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GIFTS: Incorporating Bio-Inspiration into First-Year Design

Dr. Danielle Grimes, Cornell College
Dr. Niloofar Kamran, Cornell College

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Introduction

The purpose of our first-year engineering course is to introduce students to the ABET seven student outcomes: 1) an ability to solve problems (utilizing computer-aided design) 2) an ability to apply engineering design 3) an ability to communicate effectively 4) an ability to apply professional ethics 5) an ability to work effectively in teams 6) an ability to design and conduct experiments and 7) an ability to acquire and apply new knowledge. Our courses have the additional challenge of fitting into a One Course at a Time block plan where students enroll in one course for 18 days of instruction. Due to the amount of content, we need to cover and the limited time for a design cycle, we utilize a term project that touches on each of the student outcomes and requires them to use 3D printing in the design and is bio-inspired. Through this paper, we will describe the course design, how we utilize bio-inspired design with projects, and our assessment procedures.

Course Design

Our courses are designed on a One Course at A Time (OCAT) basis, where students take one course for 18 instructional days where each day encompasses 3-4 hours of instructional time. The course is divided into two parts: lecture and a 3D modeling lab which each meet for 2 hours a day, except for Wednesdays where the students are required to meet with their term project groups. The course produces 4 semester credit hours or approximately 60 hours of instruction per block, with the course meeting 3960 minutes per block.

The lecture introduces students to engineering concepts and has stated weekly goals as dictated by the engineering design process. Each week also concludes with a group presentation on how the lecture has informed their continued design of their term projects. The week structure is as follows:

Week 1
Identifying a problem and research. Students are introduced to engineering as a career field and the term project. They are shown examples of successful bio-inspired designs and encouraged to brainstorm potential solutions/designs independently before being assigned teams. An instructor from the library also visits during this week to show searching capabilities through our institutional library. The week concludes with 7-10 minute presentations where the students are challenged to prove that they have identified a problem and that their bio-inspiration can generate a potential solution.
Week 2
Prototype design and experimentation. During this week, students are educated on the different variable types (control, independent, and dependent) and different research study design types.

During class time, students are challenged to design parachutes for bouncy balls and generate ways to prove their designs are effective. This short project allows them to engage in variable manipulation and data collection in the classroom before engaging with it independently. The week concludes with the students presenting their proposed designs with 3D modeled components and testing procedures, and students must submit a final proposal for their design before week 3 begins.

Week 3

Data collection/analysis and redesign. During this week, the students generally need more time to work in their groups. The lecture is, therefore, split into 2 parts: continued engineering topics (e.g., ethics, marketing opportunities, human factors, etc.) and guided instruction on projects. Students are required to show their current data by Wednesday of this week and propose how they will evaluate and display their data. The week concludes with a first draft of their final presentation, on which they are given feedback on how to improve.

Week 4

Technical communication. Students begin this week with their final presentations of all components of the engineering design process. The students are also required to bring in their projects for demonstration and assessment. The groups submit their final research papers and engineering notebooks for assessment.

While the lecture topics are ongoing, students are also required to learn 3D Modeling through Parametric Creo software. Each individual in the course is required to learn how to sketch, extrude, revolve, dimension, pattern, sweep, and assemble parts in the software. Students conduct individual labs and homework to develop and test these skills, and they are assessed in the midterm and final exams. Groups must also apply these skills in the development of their term project.

Bio-Inspired Design

One of the largest hurdles to our course design historically has been rapid idea generation to accommodate the condensed nature of the block plan. While initially, our solution to this problem was providing students with a specific problem to solve, we found that the students engaged less with the projects when their designs were limited. Bio-inspiration allows the students to use previous knowledge, apply their creativity, and effectively engage in research in the gathering of new knowledge.

Bio-inspired design is first introduced to students through the Shinkansen train design by Eiji Nakatsu. The students are then introduced to ongoing research projects that utilize bio-inspired designs such as helmets, hedgehogs, and other animals, before they are challenged to conduct research on their own.

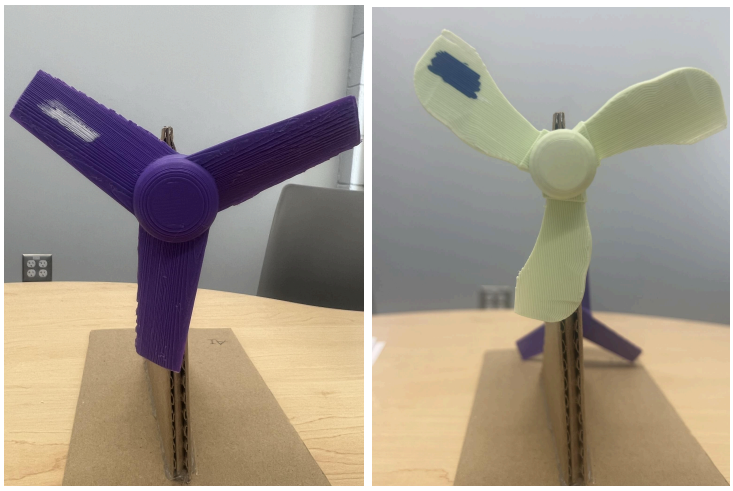
Project Outcomes

Our bio-inspired design incorporation is in its third iteration in January 2024. Two of our previous projects are:

Maple Seed Windmills

Students found that maple seeds are a naturally occurring airfoil that generates spin. The students proposed that by applying a similar geometry to windmill blades, they could create more efficient windmills. The students 3D printed a traditional windmill blade and one of their own designs that is similar to a maple seed. They then used a fan to generate wind speed and high-speed cameras to count the RPM of the different windmills. Their results found that the bio-inspired windmill spun 133.9% faster than the traditional windmill.

Figure 1 Maple Seed and Traditional Windmill Blades



Above are the two 3D-printed windmill blade types that the students designed and printed themselves. The straight windmill replicates existing designs, and the curved windmill replicates maple leaves.

Ram Horn Phone Case

Students utilized the geometry of ram horns to 3D print phone cases that could potentially withstand higher forces. The external horns had a curved shape, and the internal infill was left low to replicate the soft epithelium core. These were tested through pendulum swings, where the force was calculated through the change of momentum/time of impact, and the ram horn had a force of 17.6 N compared to the control design with 5.7 N.

Figure 2 Ram Horn Phone Case

Ram horn phone case where the students modified the infill and shape to replicate ram horns.

Assessment Procedures

Our assessment procedures were established to evaluate student growth on all ABET SOs that they are introduced to through the course. Weekly assessment of the projects came in 3 different ways: team updates through engineering notebooks and team evaluations (SOs 2 and 5), presentations on the new information acquired for their project every week (SOs 3, 6, and 7), and written communication evaluated through a proposal and final paper (SOs 2 and 3) (rubrics found in the Appendix). SO 1 is evaluated through a midterm and final exam where students are required to recreate 3D models based on Engineering Drawings, and SO 4 is evaluated through ethics presentations where they explore the ethics of emerging engineering technology. Repeated assessments are also designed to encourage a growth mindset in students.

Conclusion

The application of bio-inspired design to our Introduction to Engineering Design course has had an overall positive impact on the course flow and student development. Students have an easier time deciding on their projects because of the limitation of bio-inspired design which gives them more time for redesigning their models and testing procedures.

By the conclusion of the course, all students have experience with working in teams, utilizing the engineering design process, 3D modeling, and both written and oral communication. Their repeated assessments allow students to experience greater growth throughout the 18-day block period than previous iterations of the course.

Appendix

Team Evaluation Questions for Weekly Assessment

1. My team met outside of class for at least _____ this week
    a. <1 Hour
    b. Less than 2 hours but more than 1
    c. 2 hours or more
2. Rate your team on a scale of 1 to 5 in terms of its ability to cooperatively work (maximizing individual strengths and minimizing weaknesses)
3. Rate your team on a scale of 1 to 5 on its ability to communicate
4. Write your team's goals from this week and indicate if it was accomplished. If you did not reach your goals, please explain why
5. Was your team able to equally divide the work this week
    a. Yes
    b. No
    c. Other (with comments)
6. Do you have any concerns about your team going forward? Please detail them below

Team Evaluation Questionnaire for Final Assessment (Required)

1. How would you assess yourself and each of your group members on the effort they put into this project? Write down every group member's name (including your own), give them a rating from 1-5 (1 being the worst) in terms of their effort. Explain as needed. Effort is defined as: Preparation and Readiness to work, acceptance of responsibilities, level of participation, time commitment, and work load.
2. Work Contribution: Below, write how much (by percentage) yourself and each group member contributed to the overall project
3. Group atmosphere: How would you assess yourself and each member of your groups in terms of your ability to work together effectively and create a functional atmosphere from 1-5? Please explain your answer.
4. Self-Reflection. What areas of the project do you feel like you could have improved upon/supported your group better?
5. How would you rate your groups' use of time? (Keep in mind your Gantt Chart and if it was followed) 1- Procrastinated heavily to 5 - Met every deadline
6. How would you rate your group's project and performance overall? 1- Poorly, 5 - Perfectly
7. What would you do next time to improve your ability to create a product in the block plan?
8. To what degree do you feel that this project helped your ability to apply engineering design to the production of solutions? How so?

9. To what degree do you feel this project helped develop your skills to communicate effectively with a range of audiences? How so?
10. To what degree do you feel this project helped develop your ability to function effectively on a team? How so? (Note: This is about your skill development, not about how your team functioned)
11. Are there any details I should know while finishing the grading?

Rubric for Research Proposal

Criteria	Low	Middle	High	Points Earned	
Point Value	1	3	5		
Title Page	All components are not included; not properly formatted	Evidence of 3 items	Research title, your name, course title, date, teacher name, and period.	X 1	
Introduction	Neither implicit nor explicit reference is made to the topic or purpose of the article.	Gives the reader information on the general subject of the paper.	Clearly and concisely gives an attention getter that grabs the reader and the groundwork is laid as to the direction of the project	X 4	
Body: Background and Methods	The summary appears to have no direction, with subtopics appearing disjointed.	There is a basic flow from one section to the next. Problem is presented but not fully explained. Methods present but do not reflect problem	The summary goes from general ideas to specific conclusions. Problem well depicted that leads to solution idea and methods	X 4	
Body: Data Collection and Discussion	Major sections of pertinent content have been omitted or greatly run-on.	Evidence of data collection but it is not explained or analyzed. Or the data collected does not reflect the problem posed.	The data analysis correctly reflects the collection techniques. The data collection is well designed to suit problem.	X 4	
Conclusion/ Future Work:	There is no indication the author tried to synthesize the information or make a conclusion based on the research proposal	The author provides concluding remarks that show an analysis and synthesis of ideas occurred. Some of the conclusions, however, were not supported in the body of the report.	The author was able to make succinct and precise conclusions based on the review. Proposed future designs present and explained	X 4	
Grammar and Spelling	It is hard to know what the writer is trying to express. Writing is convoluted. Misspelled words, incorrect grammar, and improper punctuation are evident.	Writing is generally clear, but unnecessary words are occasionally used. Meaning is sometimes hidden. Paragraph or sentence structure is too repetitive. Few (3) spelling, grammar, or punctuation errors are made.	Writing is crisp, clear, and succinct. No spelling, grammar, or punctuation errors are made. No errors in sentence structure and word usage.	X 1	
Citations: Proper APA Format	Not all sources are cited in paper; Citations are not properly formatted in APA format	All sources are cited in paper, however citations are not properly formatted in APA format	All sources are cited in the paper and are properly formatted in APA format	X 1	
Works Cited Page	Not in APA format. Includes only popular sources	Done in APA format with some errors. Includes less than 4 required references.	Done in APA format with no errors. Includes 4 peer reviewed sources	X 1	

TOTAL SCORE _____/100

Final Presentation Rubric

Project Title: _____

Presenters:

_____

Evaluation	Description	Points Worth	Points Rewarded
Time	• Within 10-15 minutes • Pacing stays consistent but with good energy	3	
Background/ Justification	• Problem is well introduced and well researched • Market comparisons present • The solution is well justified	5	
Methods	• The methods are clearly presented • Methods are well justified • The testing methodology has clear ties to the prototype and problem	5	
Data/Results	• Data is presented visually • The results are clearly explained • The data and the explanations match	5	
Conclusions/Future Work	• The conclusions tie back to the problem presented • The presenters discuss future steps • The presentation has a clear conclusion	5	
Individual Grade on Preparation	• Individual seems well prepared	4	
Quality of Video/Slides	• Video/Slides are interesting and engaging	3	
		Points Rewarded:	_____/30

Rubric for Final Paper

Criteria	Low	Middle	High	Points Earned	
Point Value	1	3	5		
Title Page	All components are not included; not properly formatted	Evidence of 3 items	Research title, your name, course title, date, teacher name, and period.	X 1	
Introduction and Problem Statement	Neither implicit nor explicit reference is made to the topic or purpose of the article.	Gives the reader information on the general subject of the paper.	Clearly and concisely gives an attention getter that grabs the reader and the groundwork is laid as to the direction of the research.	X 4	
Body: Flow of the review	The summary appears to have no direction, with subtopics appearing disjointed.	There is a basic flow from one section to the next, but not all sections or paragraphs follow in a natural or logical order.	The summary goes from general ideas to specific conclusions. Transitions tie sections together, as well as adjacent paragraphs. Research Evident	X 4	
Methods: Design and Data Collection	Major sections of pertinent content have been omitted or greatly run-on.	All major sections of the pertinent content are included, but not covered in as much depth, or as explicit, as expected	The body includes a discussion of the problem, objectives, and experimental design (control, IV, DV) Sketches of proposed design with explanation	X 4	
Broader Impacts:	There is no indication the author tried to synthesize the information or make a conclusion based on the research proposal	The author provides concluding remarks that show an analysis and synthesis of ideas occurred. Some of the conclusions, however, were not supported in the body of the report.	The author was able to make succinct and precise conclusions based on the review that justify the project and openly state their expected outcomes.	X 4	
Grammar and Spelling	It is hard to know what the writer is trying to express. Writing is convoluted. Misspelled words, incorrect grammar, and improper punctuation are evident.	Writing is generally clear, but unnecessary words are occasionally used. Meaning is sometimes hidden. Paragraph or sentence structure is too repetitive. Few (3) spelling, grammar, or punctuation errors are made.	Writing is crisp, clear, and succinct. No spelling, grammar, or punctuation errors are made. No errors in sentence structure and word usage.	X 1	
Citations: Proper APA Format	Not all sources are cited in paper; Citations are not properly formatted in APA format	All sources are cited in paper, however citations are not properly formatted in APA format	All sources are cited in the paper and are properly formatted in APA format	X 1	
Works Cited Page	Not in APA format. Includes no peer-reviewed sorces	Done in APA format with some errors. Includes less than 4 required references.	Done in APA format with no errors. Includes a minimum of 4 peer reviewed articles.	X 1	

TOTAL SCORE _____/100