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Collaborating with Aviation Museums to Enhance Authentic Assessments for Aerospace Structures

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Abstract

Aerospace structures courses often appear in the third year of aerospace engineering programs, and are a cornerstone course providing required technical content for the fourth year capstone design course. As cornerstones, these courses should also help develop engineering students' understanding of design and professional skills. A novel approach taken at Clarkson University involves collaborating with over a dozen aviation museums across the United States and Canada to implement authentic assessments. The collaboration was created in 2020 in response to COVID-driven online learning, and has continued to the present, impacting over 150 students in Clarkson University's aerospace engineering program.

Each museum selects an aircraft from their collection for a team of four to five students to examine. The students interact with the curatorial, restoration, and archive staff at the museum via email and Zoom calls to retrieve the necessary technical data to complete analyses ranging from beam bending and web-stringer to plates and shells. Further, each aircraft has an associated pilot or engineer that the students must study to determine the use case of the aircraft that drives their subsequent structural analyses. For the museums, the teams produce non-technical abstracts and CAD models that supplement the museums' displays.

By design, this course project is open-ended and requires the students to make a series of assumptions, depending on the data available, to complete their technical analyses. Further, the students must deliver their analyses through technical memoranda, reports, and presentations. This course structure follows Wiggins' framework for authentic assessments [1, 2].

The objectives of the present work-in-progress study are to assess the impact that interacting with museums has on the technical and professional development of the students. Two cohorts of students are studied, the first cohort is currently (2022-2023 academic year) taking the aerospace structures courses at Clarkson University, while the second cohort took the courses during the 2021-2022 academic year. Two cohorts are studied to assess the short term and longer-term development of the students. The research questions considered are

1. What are the students' initial responses to encountering an open-ended analysis project?
2. Do the students' technical skills develop linearly during the courses or is the development recursive?
3. How do students' conceptualizations of an open-ended problem develop throughout the project?
4. Does an open-ended project in a cornerstone course provide improved preparation for senior capstone?

These research questions are assessed via a sequence of surveys and interviews of students from both cohorts.

Introduction

The arrival of COVID-19 in 2020 to North American university campuses was disruptive to students' education, but also provided an opportunity to innovate new educational approaches and course projects leveraging videoconferencing platforms. Key to these innovations was the pursuit of relatedness as targeted by an American Society of Engineering Education (ASEE) NETI-3B workshop offered during the summer of 2020. The instructor, and the first author of this paper, attended this workshop and the fundamental principles of relatedness aligned with the instructor's concerns about his students feeling connected to each other, to the course instructor, and to the course content. The instructor teaches two, consecutive aerospace structures courses that juniors in the aerospace engineering program at Clarkson University are required to take. Clarkson University is a small, private university specializing in engineering and business located in the Northeastern United States.

Prior to COVID-19, the instructor used project based learning approaches in both aerospace structures courses. The instructor started teaching both courses in 2016, and the projects up to the 2019-2020 academic year required the students to select an aircraft accident that involved a structural failure. For the 2019-2020 academic year, the instructor organized the projects to celebrate the 50th anniversary of the Apollo 11 landing on the Moon. The students analyzed the structures of aircraft and rockets used by NASA to train and launch the astronauts. Retrieving the necessary technical information from public sources about the aircraft and rockets proved challenging.

During the summer of 2020, the instructor read several media reports about museums in Canada and the United States cancelling events and commemorations of the 75th anniversary of the end of World War II (WWII) because of pandemic safety requirements. These reports, combined with the training from the NETI-3B workshop, led to the instructor cold-calling over 40 aviation museums across Canada and the United States to propose that the museums interact with the students in his courses to analyze a WWII aircraft in their collections. Ten museums agreed to participate for the 2020-2021 academic year. The projects were considered a success by the museums' staff and the instructor, thus continuing the collaboration for the 2021-2022 and 2022-2023 academic years. During the subsequent years, different themes were selected annually and additional museums joined the collaboration.

The first sections of this paper describe the organization of the courses and their deliverables, and the annual themes and the aircraft that the museums provided, followed by examples of the students' work. Subsequent sections describe the methodology used to study the students, the results of surveys and interviews, and a discussion of the findings in relation to the following research questions:

1. What are the students' initial responses to encountering an open-ended analysis project?
2. Do the students' technical skills develop linearly during the courses or is the development recursive?
3. How do students' conceptualizations of an open-ended problem develop throughout the project?
4. Does an open-ended project in a cornerstone course provide improved preparation for senior capstone?

Description of Course Delivery, Content, and Organization

The two courses, Structures I and Structures II, have been taught by the instructor since the 2016-2017 academic year; however, Structures II was originally more designed focus and not a direct sequel to Structures I. Starting in the 2017-2018 academic year, the two courses were aligned and featured a continuous project. Both courses are delivered using a flipped-classroom approach where the instructor pre-recorded videos regarding the theories for each course, and organized the videos into YouTube play lists. Links to the play lists are provided through the courses' Moodle pages. The students are provided with a schedule of the videos that must be watched prior to each class meeting session. In each class meeting session, the instructor poses a series of conceptual questions regarding the content shown in the assigned videos. The conceptual questions are to gauge the students' understanding of the theories and concepts. Depending on the students' responses, the class examples are modified appropriately or time is allocated to further explain the concepts.

The examples are intended to provide the students with realistic scenarios that practicing engineers encounter where simplifying assumptions must be made. The instructor designed both courses following the Wiggins framework for authentic assessments where the in-class examples and some components of the project are formative assessments, while the final reports and final exams are summative assessments. The Wiggins framework enumerates the elements that an assessment must have to be considered authentic [1, 2]. An assessment must

1. be realistic,
2. require judgement and innovation,
3. push students to work in the subject,
4. duplicate what practitioners encounter,
5. assess a range of knowledge and skills, and
6. provide an opportunity to practice and receive feedback.

Additionally, the instructor used an inverse design approach to the courses where the final exams were designed first, then the course projects were defined. Once the course projects were defined, the individual project deliverables were developed and scheduled for a semester. These deliverables, in turn, defined the concepts, knowledge, and skills that individual classroom examples were required to provide.

This framework overlaps with some of the principles of open-ended modelling problems (OEMPs) [3, 4]. Research on authentic assessments predates OEMP research, and was driven by case-based learning and project-based learning. The more recent OEMP research postulates the need for certain elements in a given classroom example that may not originate from a case study or project. Further, the course projects used in Structures I and II are at a much larger scale than typical OEMPs.

The focus of Structures I is the analysis of the loads and resulting displacement, strain, and stresses in the wings and stabilizers of an aircraft. Students learn and apply energy methods, Rayleigh-Ritz approximation for beam bending, single-cell web-stringer analysis, multi-cell web-stringer analysis, and column and sheet buckling. The Accreditation Board for Engineering and Technology (ABET) [5] outcomes for this course are

- (1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
- (3) an ability to communicate effectively with a range of audiences
- (5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

These outcomes are achieved through a sequence of deliverables displayed in Table 1 with their corresponding weights toward the final grade. The order of the deliverables in the table reflects the order of submission throughout the semester. Most deliverables are completed by the group as a whole; however, the six digital logbooks and the final exam are completed individually. The digital logbooks do not carry a weight toward the final grade, instead they are to encourage the professional practice of engineers documenting their work.

The instructor also reads the logbooks to assess where students may be struggling or to determine if the distribution of work within a group is unbalanced. Work distribution is further monitored

Table 1: Course Deliverables for Structures I

Quantity	Description	Weight (%)	ABET Outcome
1	Project Proposal	2.5	3
1	Loads Memo	5	1, 3, 5
1	Progress Report	7.5	1, 3, 5
1	Multi-Cell Web-Stringer Memo	5	1, 3, 5
1	Presentations	10	1, 3, 5
1	Buckling Memo	5	1, 3, 5
1	Final Report	15	1, 3, 5
1	Final Exam	50	1
6	Digital Logbook	0	1, 5

through periodic CATME surveys. For each deliverable, the students are encouraged to submit drafts of the memos and reports to the instructor in advance of the due date. The instructor provides extensive feedback to the students, thus meeting the last element (6) in the Wiggins' framework.

The first five elements of the Wiggins' framework are met through the other deliverables. The students work on actual aircraft and/or spacecraft in museums' collections thus satisfying (1) be realistic and (3) push students to work in the subject. The analyses that the students use are the same analyses used by practicing engineers so (4) duplicate what practitioners encounter is satisfied. These analyses require judgement (2) to achieve certain simplifications between the real structure and the analysis techniques. The scale of the project helps achieve requirements (3) and (5) where students use a range of techniques.

In January, when the students return from the winter break, they enter Structures II. The groups are reformed, using CATME, and the aircraft are reassigned. The group reformation is to expose students to working in new teams, while the aircraft assignments are to broaden students' exposure to different aircraft designs. The focus of Structures II is the analysis of the loads and resulting displacement, strain, and stresses in the fuselage of an aircraft or the body of a spacecraft. Structures II features MATLAB as students are exposed to Galerkin's method for solving partial differential equations, convergence studies, and validation techniques. The concepts included in the course are longitudinal and lateral displacements of beams, circular plates, rectangular plates, simple cylindrical shells, and stiffened cylindrical shells. The ABET outcomes for this course are

- (1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
- (3) an ability to communicate effectively with a range of audiences
- (5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

Similar to Structures I, there are a sequence of deliverables to achieve the ABET outcomes. The deliverables are shown in Table 2, and the course also uses CATME and frequent feedback mechanisms.

Table 2: Course Deliverables for Structures II

Quantity	Description	Weight (%)	ABET Outcome
1	Project Proposal	2.5	3, 5
1	Load Memo and Code	5	1, 3, 5
1	Progress Report	7.5	1, 3, 5
1	Plate Memo and Code	5	1, 3, 5
1	Presentations	10	1, 3, 5
1	Shell Memo and Code	5	1, 3, 5
1	Final Report	15	1, 3, 5
1	Final Exam	50	1
6	Digital Logbook	0	1, 5

The unique features of Structures II is that the final exam also involves MATLAB; therefore, the final exam is sat in a computer lab. The students are provided with a specialized toolbox of functions for the exam, created by the instructor. The groups create MATLAB code during the project, but the student code is often too slow and too specific to be compatible with the exam questions and the three hour time limit of the exam.

For both courses, the museums are invited to attend the presentations via Zoom. The presentation periods have allocated time for the museum staff to ask questions of the students. The museums are also provided copies of the progress reports and the final reports. The instructor reserves the right to not share a report if the quality is inadequate. The instructor has exercised this right most often with the progress reports in Structures I with typically two progress reports each year not being shared. The students make the necessary improvements to their analyses and report writing by the final report. Only once has the instructor not shared a final report from Structures I. By Structures II, the students are more familiar with the expectations and the progress and final reports are shared.

Examples of Course Projects

During the 2020-2021 academic year, the course project theme was WWII and each museum provided an aircraft from their collections that was used during the war. The aircraft and their associated museums are listed in Table 3.

Table 3: Participating Museums and Their Aircraft During 2020-2021

Aircraft	Museum	Location
Consolidated PBY Catalina	Alaska Aviation Museum	Anchorage, AK
Douglas SBD-1 Dauntless	Flying Leatherneck Aviation Museum	San Diego, CA
Beech SNB-5	Combat Air Museum	Topeka, KS
Avro Lancaster	National Air Force Museum of Canada	CFB Trenton, ON
Fairey Firefly	Canadian Warplane Heritage Museum	Hamilton, ON
Grumman FM-2 Wildcat	New England Air Museum	East Granby, CT
Grumman F6F Hellcat	Cradle of Aviation	Garden City, NY
Douglas C-47 Skytrain	National Warplane Museum	Geneseo, NY
Mitsubishi A6M5 Zeke	Planes of Fame	Chino, CA
Martin AM Mauler	Martin Maryland Aviation Museum, National Naval Aviation Museum*	Middle River, MD Pensacola, FL
Vought F4U Corsair	National Naval Aviation Museum	Pensacola, FL

* The National Naval Aviation Museum graciously stepped in for the Mauler when the Martin Maryland Aviation Museum was unable to continue.

Examples of the work that the students produced for the Consolidated PBY Catalina during both courses are shown in Figure 1. This work includes a load analysis, multi-cell web-stringer analysis of the wing, and plate and shell analyses of the fuselage under hydrodynamic loads. The wing analysis is representative of most group's abilities in Structures I, while the CAD drawings of the fuselage are exceptional for Structures II:

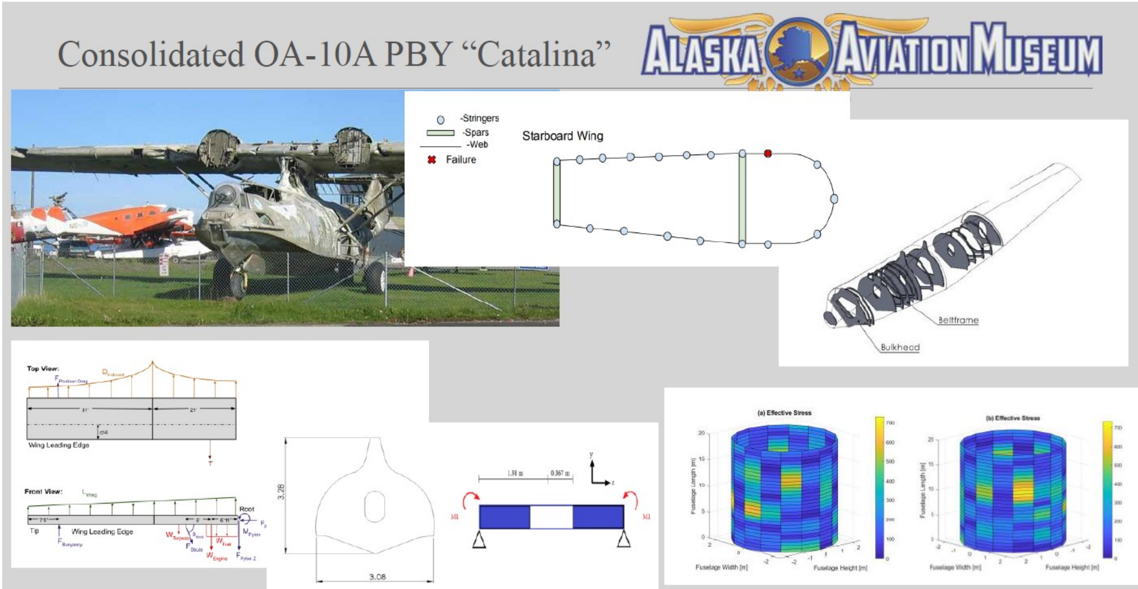

Figure 1: Structural analyses completed by two groups working on the Consolidated OA-10A PBY Catalina provided by the Alaska Aviation Museum during 2020-2021

The students also encountered challenges with the source documentation. One of the aircraft was the Mitsubishi A6M5 Zero, shown in Figure 2, and all of the source documentation was in Japanese. The students were resourceful and used Google Translate’s image function to translate the relevant portions of the documentation.

For the 2021-2022 academic year, a new theme was selected in collaboration between the lead author and the curatorial staff at all the museums. The new theme was Diversity and Inclusion in Aerospace Engineering because 2021 was the 100th anniversary of Bessie Coleman being the first African-American woman to receive a pilot’s licence. The project was modified to include an under-represented minority pioneer with each aircraft because the museums indicated that their guests are more attracted to an exhibit if the technology is connected to a person. The aircraft and individuals are listed in Table 4. New museums joined the project during this year including the National Aviation Hall of Fame to provide biographical information about the pioneers. Further, some of the pioneers are currently alive and the students were able to interview the pioneers with the guidance of an oral history professor at Clarkson University.

The students’ study of the pioneers provided information about how the pioneers flew or designed the associated aircraft. This information was used to compute the loads applied to the aircraft for the subsequent structural analyses. A particular challenge during this iteration of the project was that the aircraft represented 100 years of aviation history, whereas the previous iteration had aircraft from the same era. Students encountered the limitations of some of the more modern structural analysis techniques when they were applied to early aircraft such as the Tiger Moth shown in Figure 3.

The San Diego Air and Space Museum joined the project in January 2022 and provided the Apollo 9 capsule for students to do a forward study of the Orion capsule as Artemis will have the

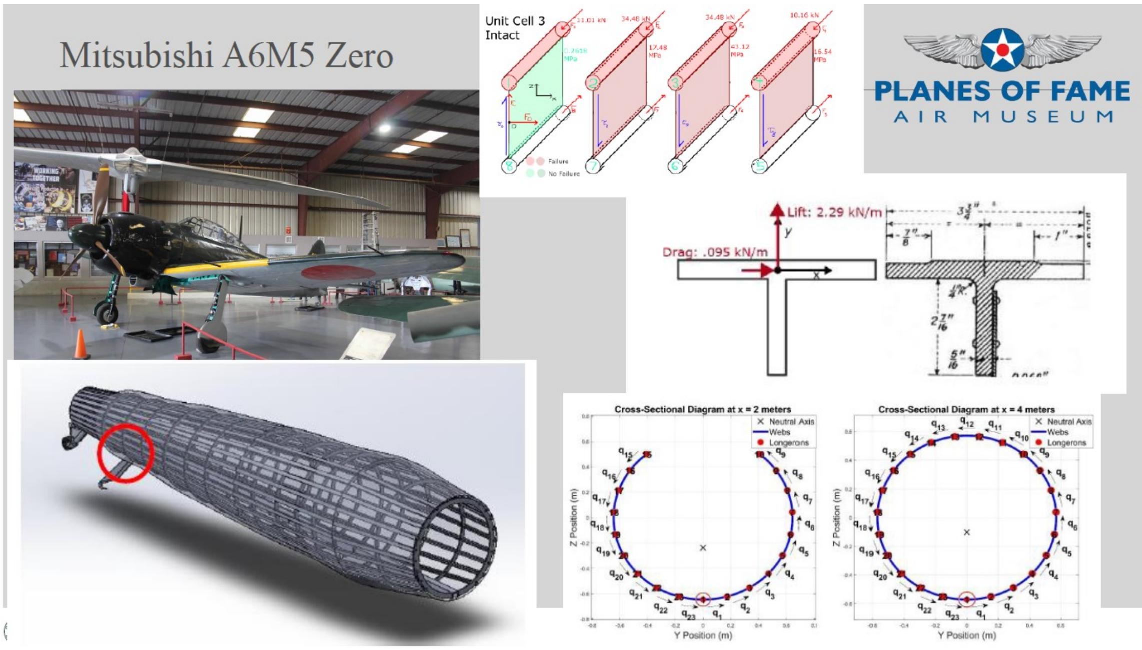

Figure 2: Structural analyses completed by two groups working on the Mitsubishi A6M5 Zero provided by the Planes of Fame Air Museum during 2020-2021

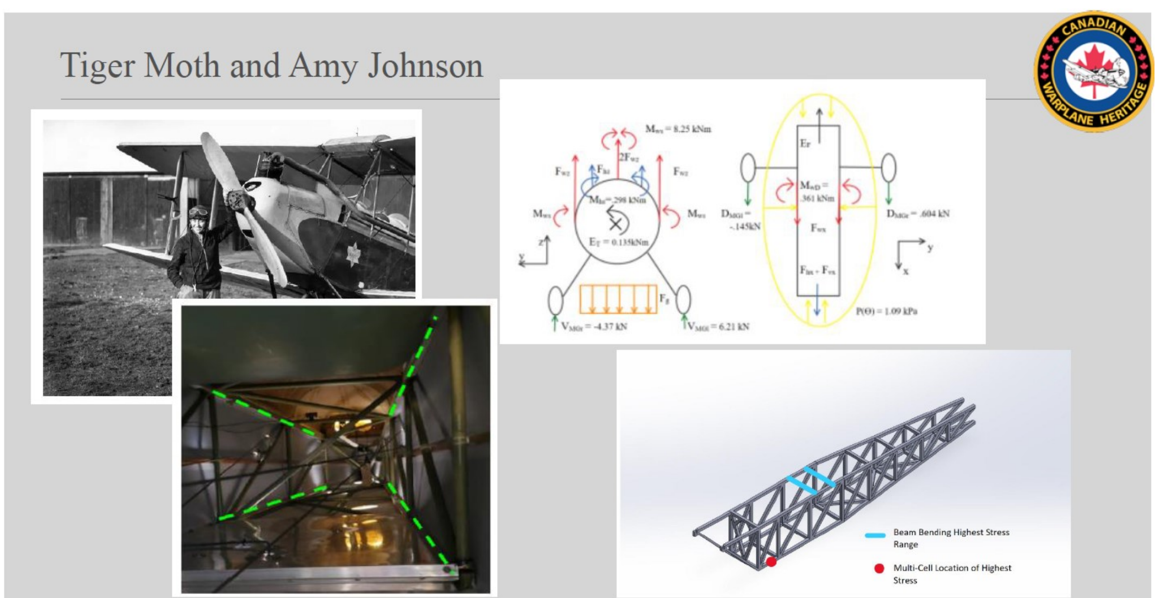

Figure 3: Structural analyses completed by two groups working on the De Havilland Tiger Moth as flown by Amy Johnson, provided by the Canadian Warplane Heritage Museum during 2021-2022

Table 4: Participating Museums, Their Aircraft, and Under-Represented Minority Pioneer During 2021-2022

Person	Aircraft	Museum	Location
Lee Ya-Ching	Stinson V-77	Alaska Aviation Museum	Anchorage, AK
Olga Custodio	Northrop T-38 Talon	Flight Test Museum	Edwards AFB, CA
Bessie Coleman	Curtiss JN Jenny	Combat Air Museum	Topeka, KS
Micky Colton	Lockheed CC-130E Hercules	National Air Force Museum of Canada	CFB Trenton, ON
Amy Johnson	Tiger Moth	Canadian Warplane Heritage Museum	Hamilton, ON
Amelia Earhart	Lockheed Model 10-A	New England Air Museum	East Granby, CT
Eileen Collins	Orbiter - Discovery	Cradle of Aviation	Garden City, NY
Harriet Quimby	Bleriot Type XI	Cradle of Aviation	Garden City, NY
Mary Golda Ross	Lockheed P-38 Lightning	Planes of Fame	Chino, CA
Brandy Jackson Ashley Ruic Nydia Driver Ashley Ellison Tara Refo	Northrup Grumman E-2 Hawkeye	Naval Aviation Museum	Pensacola, FL
Stephanie Wilson	Apollo 9 Capsule	San Diego Air and Space Museum	San Diego, CA

first under-represented minorities landing on the Moon. The results of these analyses are displayed in Figure 4.

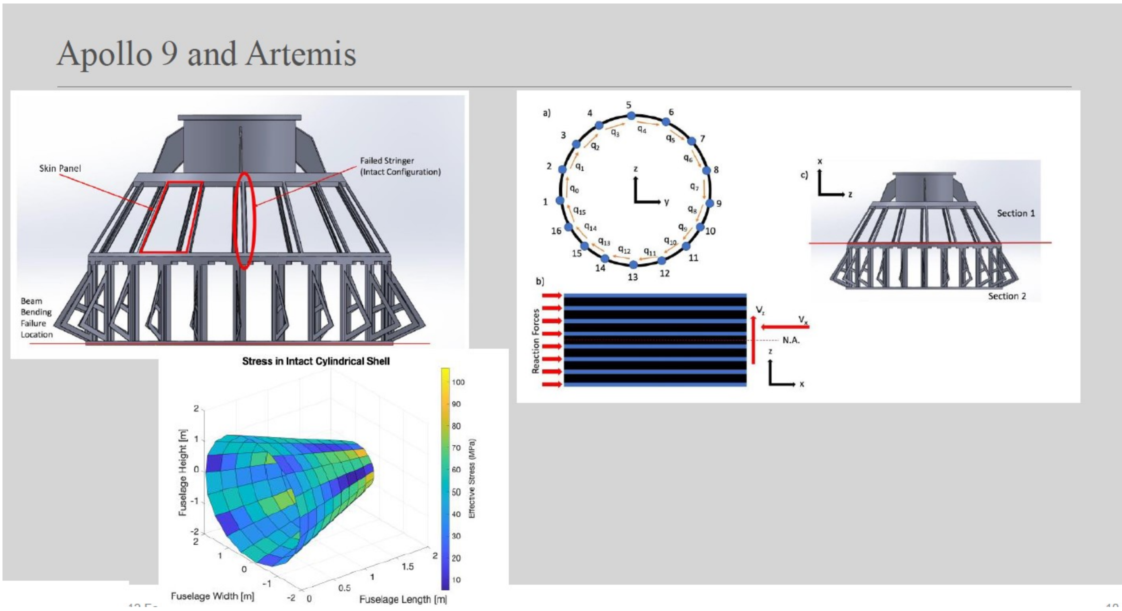

Figure 4: Structural analyses completed by two groups working on the Apollo 9 capsule as a representative capsule for Artemis to be flown by a future pioneer, provided by the San Diego Air and Space Museum during 2021-2022

For the 2022-2023 academic year, the theme is Pushing Limits in recognition of a number of significant aerospace events including

- 15th anniversary of the Afghanistan War
- 50th anniversary of the Vietnam War
- 50th anniversary of the F-15 Eagle
- 70th anniversary of the Korean War
- 75th anniversary of Breaking the Sound Barrier
- 80th anniversary of the founding of the Mighty Eighth Air Force
- 100th anniversary of Carrier Landings

Similar to the 2021-2022 academic year, each aircraft is analyzed in the context of someone who flew or designed the aircraft. The aircraft and individuals are listed in Table 5, and include two new museums from Georgia.

Similar to the previous year, the students overcame challenges applying the structural analyses to some of the aircraft given the range of time periods included in the project. Also, some of the aircraft designs were unique such as the Burnelli CBY-3 displayed in Figure 5.

Table 5: Participating Museums, Their Aircraft, and Individual During 2022-2023

Person	Aircraft	Museum	Location
Lt. Col. Kettles	Bell UH-1H Huey	Alaska Aviation Museum	Anchorage, AK
Jack Ridley	Northrup X-4	Flight Test Museum	Edwards AFB, CA
George Graff	McDonnell Douglas F-15 Eagle	Combat Air Museum	Topeka, KS
Capt. William Fielding	Boeing CH-47 Chinook	National Air Force Museum of Canada	CFB Trenton, ON
Flt. Lt. Omer Leveque	North American F-86 Sabre	Canadian Warplane Heritage Museum	Mount Hope, ON
Vincent Burnelli	Burnelli CBY-3	New England Air Museum	East Granby, CT
Jim “Slug” Kidrick	LTV A-7B Corsair II	San Diego Air and Space Museum	San Diego, CA
Lindell Hendrix	Consolidated B-24 Liberator	National Museum of the Mighty Eighth Air Force	Pooler, GA
Ben Rich	Lockheed F-117 Nighthawk	Museum of Aviation	Robins AFB, GA
F-8 pilots	Vought F-8 Crusader	National Naval Aviation Museum	Pensacola, FL
Lt. Kheim Pham	Lockheed C-130A “Saigon Lady”	National Warplane Museum	Geneseo, NY

Figure 5: Structural analyses of the wings completed by one groups working on the Burnelli CBY-3, provided by the New England Air Museum during 2022-2023

Student Demographics in the Courses

For the subsequent analyses of the students' survey and interview data, the demographics of the courses during each iteration are useful to consider. The gender demographics are provided in Table 6 through data collected during the CATME team formation survey that had limited options for gender. For reference, Structures I 2020 had 53 students, Structures II 2021 had 48 students, Structures I 2021 had 53, Structures II 2022 had 50 students, and Structures I 2022 had 46 students:

Table 6: Gender Demographics in Structures I and Structures II for 2020 through to 2022

Gender	Structures I 2020	Structures II 2021	Structures I 2021	Structures II 2022	Structures I 2022
Female (%)	15	16.6	13.2	14	8.7
Male (%)	85	83.3	86.9	86	91.3
Other (%)	0	0	0	0	0

Table 6 indicates that in all iterations of the courses, the student populations were predominately male. The ethnicity demographics are shown in Table 7 via self-reporting:

Table 7: Ethnicity Demographics in Structures I and Structures II for 2020 through to 2022

Ethnicity	Structures I 2020	Structures II 2021	Structures I 2021	Structures II 2022	Structures I 2022
Asian (%)	0	0	1.9	2	0
Black (%)	0	0	5.7	6	2.2
Hispanic (%)	1.9	2.1	0	0	0
Islander (%)	3.8	4.2	0	0	0
White (%)	94.3	93.8	90.6	92	91.3
Other (%)	0	0	1.9	0	6.5

In all iterations of the courses, the student population was predominantly white with other ethnicities accounting for less than 10% of the student population.

Methods

As described in the Course Delivery section, Structures I and Structures II were designed following the Wiggins framework for authentic assessments. The research approach taken by the authors is to apply an OEMP lens to the students' conceptualization and integration of the course content. As a result, the survey questions described in the following are derived from earlier OEMP research [3, 4]. The surveys were administered by the third and fourth authors as they are from different institutions, thus avoiding conflict of interest issues, and have extensive experience in surveying students. The surveys were approved by the Institutional Review Boards. The responses to a subset of the survey instrument questions are examined here

- 2. I know what the expectations are from me when completing the case study project.
- 4. I am confident in the answers I submit for the case study project.
- 7. Before the semester started, I expected to do a case study project like this in Aircraft Structures.
- 11. I expect to work on tasks similar to the case study project if I work professionally as an engineer.
- 21. The case study project helped improve and reinforce my understanding of concepts taught in Aircraft Structures.
- 22. I enjoy completing the case study project.
- 26. I have done case study projects like this in my other non-lab/non-design engineering courses.
- 29. I enjoy working within a group on the case study project.

These questions were administered using a Likert scale with five levels: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree. Students were also asked to construct an affective pathway that describes their emotional state as they progressed through the projects [6]. The survey prompt for the pathways was

- 32. Drag and drop words to best describe your emotional pathway from start (top) to finish (bottom) of the project. - Groups - Emotional pathway while doing the case

Students could select the following adjectives for each step of the pathway that they constructed. Shown with each adjective is the valence, where +1 is positive, 0 is neutral, and -1 is negative.

- Accomplishment +1
- Anxiety -1
- Bewilderment 0
- Confident +1
- Confusion -1
- Curiosity 0
- Despair -1
- Distress -1
- Elation +1
- Encouragement +1
- Enjoyment +1
- Fear -1
- Frustration -1
- Pleasure +1
- Pride +1
- Puzzlement 0
- Satisfaction +1

Results

Formal surveying of the students began during the Structures II 2022 course and continued to the present. The results presented here are for Structures II 2022 and Structures I 2022, which are two different groups of students. Each subsection is organized with the Likert scale question results presented first, followed by the affective pathways that the students created.

Structures II 2022

The Structures II 2022 data is presented first because the course occurred between January 2022 and May 2022, while Structures I occurred later, September 2022 to December 2022. The students in Structures II were the first students to be surveyed from an OEMP perspective, and their responses to Questions 2, 4, 7, 9, 10, 22, 26 and 29 are presented in Figures 6 to 13. The students were surveyed at the end of the course, and 21 students responded to the survey leading to a response rate of 42%.

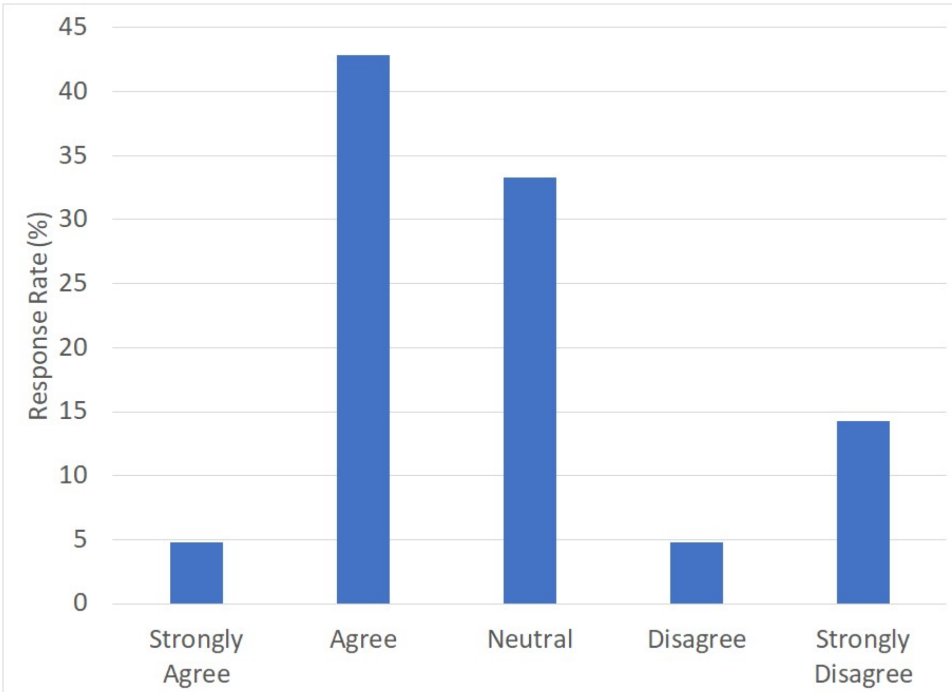

Figure 6: Results for Q2: I know what the expectations are from me when completing the case study project.

The affective pathway data is presented using a word cloud approach (Figure 14). The size of the words corresponds to the frequency of that adjective, and the colour relates to the valence of the adjective. Words in blue are positive, words in black are neutral, and words in red are negative. The average path length created by students was approximately 7 with a standard deviation of 2.

Structures I 2022

In Structures I 2022, the students were surveyed near the start of the course (October 2022), and after the completion of the course (January 2023). This group of students was different than the group surveyed for Structures II 2022. The results of both surveys are combined in the following histograms. The number of respondents were different between October (22 students) and January (26 students) requiring the use of percentages to compare the results. Further, the IRB in use did not allow for collecting identifiable data; therefore, the number of students that responded to both surveys is unknown.

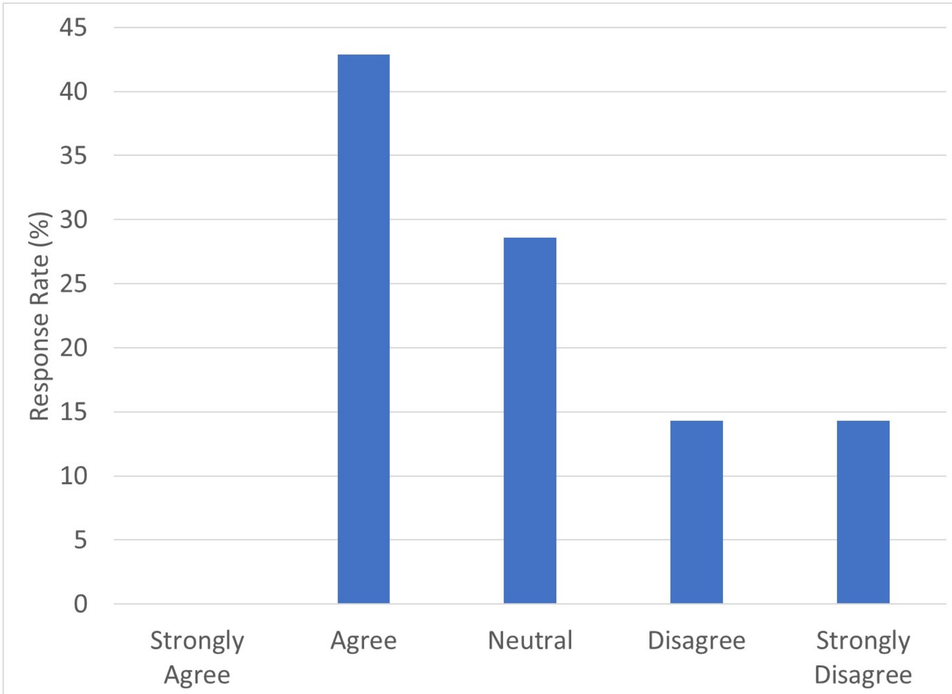

Figure 7: Results for Q4: I am confident in the answers I submit for the case study project.

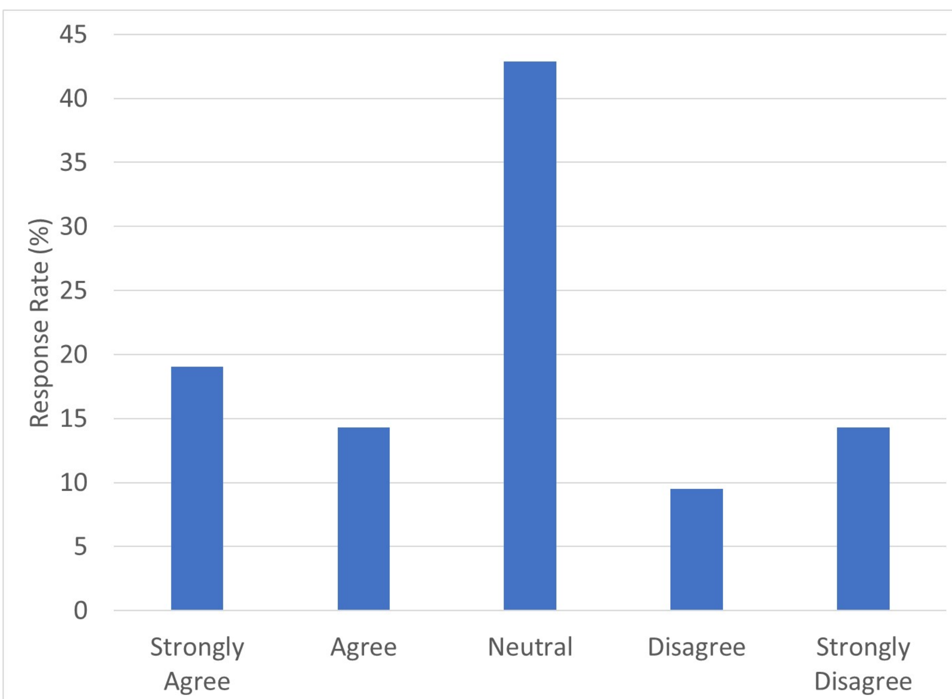

Figure 8: Results for Q7: Before the semester started, I expected to do a case study project like this in Aircraft Structures.

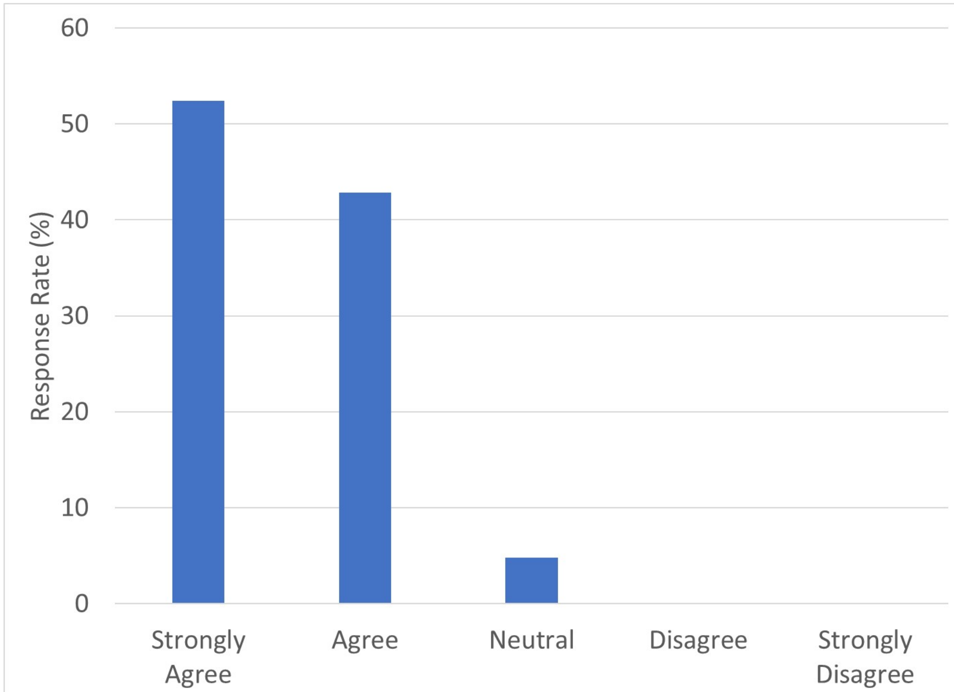

Figure 9: Results for Q11: I expect to work on tasks similar to the case study project if I work professionally as an engineer.

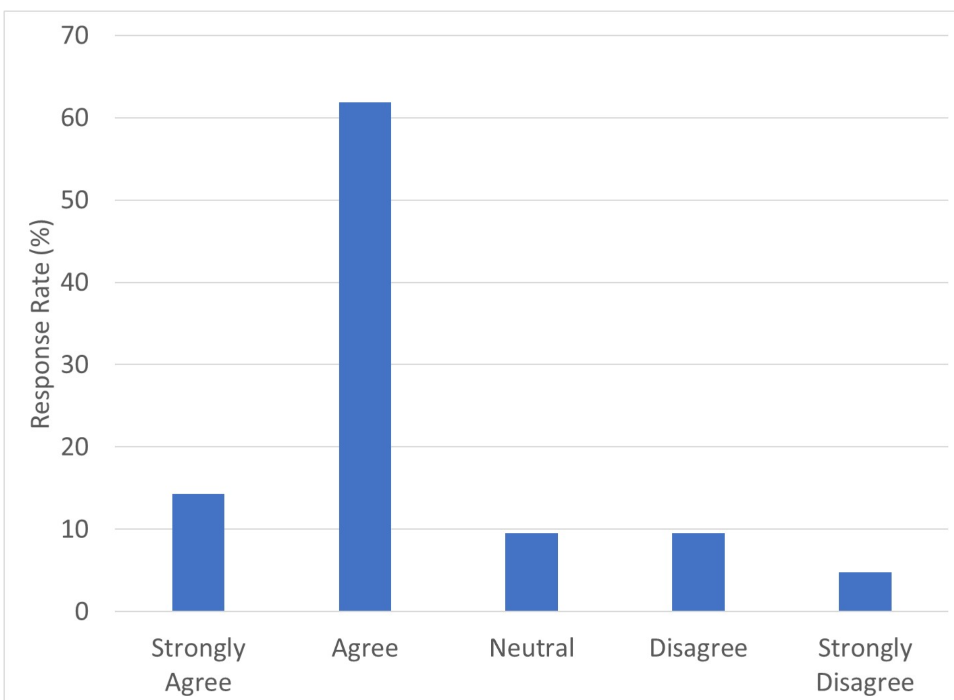

Figure 10: Results for Q21: The case study project helped improve and reinforce my understanding of concepts taught in Aircraft Structures.

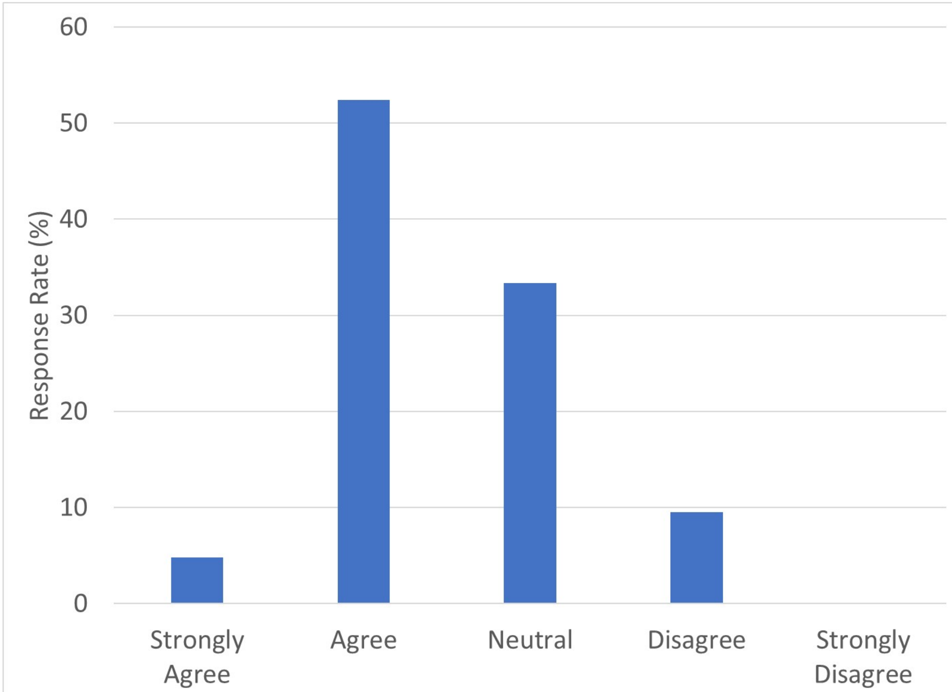

Figure 11: Results for Q22: I enjoy completing the case study project.

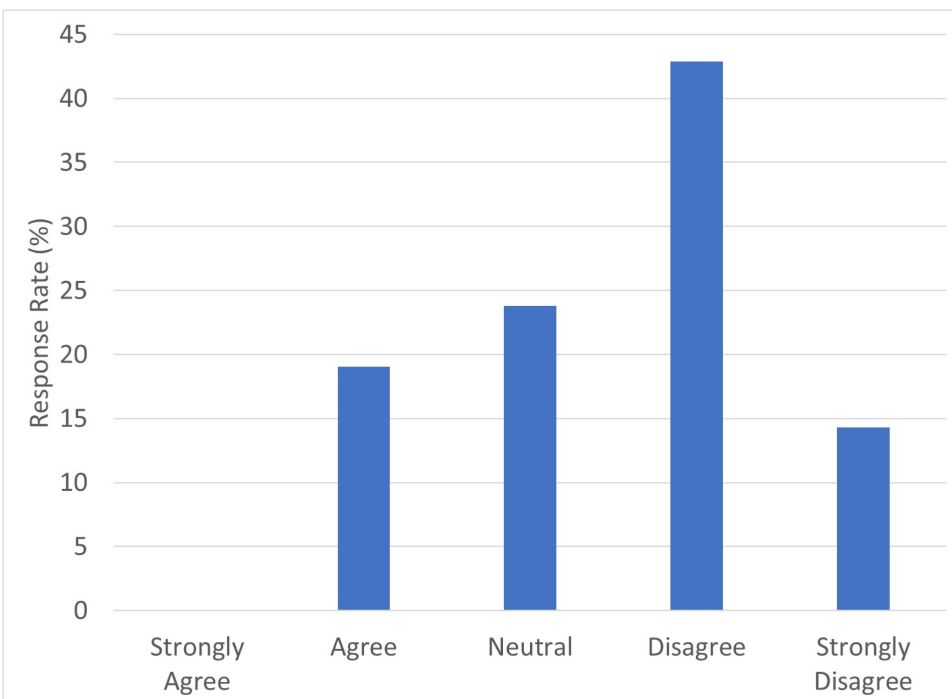

Figure 12: Results for Q26: I have done case study projects like this in my other non-lab/non-design engineering courses.

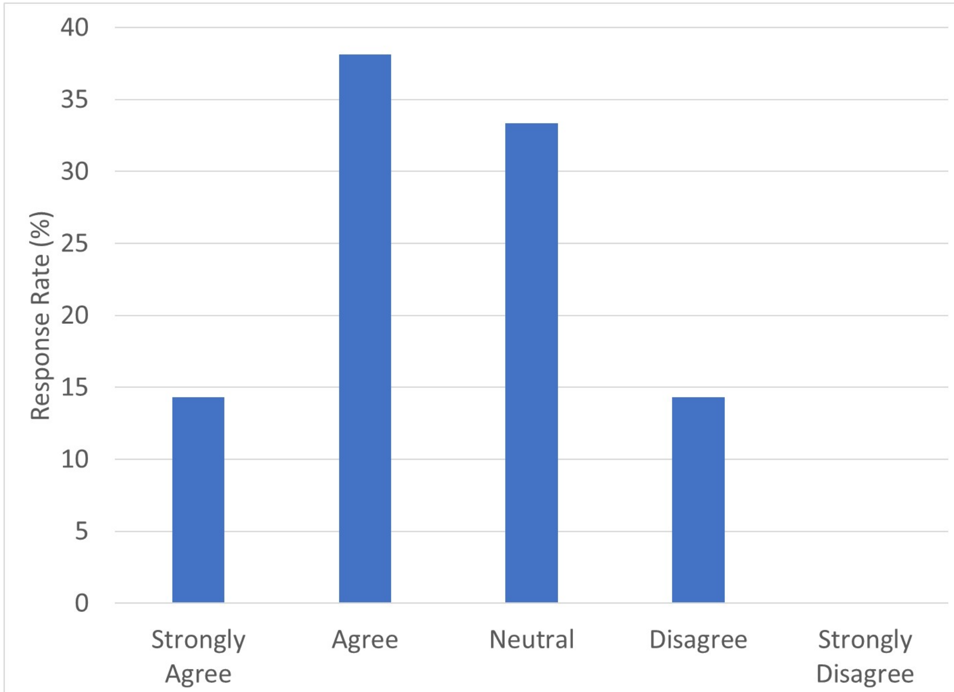

Figure 13: Results for Q29: I enjoy working within a group on the case study project.

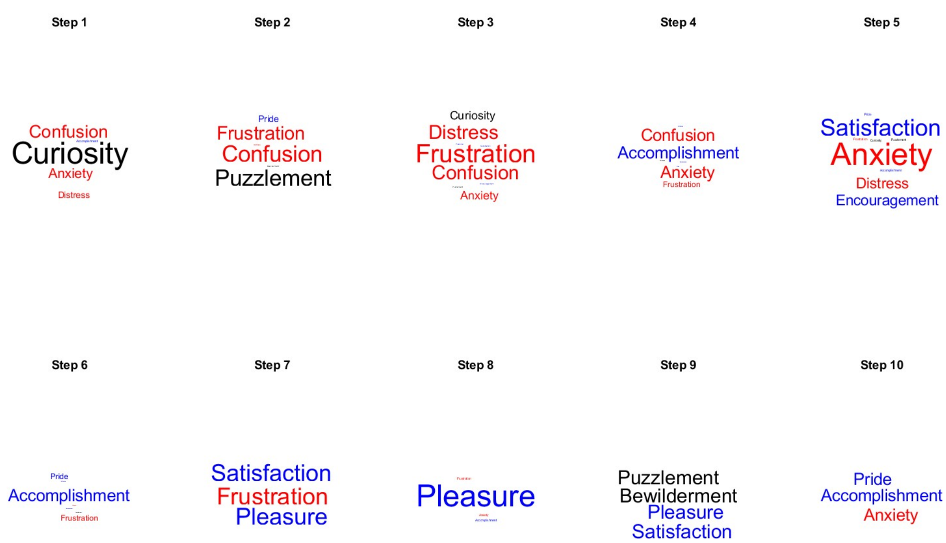

Figure 14: Affective pathways for Structures II, surveyed in May 2022

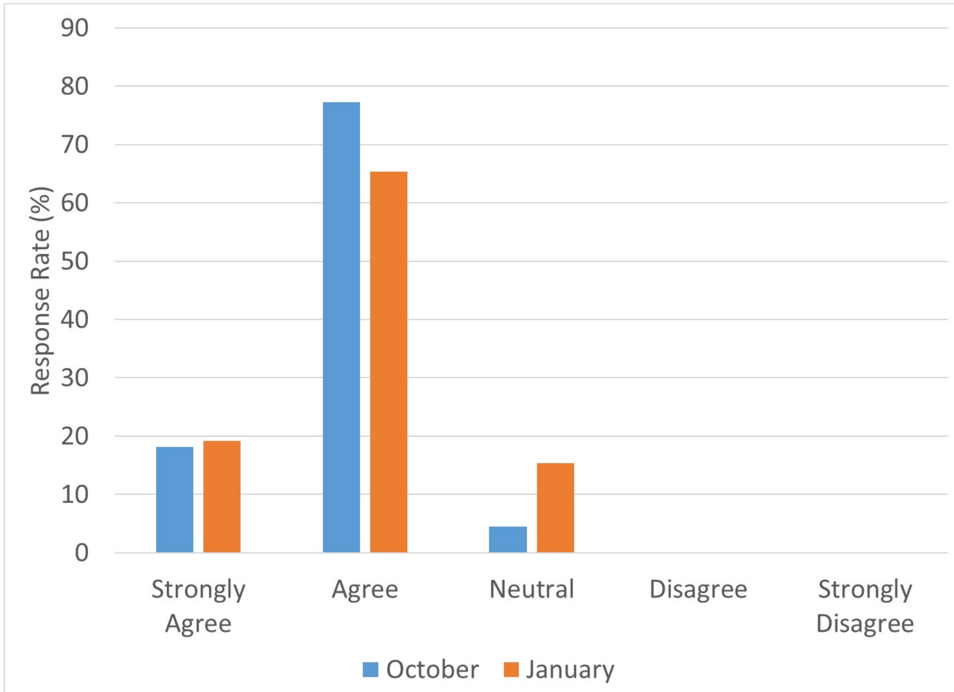

Figure 15: Results for Q2: I know what the expectations are from me when completing the case study project.

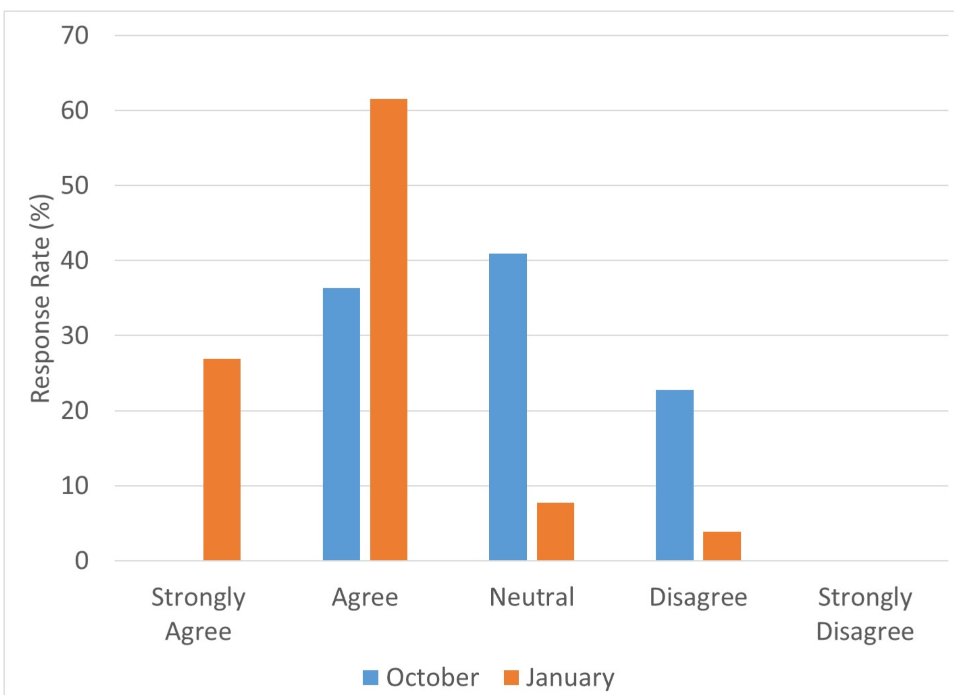

Figure 16: Results for Q4: I am confident in the answers I submit for the case study project.

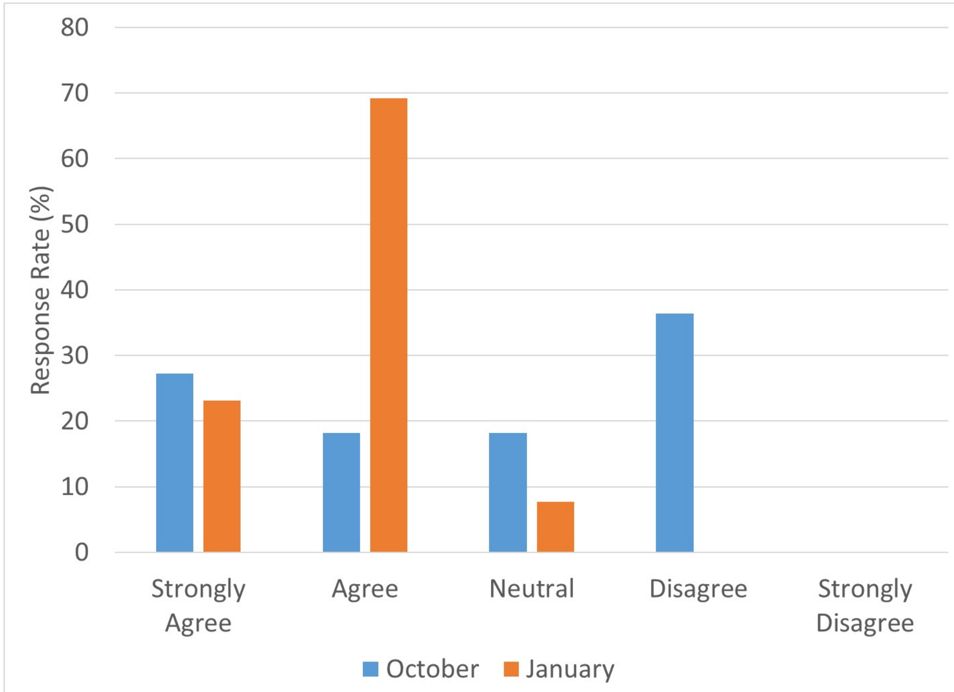

Figure 17: Results for Q7: Before the semester started, I expected to do a case study project like this in Aircraft Structures.

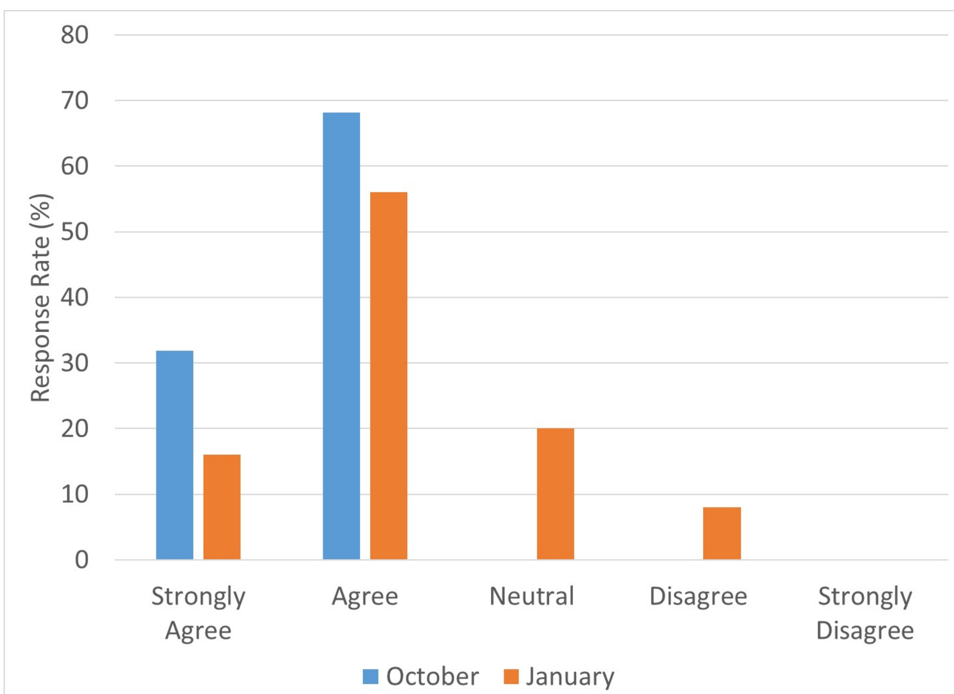

Figure 18: Results for Q11: I expect to work on tasks similar to the case study project if I work professionally as an engineer.

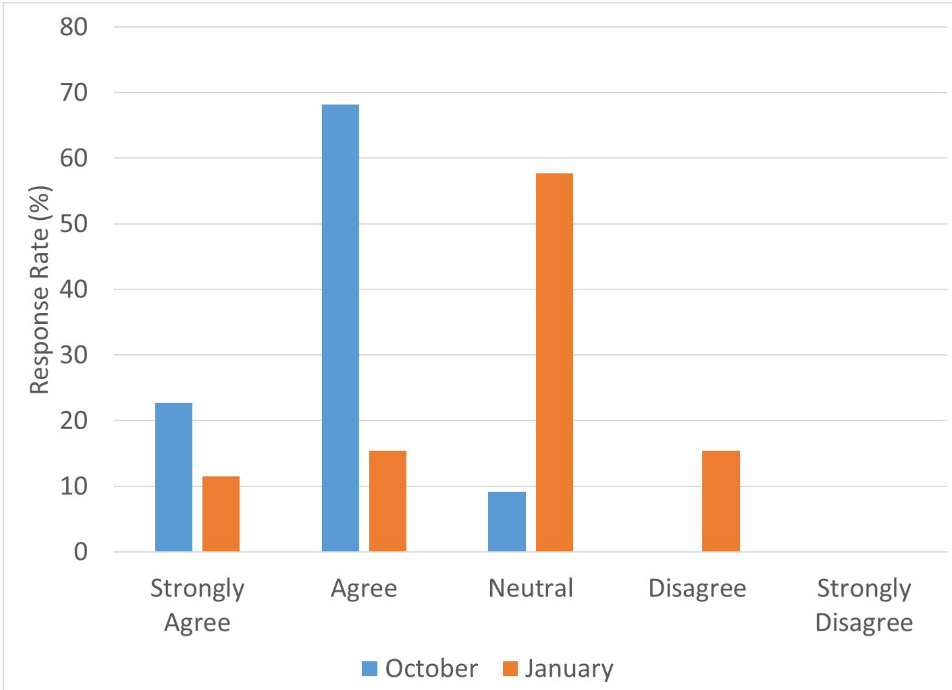

Figure 19: Results for Q21: The case study project helped improve and reinforce my understanding of concepts taught in Aircraft Structures.

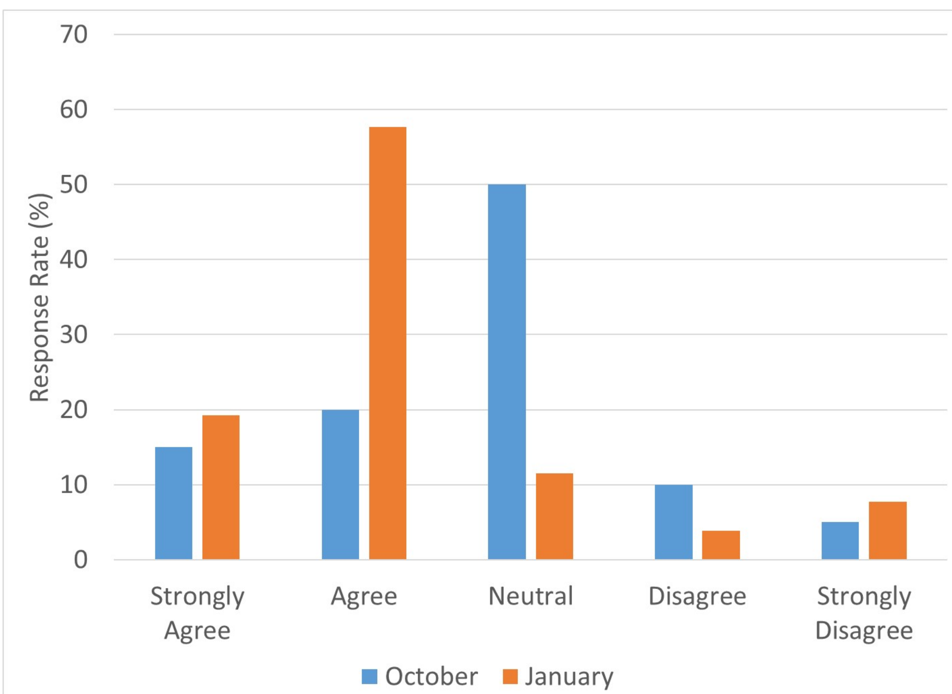

Figure 20: Results for Q22: I enjoy completing the case study project.

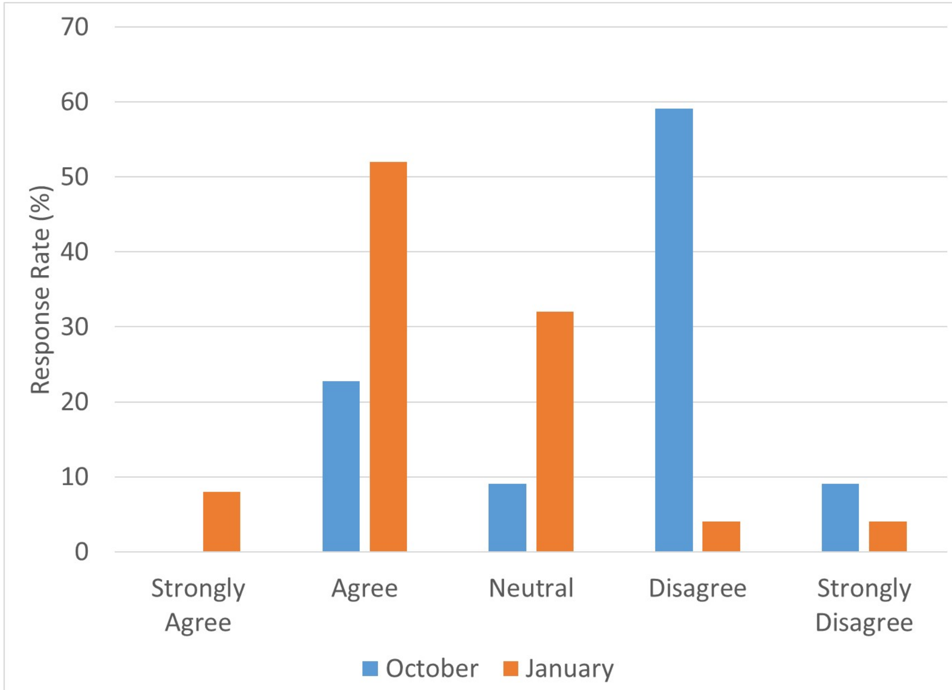

Figure 21: Results for Q26: I have done case study projects like this in my other non-lab/non-design engineering courses.

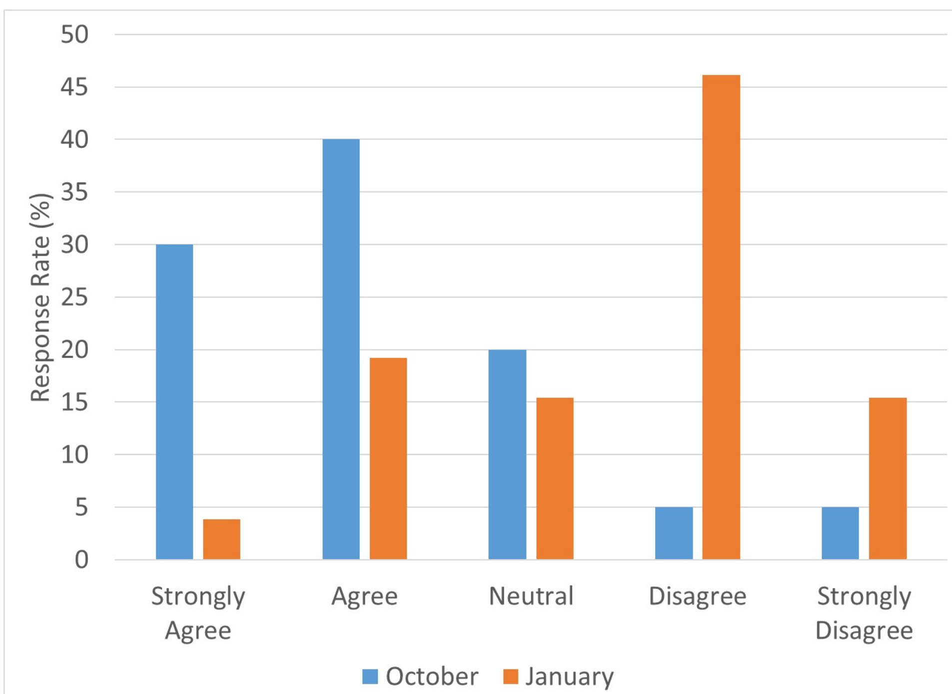

Figure 22: Results for Q29: I enjoy working within a group on the case study project.

The affective pathway data for Structures I is shown in Figures 23 and 24. The average affective path length when surveyed in October and January was 5 with a standard deviation of 2.

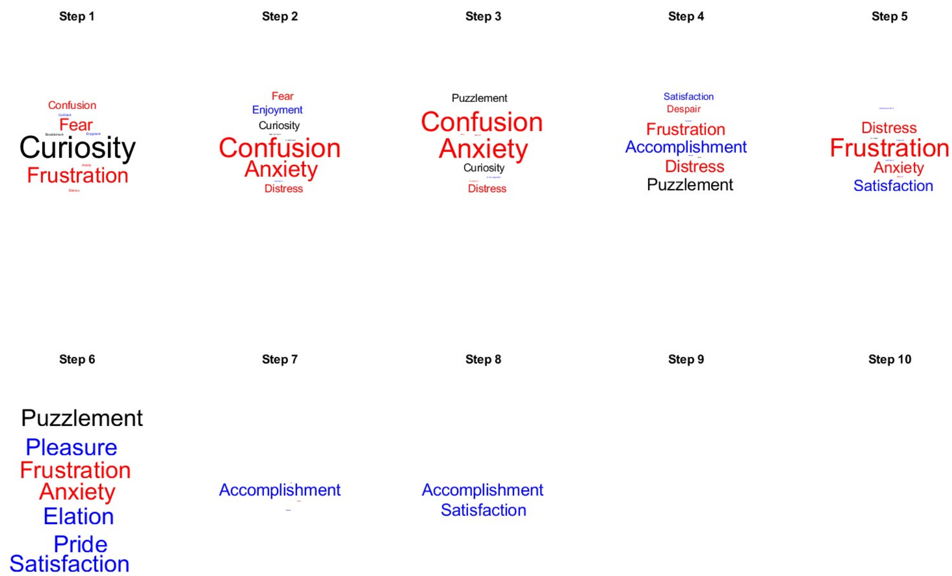

Figure 23: Affective pathways for Structures I, surveyed in October 2022

Discussion

The results shown for Structures II 2022 and Structures I 2022 are useful for demonstrating the students' progression through open-ended modelling problems. The students surveyed for Structures II 2022 had already completed Structures I and the survey was completed near the end of Structures II; therefore, the results reflect students who are at the end of the two courses. The students surveyed for Structures I 2022 were surveyed twice throughout the course thus their results reflect students' progression in handling OEMPs.

What are the students' initial responses to encountering an open-ended analysis project?

From the affective pathway construction data collected in October 2022, the students initially have a largely neutral response denoted by the Curiosity adjective. As the students progress through the project, they encounter negative feelings such as Confusion, Anxiety, Frustration, and Distress. These emotions eventually change (shown in the January 2023) data to positive feelings such as Satisfaction, Accomplishment, and Pride. A similar path was seen for the students surveyed in May 2022, after completing both Structures I and Structures II.

A possible limitation of the data is that different subsets of the students may have replied to each survey. For example, students that enjoyed the project responded during the October 2022 survey, while students that disliked the project responded during the January 2023 survey.

Figure 24: Affective pathways for Structures I, surveyed in January 2023

Do the students' technical skills develop linearly during the courses or is the development recursive?

The development of the students' technical skills appears to be a recursive process based on the results for Question 21 for both Structures I and Structures II. In October for Structures I, a majority of students agreed (70%) that the project helped to improve their conceptual understanding; however, by January a majority of the students were neutral in their response. By the end of Structures II in 2022, the majority of students surveyed agreed that the project helped their conceptual understanding.

How do students' conceptualizations of an open-ended problem develop throughout the project?

Students' answers to Questions 4 (Figure 16), 11 (Figure 18) and 21 (Figure 19) are useful in exploring students' conceptualizations of OEMP. The students answers to Question 4 show an increase in confidence in their answers as they progressed through the project which was an objective of the course instructor. Further, this result indicates that OEMPs are effective in increasing students' confidence. The results for Question 11 show an unexpected trend where students' expectation of working on similar tasks in industry decreased between October and January. These results are unexpected because the techniques that the students are shown in both courses and their applications mirror industry. The Structures II 2022 results show a highly positive responsive, suggesting a recursive aspect to students' thoughts about what they will do in industry. A potential limitation with this question is a lack of clarity between OEMP tasks and structure specific tasks. The students' answers may reflect a decreased interest in pursuing an aerospace structures related position in industry. Last, Question 21 also demonstrated an unexpected result showing a decrease in conceptual understanding between October and January; however, the results from Structures II 2022 (Figure 10) survey indicate much higher agreement about the project reinforcing conceptual understanding. This trend indicates that students' conceptualizations of OEMP follow a recursive development similar to their technical skills.

Does an open-ended project in a cornerstone course provide improved preparation for senior capstone?

Surveys of students enrolled in the senior capstone are currently ongoing. These are the same students who completed the May survey in Structures II. The senior capstone involves a large design challenge that students pursue in teams of 10 or more students. From the presented data related to Questions 22 (Figure 20) and 29 (Figure 22), students are likely to enjoy the senior capstone because the project involves designing an aircraft. Last, students are expected to encounter similar group challenges that led to an overall negative assessment of their enjoyment of group work in Question 29.

Implications

The implications of this study are related to the use of museum exhibits to provide authentic assessments, and how these assessments support open-ended modelling behaviours and skills in students. The results indicate a recursive relationship in the development of students' technical skills and conceptual understanding. The study at Clarkson University has the benefit of two, consecutive Structures courses where this recursive relationship can be detected. Executing a similar museum project in a single course without a consecutive sequel may cause a decline in students' skills suggesting that OEMP type projects should be structured across at least two courses. Another implication of the study is that these projects increase students' confidence in their answers.

Conclusions

Clarkson University implemented authentic assessments that leverage open-ended modelling in two consecutive, mandatory aerospace structures courses taken during the junior year by students enrolled in the aerospace program. These projects involve collaborations with aviation museums across Canada and the United States where students, in teams of 4 to 5, work with a given museum to structurally analyze an aircraft in the museum's collection. Each academic year, a new theme is selected for the project, and recent themes involved students also studying a pilot or engineer related to their aircraft to determine the loads applied to the aircraft. The students complete a series of deliverables that involve non-technical communications with the museums, and the delivery of content that could be incorporated in a museum's display.

Three surveys of two classes of students have been completed to date. These surveys attempt to determine the effectiveness of the museum project in increasing students' technical skills, confidence, conceptual understanding, team work ability, and preparation for industry. Further, the surveys assess the students' affective pathways as they progress through the projects. The projects were found to increase students' confidence and revealed a recursive relationship in the development of students' technical skills, conceptual understanding, and expectations of what they will do as practicing engineers. Last, the affective pathways demonstrate that students begin with a neutral perspective (Curiosity) that evolves into a positive outcome (Pride, Satisfaction, Accomplishment) through a period of negative emotions (Distress, Confusion, Anxiety). The affective pathway indicates possible periods during the project when a course instructor should intervene.

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