August), *Project–Based Learning: Piezoelectric Energy Wheel* Paper presented at 2022 ASEE Annual

Conference & Exposition, Minneapolis, MN. 10.18260/1-2—40452

10. *The Inclusive Engineering Mindset: A Vision for Change in Undergraduate Engineering and Engineering Technology Education,* ASEE/NAE, June 2025.

Appendix 1: Project Information

Cornerstone of Engineering

Northeastern University

College of Engineering
DA3: Heliostat Model Assembly
Concentrated Solar Power (CSP)

Objective: This hands-on activity will provide participants with an understanding of solar concentration principles and showcase the potential of heliostat technology for renewable energy generation. By engaging in this activity, you will explore how heliostats can enhance solar power systems.

Activity: Build a paper prototype of a heliostat that tracks the sun's movement and reflects sunlight onto a specific target, simulating the functionality of a heliostat-based solar power plant.

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Presentation Requirements

Prepare a 10-minute oral presentation for the class using PowerPoint, websites, film clips, images, or other multimedia tools. Your presentation should cover the following points:

- Summary of the Heliostat Model
- Insights gained about engineering design
- Identified inefficiencies in the model
- Suggested improvements
- SolidWorks Simulation tutorial and design

Submission Guidelines

Submit your team report via Canvas with the following components:

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- Detailed procedure from concept to prototype and 3D model
- Design details
- Results
- Analysis
- Save your file as *da3_teamID.docx*

Appendix 2: Survey Questions

Likert Scale Survey Questions for the Heliostat Model Assembly Activity

Please answer using a scale of 1 to 5, where 1 = Disagree, 2 = Neutral, 3 = Somewhat Agree, 4 = Agree, and 5 = Strongly Agree.

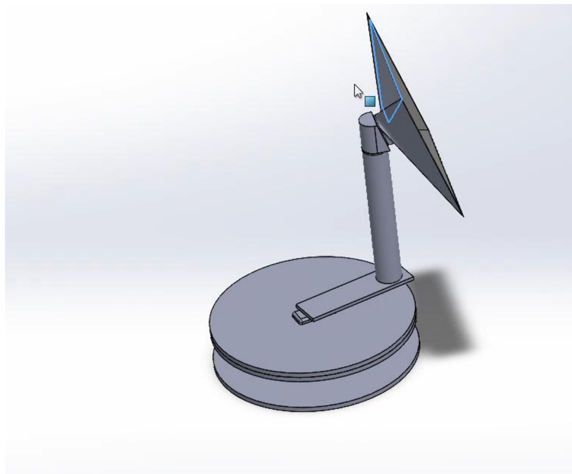
1. **Understanding Solar Technology**
   The heliostat model assembly helped me understand the principles of concentrated solar power and its applications in renewable energy.
2. **Value of Hands-on Learning**
   The hands-on experience of building the model enhanced my understanding of heliostat technology.
3. **Engagement with Technology**
   I felt engaged and interested while working with the 3D-printed and laser-cut materials.
4. **Engineering Design Insights**
   I gained valuable insights into the engineering design process from constructing the heliostat model.
5. **Identifying Inefficiencies**
   I was able to effectively identify inefficiencies in the heliostat model during the project.
6. **Suggestions for Improvement**
   I feel confident in suggesting improvements for the heliostat model based on my experience.
7. **Simulation and Design Tools**
   The SolidWorks simulation provided me with useful skills for future engineering projects.
8. **Team Collaboration**
   I believe that collaborating with peers during this activity improved the overall learning experience.
9. **Confidence in Presenting Insights**
   I feel confident in my ability to present the insights I gained from the heliostat model project.
10. **Interest in Renewable Energy**
    This activity increased my interest in renewable energy technologies, particularly concentrated solar power.

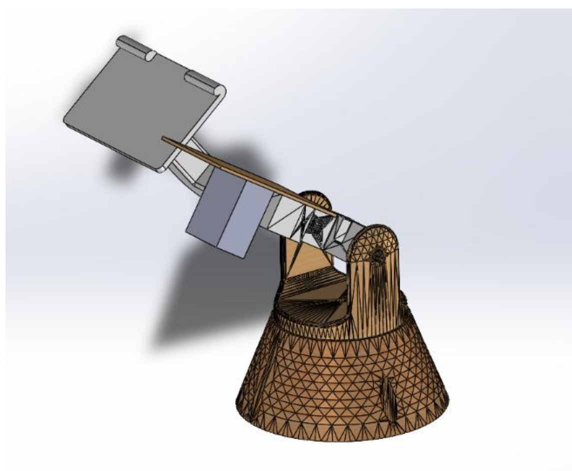
Open-Response Survey Questions Related to the Heliostat Model Assembly Activity

1. **Mindset**
   How has your involvement in the heliostat project motivated you to address future challenges in sustainable energy? Please describe.
2. **Insights Gained**
   What key insights did you gain about solar concentration principles and heliostat technology during the assembly of the model?
3. **Identified Inefficiencies**
   In your opinion, what specific inefficiencies did you identify in the heliostat model, and what factors contributed to these issues?
4. **Suggestions for Improvement**
   What suggestions would you make to improve the design or functionality of the heliostat model based on your experience.

Appendix 3: Sample Prototypes

Solidworks Model





Prototypes