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Implementation of an inductive learning and teaching framework for an Aircraft Flight Dynamics and Control class

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Abstract

Many aerospace engineering students have difficulties when learning the concepts in aircraft flight dynamics and control (AFDC) due to the complexity of the materials. Inductive learning and teaching methods promote connections between physical-hardware systems and the complex mathematical concepts by performing the dynamic modeling activities with fixed-wing Unmanned Aerial Systems (UASs). The inductive learning and teaching framework implemented at Iowa State University by combining two existing courses (AFDC class and project-based, student-run program). The inquiry-based teaching and project-based learning, which are components of inductive learning and teaching methods, have been applied for the lecture and project portion, respectively. The instructor posed challenging questions from previous lectures and provided opportunities for students to share answers among themselves during the lecture. The projects were given to students to provide hands-on experience while they learned the contents in class. Three surveys were collected throughout the semester to track the improvement of students' understanding. The study results show that students' perception of their understanding of class materials has improved. However, the minimal project instruction led to students' resistance. This paper may be useful for instructors who want to implement inductive-learning and teaching method to traditional lecture-based engineering courses.

1. Motivation and Background

Typically, flight dynamics classes are taught in a lecture form. The complexity of flight dynamic classes comes from mathematically heavy materials. The standard aerospace engineering curriculum requires students to take these classes when they become juniors. Suddenly, students are asked to combine and apply what they have learned during their freshman and sophomore years, including differential equations, linear algebra, vector calculus, and physics to understand the flight dynamics. Also, many research studies have examined effectiveness of active-learning technique. References [1-5] show that the active-learning technique correlated to positive and effective student achievement (e.g., critical thinking, writing, attitudes, and retention). Therefore, using a lecture-only approach as the delivery of class contents might not be efficient or useful for students in the long-term retention of the course material. In this work, the research team implemented inductive learning and teaching methods into lectures and projects to help students understand complex concepts.

The University of Kansas (KU) implemented a project-based learning approach for the flight dynamics and control class with meaningful and profound successes for students' learning outcomes, see Ref. [6]. However, the survey during the semester was not collected, and the size of the class was not large. In this paper, the research team deals with a large number of students, and a survey has been administered to capture students' performance. The goal of this work is to assist Aerospace engineering students in linking the theoretical concepts with the real-world application by implementing the inductive learning and teaching methods, see Ref. [7]. These methods are chosen to improve the lecture delivery by posing adequate challenges during the class lecture and combine with the project-based learning to provide the opportunity of hands-on to apply what students learn in class to the real-world example. In this work, these methods are implemented in a way that minimizes the modification of the existing curriculum and required efforts by combining the flight dynamics class and with a project-based learning program Make-to-Innovate program (M:2:I) at Iowa State University. The project has been designed to strengthen the connection between the unmanned aerial systems (UAS) and the mathematical concepts that students learned in lectures. The survey has been collected three times (pre-, mid-, and end-term) during the semester to track how well students understand the required material throughout the semester.

In summary, the class group performed dynamic modeling for variations of the aircraft geometry. The [program name redacted] provided the manufacturing capability of various platform designs to assist the class group during the semester. This paper presents the details of the implementation and the results of the data collected from this study.

2. Methods

In this section, we will (1) define the theoretical framework of inductive learning and teaching, (2) introduce the class project, (3) M:2:I at Iowa State University, and (4) the outcome measurement through survey.

Inductive learning and teaching method

Inductive learning and teaching methods have shown to be an efficient tool in motivating students by utilizing adequate challenges in class (e.g., cases in the real-world applications, complex problems, experimental data, etc.), see Ref. [7]. When an instructor delivers lecture materials using inductive learning and teaching methods, students rapidly recognize the necessity of engineering knowledge and skills to overcome the given challenge. Ref. [7] introduces many forms of inductive learning and teaching methods such as inquiry-based learning, discovery learning, problem-based learning, project-based learning, hybrid (problem/project-based) methods, case-based teaching, and just-in-time teaching. The challenge of implementing these methods are (1) logistical problem, (2) the requirement of more planning from instructors' end, and (3) the stimulation of student resistance and interpersonal conflict (Ref. [7]). In this work, inquiry-based learning for lecture and project-based learning methods were chosen because these methods align with the given challenge to students and the learning objective of this class.

Ref. [7] points out the instructional demands regarding all inductive learning and teaching methods. Inquiry-based learning does not demand any additional resources, and it demands a small amount of planning time and instructor involvement. Student resistance is often minimal to this approach. In contrast, project-based learning requires facilities for experimental projects and a considerable amount of planning time and instructor involvement. Student resistance is considerable. At Iowa State University, the instructor recognized that project-based learning would demand much time from students. The assigned credit hour for AFDC class (3 credit hours) would not be enough, so the instructor combined two existing courses, the AFDC course, and the [program name redacted]. The combination of these two courses helped avoid the modification of the existing curriculum and excessive workload of students' time.

Implementation of Inquiry-based learning in class

The definition of the inquiry-based learning is the method that motivates students' proactive thinking to solve the given challenges (e.g., questions to answer, hypothesis to test, data to be interpreted, etc.) to meet the learning objectives, see Ref. [7] and [8]. The instructor of this class implemented this method through (1) posing the review questions from the previous lecture, and (2) providing real-world examples based on the instructor's flight test experiments with answers. After the instructor poses the questions, the names of students were drawn randomly to answer the given question in the whiteboard. Two positive things were observed in this process. One is that most students would review the material before the class. The other is that the instructor can observe students' understanding of the previous lecture materials. The instructor could correct the misconceptions and share them with the entire class. Additionally, the instructor posed the question of 'what if' in the real-world problems to engage students in course materials and motivate their curiosity. A small-scale model aircraft was then used to demonstrate the equations of motion and to visually help the students' understanding of these equations and concepts.

Project-based learning by real-world applications

The project was designed to connect the theoretical concepts learned in class using the unmanned aerial system (UAS) so that students could have the opportunity to see, touch, and apply what they have learned to the real problem. Since the objective of this class was to teach the mathematic model of the fixed-wing aircraft, each team was assigned to one UAS with different geometry. The size of the class was 64 students. They were divided into seven teams for various geometric component modifications in a UAS. Table 1 shows each modified geometric component for teams. The first team did not change the geometry, and other teams modified

Table 1 Team assignment for different geometric component

Team 1	Original Platform
Team 2	Increase Wingspan
Team 3	Change sweep angle
Team 4	Change aileron size
Team 5	Change horizontal and vertical stabilizer size
Team 6	Change Elevator size
Team 7	Change Rudder size

Figure 1 Volantex RC Ranger Aircraft

Table 2 Aircraft Specifications

Wingspan	1980 mm (77.9 in)
Overall Length	1170 mm (46 in)
Flying Weight (without battery)	1500 g
Propeller Size	1060 Propeller
Motor Size	3715 Powerful Outrunner Brushless Motor
Speed Control	Easy-Plug 40 A Switch-mode BEC Brushless ESC
Servo	9-gram Servo (6 pieces included)
Recommended Battery	11.1 V/14.8 V 3300 mAh/10000 mAh LiPo
Flaps	Yes
Retracts	No
Assembly Time	~30 minutes

the required parts to model the different configurations. The goal of this project was to compare the effect of dynamic models to the original design for various geometric component modifications.

The chosen UAS was the off-the-shelf fixed-wing aircraft, Volantex RC Ranger Aircraft, see Figure 1 and Table *2*test to complete the dynamic modeling. Due to the duration of the semester and an excessive amount of required work, the motor thrust model was assigned to students.

The students were required to submit their technical report and present at the end of the semester. The instructor assessed the report and presentation to provide students with opportunities to develop their engineering communication and writing skills during the semester.

Ref. [7] showed challenges in the implementation of inductive learning and teaching methods because they demand more effort in planning, project management, and logistics. The instructor proposed to combine the existing course in Iowa State University, which is called Make-to-innovate (M:2:I), to avoid significant modification in the course catalog and logistic problems.

Make-to-Innovate program (M:2:I)

Make-to-Innovate program (M:2:I) at Iowa State University was developed 9 years ago to augment student's understanding of engineering concepts and teach them additional professional development skills. The program was designed to have students apply what they learn in the classroom to real world problems. This is done using a flipped classroom approach and a Project Based Learning (PBL) framework Ref. **[9]**. Through this program students are introduced to working on real world problems and are graded on both the goals they achieve as well as the approach they make.

The courses for M:2:I are taught using a flipped classroom and the program uses faculty advisors to guide the students. Technical advisors, often members from industry, are also brought on board to guide the students through the design, build, testing phases of the project. This allows for guidance on the project but allows the students to take ownership in the project and be active in the learning process. This allows students to learn about teamwork, communication, and leadership.

M:2:I has over 150 students in twelve different projects. The project referenced in this paper is one of those twelve. Students are assigned to a project based on a survey that asks for basic information and preference on the team. Most students are assigned to the project they request unless there need to balance the number of students. In that case students are assigned to their second or third choice project. Project managers must be a junior or senior students and they are enrolled in the course for 3 credits. Project managers are interviewed and selected by the M:2:I director and program coordinator at the beginning of the semester.

The combination of an established course, project-based learning framework and accessible lab space made this an ideal collaboration between the M:2:I and the AFDC course. The AFDC course benefited from reduced overhead while still using real world examples. The M:2:I course benefited from a well-defined project that the students then had to solve. Both courses benefited from mutual learning and in learning additional professional development skills such as communication, leadership and teamwork.

Outcome measurements

Two outcome measurements must be distinguished to show the results of this study clearly: course outcome and inductive learning and teaching outcome. For the course outcome, the instructor assigned three midterm exams and required students to submit their project report and present it at the end of the semester. In order to measure the effectiveness of inductive learning and teaching methods implementation, three surveys were administered in the beginning, middle, and end of the semester to collect and track students' understanding of class materials.

The learning objectives of this class are presented as follows:

1. Develop aircraft rigid-body equations of motion
2. Linearize developed aircraft rigid-body equations of motion
3. Assess longitudinal and lateral-directional static and dynamic stability
4. Perform flight handling characteristics analysis
5. Identify and assess aircraft flight handling qualities

The survey questions were designed by the instructor based on reviewing references [10-12]. For the efficient measurement, the common questions across the three terms were (1) 'How well do you know the geometric component of a fixed-wing aircraft?', (2) 'How well do you know about mathematically modeling a fixed-wing aircraft, also known as dynamic modeling?'. These two questions will show students' familiarity with class material throughout the semester.

In the *preterm*, the survey asked following questions:

1. Have you taken this class or equivalent course before? If you have dropped the course, you incomplete it.
2. Have you taken or are you taking Aerodynamic course?
3. How well do you know the geometric components of a fixed-wing aircraft?
4. How well do you know about mathematically modeling a fixed-wing aircraft, also known as a dynamic modeling?
5. How comfortable are you in manufacturing wings for a fixed-wing remote control aircraft using composite or Styrofoam?
6. How would you rate your technical report-writing skills?
7. Do you believe you have to spent considerable amount of time with your teammates to finish a team project?
8. Do you believe you need to collaborate with your teammates when writing a final team project report?

In the preterm survey, questions of 1 and 2 were asked to observe what year students take this course. The questions of 3,4, and 5 are related to the course outcome. The rest of the questions were asked to observe their professional skills during the project.

In the *midterm*, the survey questions were designed as follows:

1. How well do you know the geometric components of a fixed-wing aircraft?

2. How well do you know about mathematically modeling a fixed-wing aircraft, also known as a dynamic modeling?
3. How comfortable are you in manufacturing wings for a fixed-wing remote control aircraft using composite or Styrofoam?
4. Do you believe that working with members in your team helped you write/complete the report to your satisfaction?
5. Do you believe that your communication skill has been improved since the beginning of the semester as the result of participating in the team project?

In the midterm survey, questions of 1 and 2 were related to the course outcome. The rest of the questions were asked to assess the improvement in students' professional skills during the project period.

In the *end term*, the survey asked students the following questions:

1. How well do you know the geometric components of a fixed-wing aircraft?
2. How well do you know about mathematically modeling a fixed-wing aircraft, also known as a dynamic modeling?
3. Do you believe that working with members in your team helped you writing the report?
4. Do you believe that your communication skill has been improved since the beginning of the semester as the result of participating in the team project?
5. How comfortable are you in using AAA software in the future?
6. How comfortable are you in explaining the effects of control surfaces on the motion of a fixed-wing aircraft?
7. How well can you explain the process of dynamic modeling of a fixed-wing aircraft?
8. Do you believe that the project helped you better understand the class materials?

In the end term survey, question of 1, 2, and 6 were related to the course outcome. The rest of the questions were asked to observe the professional skill improvements during the project.

3. Results and Discussion

The results of the midterm exam grade and survey are presented in this section. The number of respondents for the preterm, midterm, and end-term surveys was 55, 47, and 50 students, respectively. The total number of enrollments in this class was 64 students. Figure 2 shows the results of some questions from the preterm. Most of the students took this course the first time in their curriculum. Besides, students were concurrently enrolled in the aerodynamics course at the same time.

Flight dynamics courses require a sufficient understanding of the aerodynamic contents as well. The concurrent enrollment with aerodynamics and the timing of taking this class will cause the steep learning curve for students. Also, most students believe and expect a considerable amount of time is required when collaborating as a team, see second rows of data in Figure 2.

For the comparison of course outcomes between classes with (2019) and without (2018) inductive learning and teaching methods, the midterm exam grades of both classes are contrasted. Figure 3 presents the distribution of grades in three midterm exams in the 2018 and 2019 class. In 2018, the instructor did not implement the inductive learning and teaching methods, so the research team chose this data as the control sample.

Figure 3 shows that when the instructor applied inductive learning and teaching methods in the 2019 class, more students received higher grades. The presented data were normalized by the number of enrolled students for both years. The limitation of this data is that the three midterm exam questions were not identical, but the contents taught in the class were the same. In the midterm exams, the instructor designed questions to measure the performance of solving mathematical problem. Sample exam problems are presented in Appendix A. Figure 4 shows the results of two common questions that were tracked during the semester. As it shows, the number of students increased to 'extremely well' as the semester proceeded.

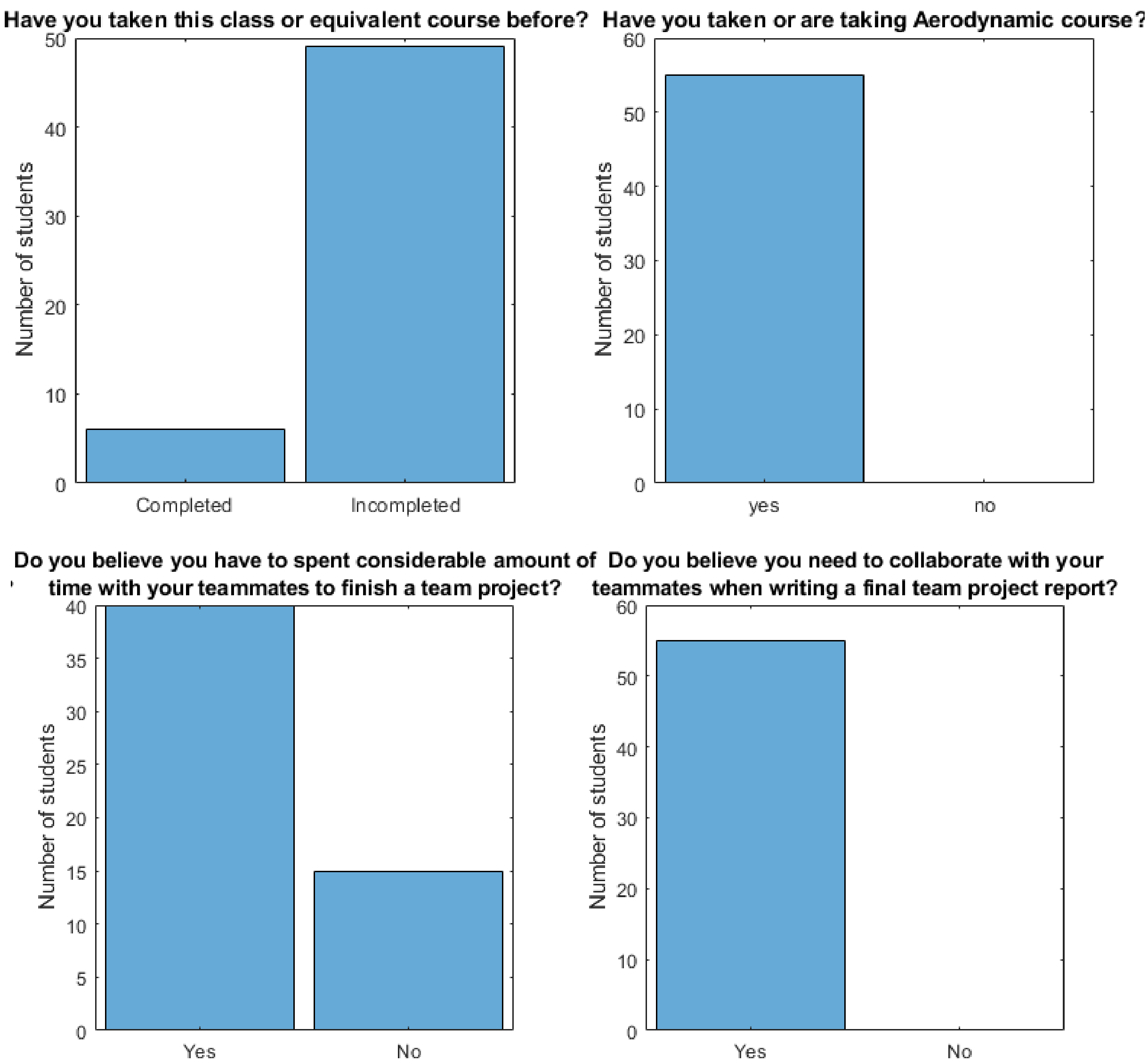

Figure 2 Pre-term survey question results

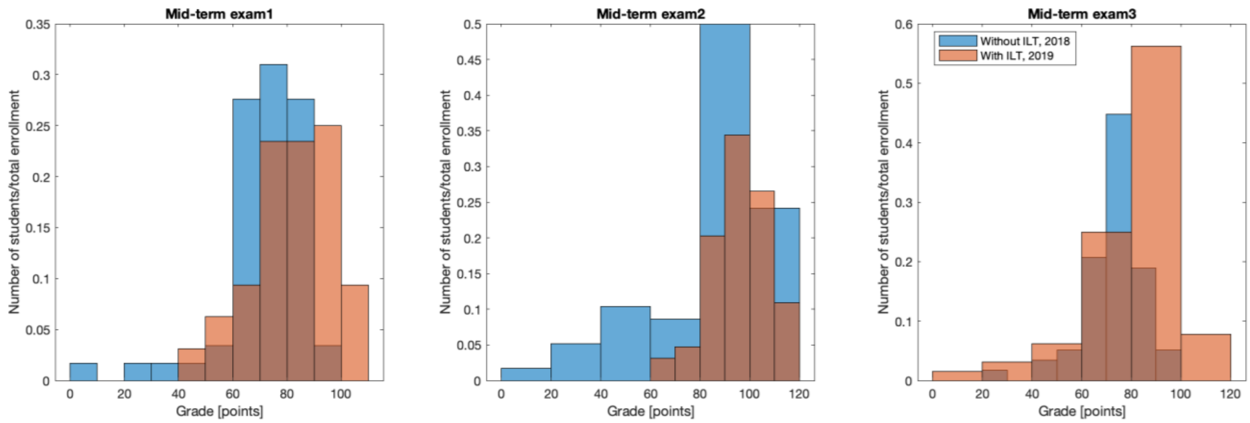

Figure 3 Midterm exam grade comparison (normalized) in 2018 (without ILT) and 2019 (with ILT) class *ILT: Inductive learning and teaching method

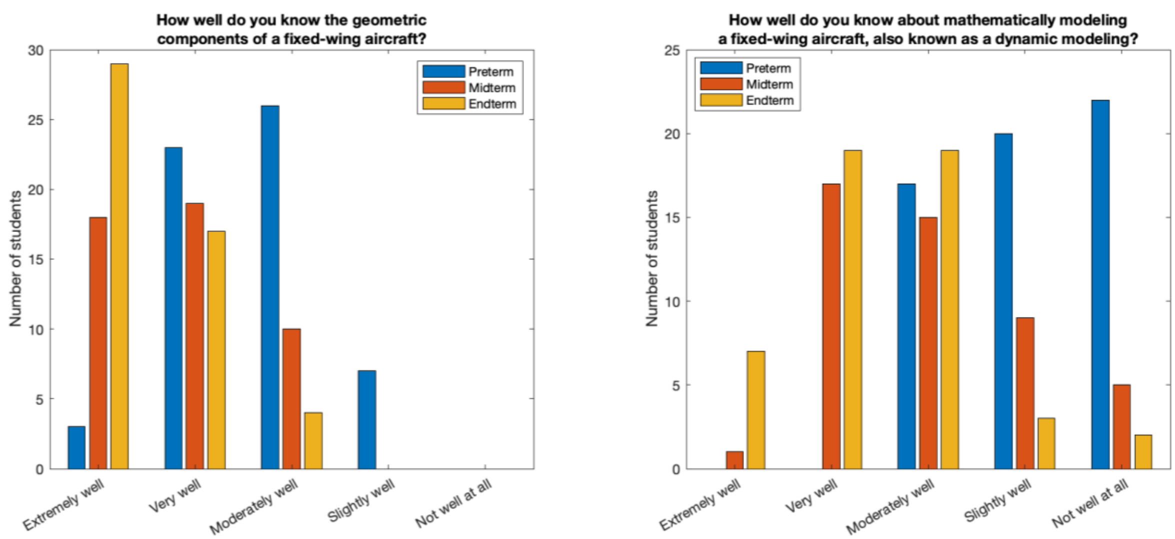

Figure 4 The result of tracking common questions during semester

The left side of Figure 4 shows that students increased their understanding of geometric components of the fixed-wing aircraft as they perform the project. The right side of Figure 4 shows the understanding level of students regarding the dynamic modeling of the aircraft. The result was not as dramatic as the instructor expected. The ‘very well’ category has not increased much, and most of the students are in ‘very well’ and ‘moderately well’ category, not in ‘extremely well’ compared to the left question of Figure 4.

At the end of the semester, students answered how much they learned regarding the software and class materials, see Figure 5.

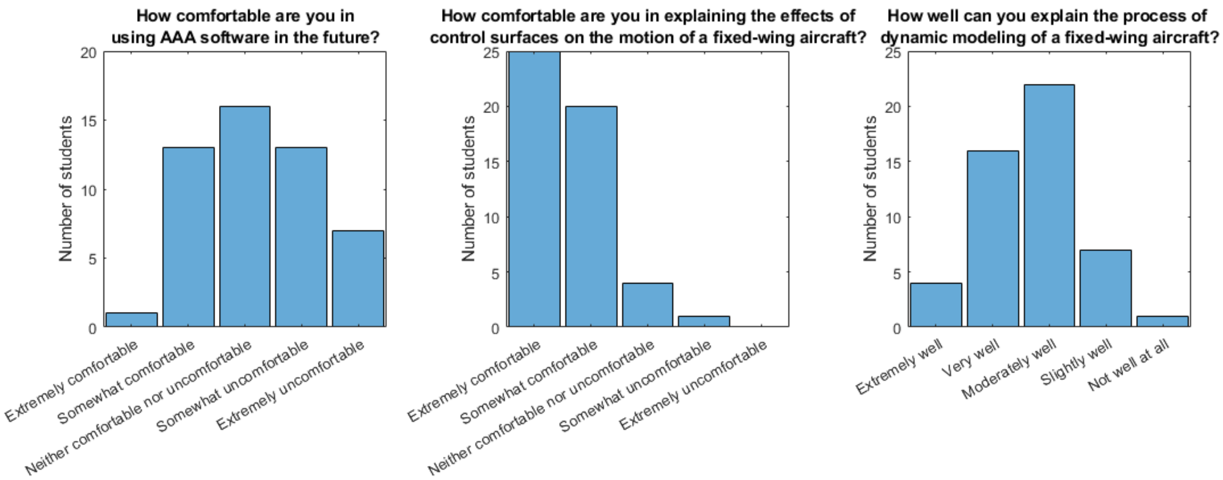

Figure 5 The perception of understanding class material via the project-based learning (These data are from the end term survey)

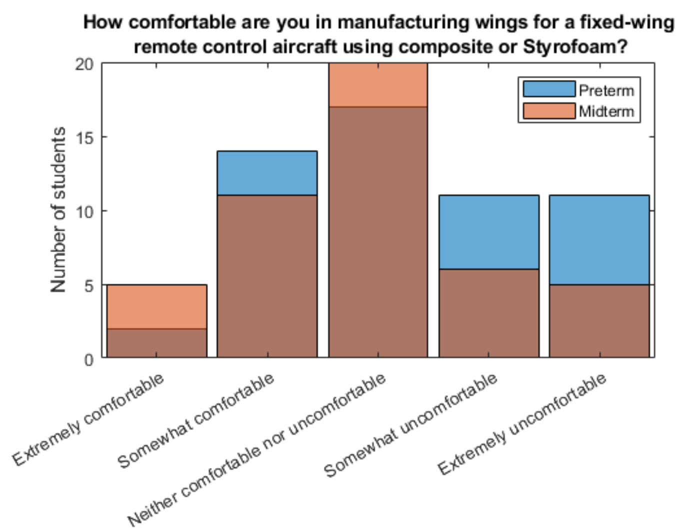

Figure 6 Manufacturing skill development

Students obtained the average level of understanding in software usage and explaining the procedure of projects because the instructor provided the minimum instruction. Therefore, students struggled much. However, most students could explain the connection between mathematical concepts and the motion of an airplane confidently. Figure 6 shows the result of the manufacturing skill question. Since the manufacturing was not a scope of the project for the class group, the dramatic improvement has not been observed. However, an increased number of students become familiar with the manufacturing process while they work with M:2:I students.

Figure 7 shows the writing (top three graphs) and communication (bottom two graph) skill measurements during the semester. At the beginning of the semester, students had a belief that they have to work with other students to improve their writing quality. The end term (top right results of Figure 7) shows that working as a team in writing helped students improve their writing skills.

In contrast, communication skill has not improved dramatically. Figure 8 shows the perception of students regarding the project-based learning. The result shows that half of the class agreed that the project helped a better understanding, and the rest of the half did not. Even though students' understanding has been improved, the students did not believe that project-based learning enhanced their learning. As Ref. [7] pointed out, the student resistance was observed. The instructor did not provide a detailed guideline for the project, and the project assistant student also had a learning curve in the software and hands-on activities for fixed-wing UAS.

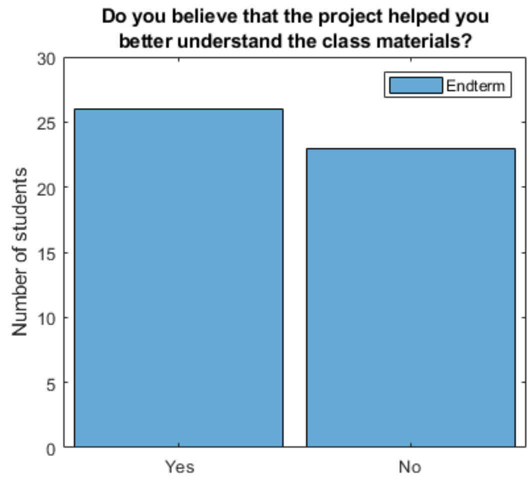

Figure 7 Students' resistance

The writing and oral presentation skills was measured by the rubrics (see Appendix B) based on Ref. [13-16]. Even though this research team does not have empirical data, from anecdotal accounts and observations, student had improved their writing skills. The rubric was developed by the instructor and it was pilot tested with a group of students. For 2018 class, the project-based learning was not implemented.

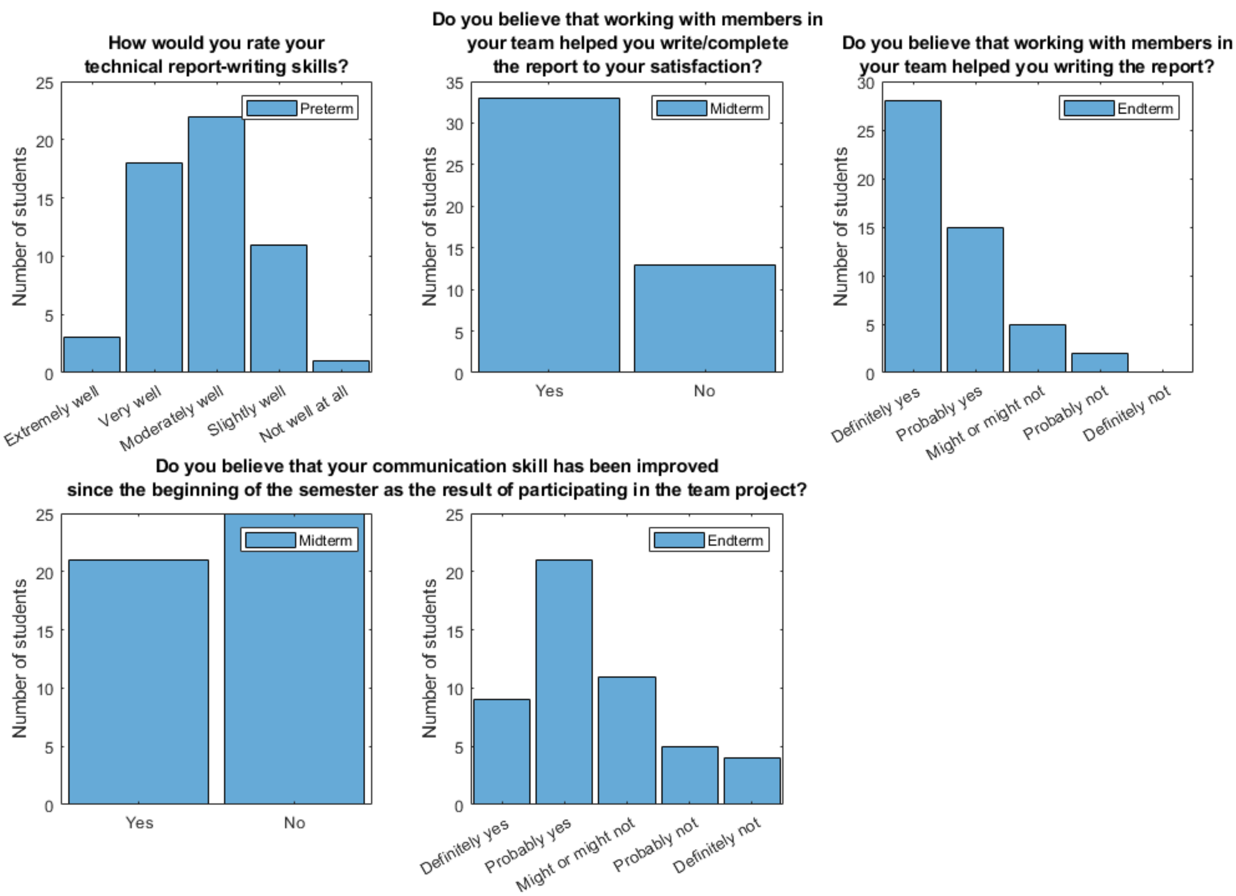

Figure 8 Writing and Communication skill

5. Conclusion

This work was motivated by the need to improve the students' learning experience in Flight dynamics and control class by implementing inductive learning and teaching. The outcome measurements were performed by two categories: course outcome and implementation of inductive learning and teaching methods. The course outcome showed the student grade improved compared to the class without inductive learning and teaching methods. The survey results also support the improvement of class material understanding through inductive learning and teaching methods. Even though the improvement of grades and understanding level occurred, students did not believe that the project helped them a better understanding of class materials.

In conclusion, the inductive learning and teaching methods are considerable for the improvement of students' understanding in flight dynamic and control class. However, minimal instruction for project-based learning can cause the students' resistance. The workload for the instructor might be increased for more management and support of projects even though the existing courses have been combined. The students will demand more attention and care from the instructor for the project-based learning activities.

Future work

Currently, students are preparing the manuscript of the AIAA SciTech conference based on what they have learned, and data collected in class. Additionally, the graduate course is taking advantage of the materials and dynamics models generated from this course. The research team will continue to investigate different inductive learning and teaching methods with the revised survey. Additionally, a future study will validate the survey measuring students' outcome and skill sets. We will look at the improvement on writing and oral presentation skills as well.

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Appendix A – Sample problem of midterm exams to measure mathematical problem solving skill

Lockheed L-1011 is flying at 1500 ft ASL where the air density is 0.000738 slug/ft3. The following information is given:

$\delta_R = 0.2$ deg	$\eta_v = 0.90$	$\beta = 0.3$ deg
$\partial\sigma/\partial\beta = 0.13$	$\alpha = 3$ deg	$x_{C.G} = 97.4$ ft from the apex (nose)
$C_{L_{0_v}} = 0.0$	$C_{L_{\alpha_v}} = 2.5369$	$V = 300$ ft/sec
$v_{sound} = 994.42$ ft/sec	$C_{y_0} = 0.0$	$\delta_A = 0$ deg
$C_{n_0} = 0.0$	$S = 3898$ ft^2	$\bar{c}_w = 21.73$ ft

Use component build up method and linear aerodynamic models and calculate the following steady state stability and control derivatives

a. Find x_{v_s} and z_{v_s} from the drawing. You must show them on the drawing and length as well. [a drawing was omitted due to copyright]
b. Calculate C_{y_β} and C_{y_R}.
c. Calculate F_{A_y} (total side force).
d. Calculate $C_{l_{\beta_v}}$ and $C_{l_{\delta_R}}$.
e. Calculate total C_l where $C_{l_{\beta_{wf}}}$ = 3:0891 rad^{-1}, the horizontal tail contribution is assumed to be negligible.
f. Calculate $C_{n_{\beta_v}}$ and $C_{n_{\delta_R}}$.
g. Calculate L_A (total rolling moment).
h. Calculate N_A (total yawing moment)

Appendix B – a. Rubric for the written report [Based on Reference [13, 15, 16]]

Written Report	
Ability and coherency of technical writing (30)	• At least two literature was cited in IEEE, APA, or MLA citation style. • Present the sentence concisely (e.g. this result is 'good' → not concise) • Present the stability and control derivative in table manner with units. • If you used the figures, sources from others (e.g. books, software), put right reference and citations. • Do you have a table of content and all contents are appropriate for each section? • Smooth transition to each content
Technical content (30)	• Present the sanity check of stability and control derivative from Roskam textbook. • Present the static stability analysis. • Present the moment of inertia testing procedure and mathematics. • Present the MOI testing and AAA procedure in detail. • Present the objective of this project.
Overall quality of the report (40)	• The report presents clear goals and conclusion. • The report does not have typo, or grammatical error. • The report formatted coherently and professionally • Are there introduction, method, results, discussion, and conclusion, reference sections?

Appendix B – b. Rubric for the oral presentation, [Based on Reference [13, 14]]

Oral Presentation	
The ability of technical presentation (25%)	• Can you explain complex concepts to general audiences? • Can you show your logical procedure for project operations? • Can you connect what you learn from class to your project? • Can you present your analysis effectively? (e.g. tables, numbers, graphs, etc.) • Can you present your Engineering aspects of contents? (e.g. engineering assumptions, rationales, etc.)
Coherency of presentation (25 %)	• Can you convey clear project goals? • Can you keep reminding the audience where you are heading? (follow the list of content/agenda) • Are Powerpoint figures and wording appropriate? • Is the font too small? • Did you cover the Introduction, methods, results, discussion, and conclusion?
Technical content (25%)	• Quality of results (e.g. sanity check from references, comparison with other data points, etc.) • Stability analysis (static) • 3D view of your airplane from AAA • Dynamic modeling introduction and your literature citation • Significance of dynamic modeling (why we do this?)
Overall quality of presentation (25%)	• Smooth transition between members • Professionalism • Confidence • Word choice • Preparedness