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Student perception on Inquiry Based Learning Ordinary Differential Equation course

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Abstract

Inquiry-Based Learning (IBL) is a student-centered pedagogical approach that emphasizes active engagement, where students explore open-ended questions and problems to discover knowledge, rather than passively receiving information from an instructor. The instructor's role is to guide and support the learning process. At our institution, IBL was introduced to teach Ordinary Differential Equations (ODE) in 2021. After three years, we revisited the course to assess students' perceptions. The study explores students' views on the benefits of IBL, the role of collaboration in mastering content, the effectiveness of the instructor's role, and the equity of IBL as an instructional method. We collected survey data from 169 students and utilized R programming, along with visualization tools such as boxplots, stacked bar charts, and pie charts to analyze the data. The results show that students generally prefer IBL over traditional methods and perceive it as an equitable and engaging learning approach. However, challenges identified include limited lecture time, insufficient guidance in introducing new concepts, difficulties with worksheets, and group work issues. Interestingly, all interviewed students expressed support for IBL. The majority recommended a hybrid approach, combining IBL with traditional lectures, while recognizing IBL's benefits in terms of higher retention and increased engagement. There is also the question of whether students are engaging with IBL in the way faculty intend.

Introduction

At many higher education institutions, differential equations classes focus on solving equations through symbolic manipulation, with applications often presented as isolated topics scattered throughout the semester. Starting in 2021, to better integrate applications and promote critical thinking, differential equation professors at one institution shifted from a traditional lecture-based approach to an inquiry-oriented, worksheet-based format. In this new design, students learn through daily structured worksheets that typically begin with an application motivating the need to solve a new type of differential equation. These worksheets guide students to develop methods for solving these equations by building on prior knowledge.

There is currently a substantial body of research on the effectiveness of (Inquiry Based Learning) IBL in all levels of and aspects of education. In studies like Abdi (2014), Duran (2016) with primary grade students, it was shown that there was a significant level of difference in achievement between the IBL and the traditional based students. A study about enablers and constraints of the use of IBL in undergraduate education was done by Spronken-Smith (2011). In the study by Arsal (2017) found out the impact of inquiry-based learning on the critical thinking dispositions of the pre-service teachers in the teacher education program. Studies like Nehls (2024) and Hassi (2011) observed how IBL positively effects women and underrepresented populations due to its student-centered approach. Some studies specifically focused on the use of IBL in mathematics courses

noted the benefits of IBL specifically in college mathematics education Laursen (2011), Lauresen (2014), Khasawneh (2016). Student perceptions on IBL in mathematics courses at undergraduate level is captured in studies Ulker (2023), Akpullukcu (2015), Spronken-Smith(2012), Dawkins (2019). Research has revealed that students' perceptions of innovative instruction and task orientation positively predict their academic achievement Li and Li (2022). Moreover, perception is considered an important measure of learning, and researchers investigate perceptions in many SoTL projects such as M. Li (2023) and M. Li (2024).

However, studies specifically addressing the IBL approach in Ordinary Differential Equations (ODE) are scarce. One study by Çiftçi (2015) found that perceptions of mathematics education quality positively influence test scores while also reducing mathematics anxiety. To date, the authors have identified only two studies focused on this topic. The first is by Spencer (2024), who examined both student performance and the impact of inquiry oriented differential equations courses on students' views about mathematics, relying on the Views about Mathematics Survey (VAMS), a standard instrument for collecting data on student views. The second one conducted by Hyland (2020), employed a 2+1 structure, consisting of two lectures followed by a tutorial or recitation each week.

In contrast, our institution uses a fully worksheet/tutorial-based approach with no formal lectures. Additionally, while Hyland's research questions focus on the changes made to their tutorial methods, our study centers on students' perception about the IBL method, drawing on Laursen and Rasmussen's four pillars of Inquiry-Based Mathematics Education (IBME), Laursen (2019).

Research questions:
Specifically, we investigate students' perceptions on the following research questions:

1. To what extent do students perceive the benefits of the IBL approach?
2. To what extent has student collaboration in IBL helped in mastering the content?
3. To what extent do students perceive the instructor's role in IBL as beneficial?
4. To what extent do students view IBL as an equitable instructional practice?

Another difference is that Hyland et al. used semi-structured interviews for data collection, while we employed a combination of surveys and a few interviews with current students enrolled in the course.

This research enriches the existing literature by providing a study that examines the impact of Inquiry-Based Learning (IBL) in Ordinary Differential Equations (ODE). We anticipate that the insights gained from this research will inform changes and improvements of ODE courses and other IBL relevant courses, ultimately enhancing support for our students.

Context

This IRB-approved research was conducted at a prominent, research-focused public university in the Mid-Atlantic region of the United States, primarily attended by white students. Within our

university, the Center for Applied Mathematics (APMA) in the School of Engineering & Applied Science (SEAS) comprises a dedicated team of educators. They offer a range of math courses to both undergraduate and graduate students from SEAS, and they engage in research aimed at improving teaching methods and revising course curricula to better address students' needs.

APMA 2130 - Ordinary Differential Equations is a 4-credit core course essential for many engineering majors, exclusively attended by students from engineering school. Each semester, the course typically offers 7-9 sections, each accommodating 40-50 students. These sections are taught by various APMA instructors and are fully coordinated by the course coordinator.

Around three years ago, several APMA instructors revamped the course by incorporating the Inquiry-Based Learning (IBL) approach. Following multiple semesters of refinement, the course was further developed in Fall 2024 to feature six core components, as shown in the table below.

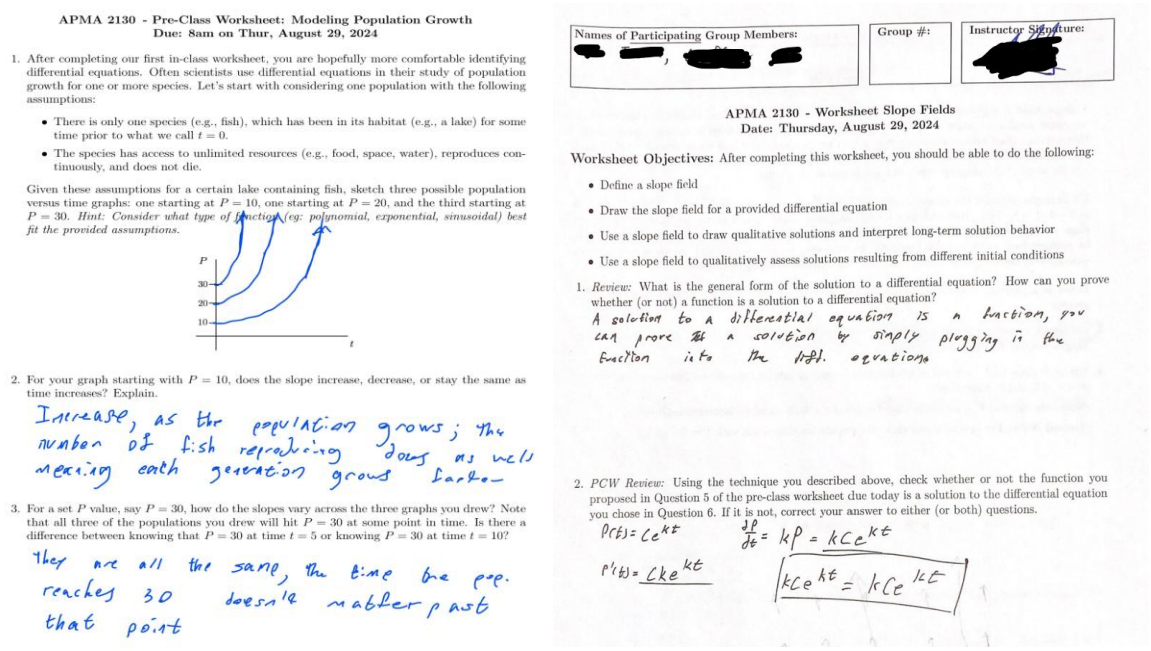
Component/resource	In-class	Description
Pre-class worksheets (PCW)	N	Most days, students are required to complete a PCW before class. These PCWs help review material from previous classes or prepare students for new content, encouraging reflection before class. Students may only use class notes and prior knowledge to answer the questions. PCWs are graded for completion.
In-class worksheets (ICW)	Y	ICWs are the primary source of content, where students answer a series of questions to enhance their understanding. They can collaborate with group mates, the instructor, and TAs for assistance and to verify their answers. This is graded for accuracy
Recap worksheets	Y	Recap worksheets summarize key content at milestones, ensuring students grasp the main points. Their objective is to ensure all students are aligned and have a clear understanding of the material before moving to new material. This is not graded for accuracy nor completion and only submission is required for the credit.
Written homework	N	Each week, students will complete written homework to reinforce their understanding and practice the material. This also includes challenging problems to deepen their comprehension. Students can seek help from instructors and group mates, and the homework is graded for accuracy.
Practice exams	N	Old exams are shared with students to help them assess their knowledge and exam preparedness. They also provide insight into the types of conceptual questions that may appear on the exam.
Instructor office hours and TA workshop hours	N	TA workshop hours provide additional support, allowing students to walk in and receive assistance with worksheets and any questions they have about the material.

Table 1: Components of IBL

In each class meeting, there is either no lecture or just a brief mini-lecture from the instructor. Students are expected to complete a pre-class worksheet before attending. Once in class, they

begin by working on problems from the in-class worksheet. Instructors and trained teaching assistants circulate around the classroom to help with any questions students may have. After completing a unit or block of content, a class session is dedicated to practicing recap worksheets that summarize the core concepts. Before each exam, students are given practice exams to help them prepare.

Below are the screenshots of a PCW and ICW of a student for two consecutive days.



APMA 2130 - Pre-Class Worksheet: Modeling Population Growth
Due: 8am on Thur, August 29, 2024

1. After completing our first in-class worksheet, you are hopefully more comfortable identifying differential equations. Often scientists use differential equations in their study of population growth for one or more species. Let's start with considering one population with the following assumptions:
   - There is only one species (e.g., fish), which has been in its habitat (e.g., a lake) for some time prior to what we call $t = 0$.
   - The species has access to unlimited resources (e.g., food, space, water), reproduces continuously, and does not die.

   Given these assumptions for a certain lake containing fish, sketch three possible population versus time graphs: one starting at $P = 10$, one starting at $P = 20$, and the third starting at $P = 30$. *Hint: Consider what type of function (eg: polynomial, exponential, sinusoidal) best fit the provided assumptions.*

2. For your graph starting with $P = 10$, does the slope increase, decrease, or stay the same as time increases? Explain.

   Increase, as the equation grows; the number of fish reproducing does as well meaning each generation grows faster

3. For a set P value, say $P = 30$, how do the slopes vary across the three graphs you drew? Note that all three of the populations you drew will hit $P = 30$ at some point in time. Is there a difference between knowing that $P = 30$ at time $t = 5$ or knowing $P = 30$ at time $t = 10$?

   They are all the same, the time the pop. reaches 30 doesn't matter past that point

Names of Participating Group Members: [redacted]

Group #:

Instructor Signature: [redacted]

APMA 2130 - Worksheet Slope Fields
Date: Thursday, August 29, 2024

Worksheet Objectives: After completing this worksheet, you should be able to do the following:

- Define a slope field
- Draw the slope field for a provided differential equation
- Use a slope field to draw qualitative solutions and interpret long-term solution behavior
- Use a slope field to qualitatively assess solutions resulting from different initial conditions

1. *Review:* What is the general form of the solution to a differential equation? How can you prove whether (or not) a function is a solution to a differential equation?

   A solution to a differential equation is a function, you can prove that a solution by simply plugging in the function into the diff. equations

2. *PCW Review:* Using the technique you described above, check whether or not the function you proposed in Question 5 of the pre-class worksheet due today is a solution to the differential equation you chose in Question 6. If it is not, correct your answer to either (or both) questions.

   $P(t) = Ce^{kt}$ $\frac{dP}{dt} = kP = kCe^{kt}$

   $P'(t) = Cke^{kt}$ $kCe^{kt} = kCe^{kt}$

Figure 1: PCW and ICW examples. Students complete the PCW the day before coming to class.

Participants and Data Sources

In Fall 2024, 265 students enrolled in seven sections of APMA 2130-ODEs were invited to participate in the study. These sections were taught by four different APMA instructors and were fully coordinated by the course coordinator.

The primary data sources for this study are the end-of-semester survey and interviews. Out of 265 students enrolled, 256 participated in the survey either fully or partially, and 169 of these students consented to use their survey data for the research. Additionally, 42 students expressed interest in being interviewed in exchange for a $20 gift card. Seven interviewees were intentionally selected from different grade categories (1 with an "F", 1 with a "D", 2 with "C", 1 with a "B", and 2 with "A"). These interviews were conducted via ZOOM by an instructor with extensive educational research experience who had no authority over any ODE student. Only the data consented to by students are used in this paper.

The end-of-semester survey was conducted during the last week of the semester using Qualtrics. It included five sets of Likert scale questions and several open-ended questions designed to

explore the four research questions. Below is an outline of how these five sets correspond to the four research questions mentioned in the introduction section.

Research Questions	Survey Likert question set
1. To what extent do students perceive the benefits of the IBL approach?	1. Student perception on the benefit of IBL 2. Student perceptions on resources 3. Student perceptions on engagement, and pedagogical approaches
2. To what extent has student collaboration in IBL helped in mastering the content	4. Student collaboration
3. To what extent do students perceive the instructor's role in IBL as beneficial	5. Instructor role and fostering equity
4. To what extent do students view IBL as an equitable instructional practice	5. Instructor role and fostering equity

Table 2: Connection between research and survey Likert question set

The interview questions were aligned with such 5 sets of Likert scale questions in the survey.

Study Method and Analysis tools

We employed an embedded mixed-method approach with a quantitative emphasis [18] to analyze the data. For the quantitative survey data, we primarily used statistical visualization tools in R programming, including boxplots, stacked bar charts, pie charts, and other exploratory analysis tools to visualize and analyze the responses. For the qualitative data from the survey and interviews, we applied the deductive method, categorizing responses into groups for analysis.

Data Analysis and results

Quantitative analysis and results (survey)

In this section, we analyze the five Likert question sets individually. The response categories for each question were recoded as follows: Strongly Disagree = 1, Somewhat Disagree = 2, Neither Agree nor Disagree = 3, Somewhat Agree = 4, and Strongly Agree = 5. This recoding allowed for the calculation of the mean response for each set of questions. With the exception of one negatively worded question, all items were framed positively, so a mean response above 3 indicates a favorable response from students. All Likert questions, except for the negatively worded one, received a mean score above 3, suggesting strong overall support for Inquiry-Based Learning (IBL).

The analysis of the first five sets of questions is structured as follows: We begin by presenting a table displaying the mean scores for each question within a set, followed by box plots and a table showing the distribution of responses across the Likert categories for each question. To

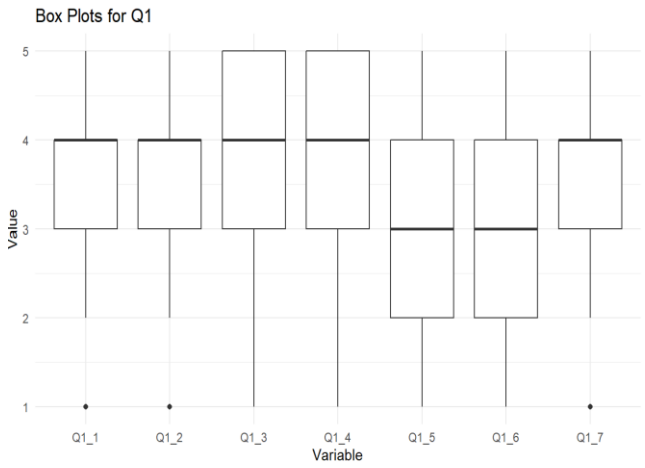
streamline the column names, we abbreviate the Likert categories as follows: Strongly Disagree = SD, Somewhat Disagree = D, Neither Agree nor Disagree = N, Somewhat Agree = A, and Strongly Agree = SA.

We exclude responses labeled as "Neither Agree nor Disagree" (referred to as "respondents with a view") and combine the "Strongly Disagree" with "Somewhat Disagree" and "Somewhat Agree" with "Strongly Agree" to gain clearer insights into respondents' perceptions. This adjustment results in different totals for each question due to the exclusion of neutral responses. To ensure fair comparisons between questions within a set, we present the data using percentages in a stacked bar chart.

Set1(Q1): Student perception on the benefit of IBL

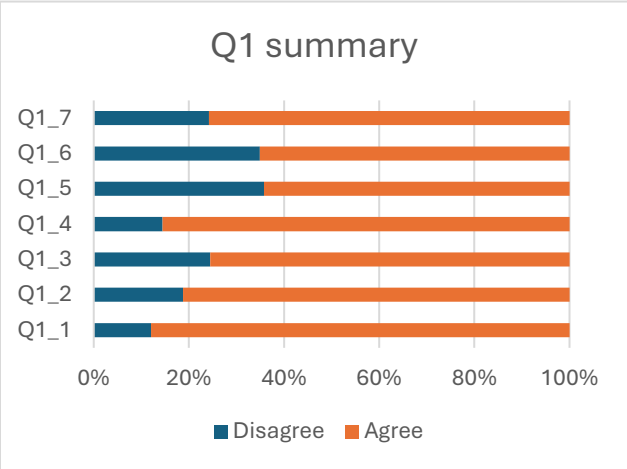
Question	Mean
Q1_1 IBL encouraged me to rethink and explore familiar mathematical concepts in new ways	3.85
Q1_2 IBL encouraged me to create mathematics that was new to me	3.72
Q1_3 I mastered ODE concepts well via IBL approach	3.63
Q1_4 IBL enhanced my self-learning ability	3.91
Q1_5 IBL improved my study habits	3.30
Q1_6 The benefit of IBL outweighs its challenges to learn ODE concepts	3.32
Q1_7 Overall, it was effective to adapt IBL approach to learn ODE concepts	3.55

Table 3: Student perception on the benefit of IBL. Strongly disagree = 1, Somewhat disagree = 2, Neither agree nor disagree = 3, Somewhat agree = 4, Strongly agree = 5



	SD	D	N	A	SA
Q1_1	4	13	28	83	41
Q1_2	3	22	36	67	41
Q1_3	12	23	26	63	45
Q1_4	7	14	24	66	58
Q1_5	11	33	46	53	26
Q1_6	11	33	43	55	27
Q1_7	12	20	37	63	37

Figure 2: Boxplot for Q1and summary statistics. SD = Strongly Disagree, SD = Somewhat disagree, N = Neither agree nor disagree, SA = Somewhat agree, SA = Strongly agree



All questions had a median score of 3 or higher, with similar box plots for Q1_1-Q1_2, Q1_3-Q1_4, and Q1_5-Q1_6, likely due to the similarity of the questions. Q5 and Q6 had almost identical responses, with around a quarter of students remaining neutral (27.21% and 25.44%, respectively). However, among those with an opinion, the majority agreed that IBL improved their study habits and that its benefits outweighed the challenges of learning ODE concepts, supporting the use of IBL in the course.

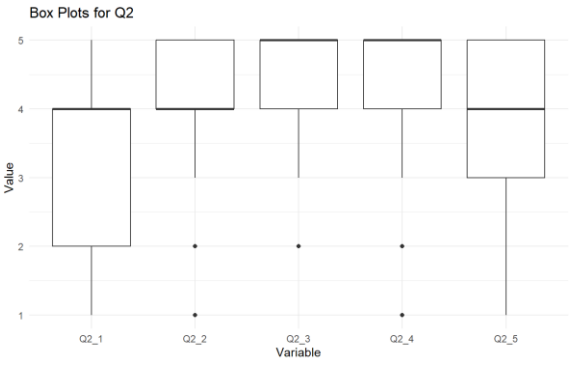
Figure 3: Stacked bar chart for student perception on the benefit of IBL

Over 60% of respondents with an opinion expressed agreement with the questions, demonstrating strong support for IBL in the course. The highest support was for Q1, which stated that IBL encouraged rethinking and exploring familiar mathematical concepts in new ways. The lowest support was for Q1_5 (similar to Q1_6), which addressed whether IBL improved study habits and whether its benefits outweighed the challenges of learning ODE concepts.

Set 2(Q2): Student perceptions on resources

Question	Mean
Q2_1 The pre-class worksheets in this IBL approached ODE class were helpful	3.40
Q2_2 The in-class worksheets in this IBL approached ODE class were helpful	4.34
Q2_3 The recap worksheet days in this IBL approached ODE class were helpful	4.52
Q2_4 A textbook is not necessary for this IBL course	4.12
Q2_5 I had sufficient resources to success in this IBL approached ODE class	3.85

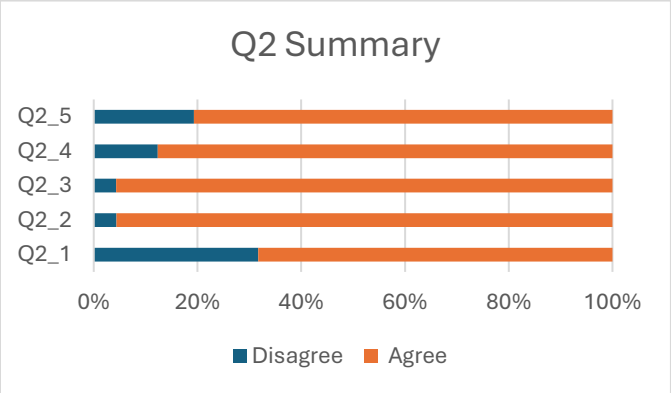
Table 4: Student perception on resources. Strongly disagree = 1, Somewhat disagree = 2, Neither agree nor disagree = 3, Somewhat agree = 4, Strongly agree = 5



	SD	D	N	A	SA
Q2_1	13	32	27	68	29
Q2_2	1	6	9	72	81
Q2_3	0	7	6	48	108
Q2_4	7	11	23	42	86
Q2_5	7	22	19	63	58

Figure 4: Boxplot for Q2 and summary statistics. SD = Strongly Disagree, SD = Somewhat disagree, N = Neither agree nor disagree, SA = Somewhat agree, SA = Strongly agree

As previously mentioned, Sets 1, 2, and 3 correspond to the original research question: "To what extent do students perceive the benefits of the IBL approach?" Among these, Set 2, which focuses on resources, appears to have the highest mean and median scores.



The analysis shows similar responses for Q2_2 and Q2_3, both being the most successful components. Notably, no respondent disagreed that recaps were useful, indicating they should be retained. The positive feedback for in-class worksheets reflects their role in delivering course content.

Figure 5: Stacked bar chart for student perception on resources

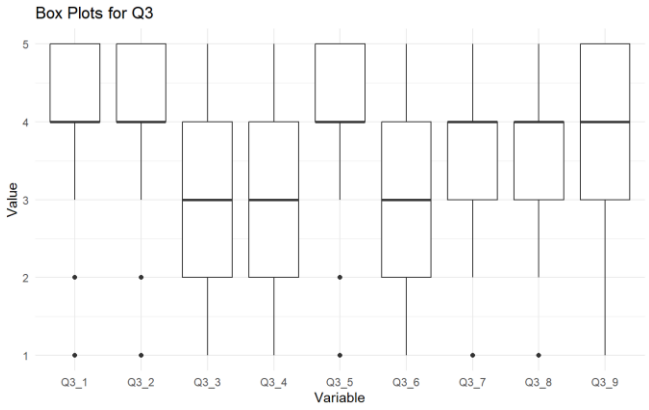
The least successful question in this set was Q2_1. While the majority agreed it was helpful, there is an indication that the pre-class worksheets should be reviewed, as they were also cited as the least helpful in interviews.

It is notable that over 80% (Q2_4) of students agree that a textbook is not necessary for this course. This aligns with other responses regarding resources, reinforcing the effectiveness of the course design, as students seem satisfied with the resources provided.

Set 3(Q3): Student perceptions on engagement, and pedagogical approaches

Question	Mean
Q3_1 I actively engaged with the course material via the IBL approach	4.23
Q3_2 I was given enough problems and opportunities to engage with the course material	4.16
Q3_3 I prefer the traditional lecture approach to learn ODE	3.14
Q3_4 I prefer the IBL approach to learn ODE	3.22
Q3_5 I prefer a combination of traditional lecture and IBL approaches to learn ODE	4.13
Q3_6 IBL helped me to understand the course materials better than the traditional lecture	3.34
Q3_7 IBL is more motivating than the traditional lecture approach	3.47
Q3_8 Using IBL for other APMA courses could be beneficial	3.48
Q3_9 I recommend continuing to utilize IBL approach for ODE class	3.57

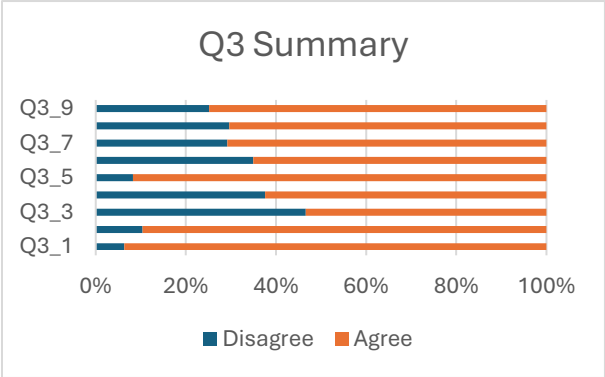
Table 5: Student perception on engagement, and pedagogical approaches. Strongly disagree = 1, Somewhat disagree = 2, Neither agree nor disagree = 3, Somewhat agree = 4, Strongly agree = 5



	SD	D	N	A	SA
Q3_1	3	7	12	73	74
Q3_2	2	14	15	62	76
Q3_3	15	40	51	32	31
Q3_4	15	32	44	56	22
Q3_5	4	8	23	61	73
Q3_6	10	34	43	52	30
Q3_7	15	25	32	59	38
Q3_8	13	27	34	56	39
Q3_9	15	20	30	61	43

Figure 6: Boxplot for Q3 and summary statistics. SD = Strongly Disagree, SD = Somewhat disagree, N = Neither agree nor disagree, SA = Somewhat agree, SA = Strongly agree

This set of questions effectively captures student sentiments toward IBL as a pedagogical approach for teaching ODE. Notably, Q3_3 and Q3_4 show similar distributions, with a median of 3 and nearly equal splits among respondents. However, for Q3_5, around 92% the respondents with a view express a preference for a combination of the two approaches. This insight may be valuable for future iterations of the course.



Q3_1 was the most successful, with 94% of respondents agreeing they engaged more actively with the material under IBL. Similarly, students felt they had sufficient opportunities to engage with the material in Q3_2. Responses to Q3_6 and Q3_7 reflect a preference for a balance between pedagogical approaches, rather than strong support for one over the other. Nevertheless, students express strong support for implementing

Figure 7: Stacked bar chart for student perception on engagement, and pedagogical approaches

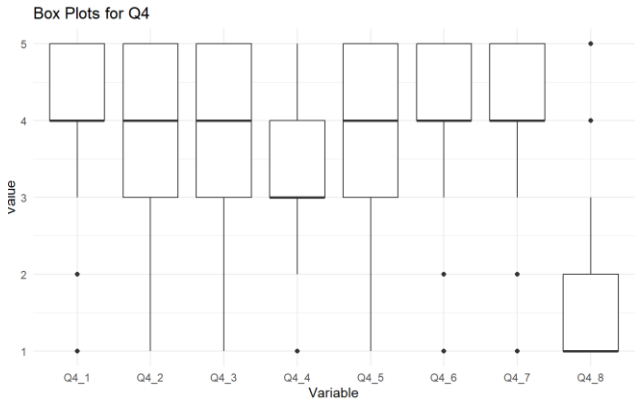
IBL in other courses and continuing its use in ODE (Q3_8 and Q3_9), with both questions receiving a median response of 4.

Set 4(Q4): Student collaboration

Question	Mean
Q4_1 IBL helped me engage in meaningful discussions with other students	3.99
Q4_2 IBL helped me improve my mathematical communication skills	3.79
Q4_3 IBL helped me to explain my thinking to others	3.82
Q4_4 IBL helped me to improve my listening skills	3.38
Q4_5 IBL helped me to discuss unfamiliar problems/content	3.82
Q4_6 Collaborations helped me to understand the material better	4.20

Q4_7 Collaborations helped me to process mathematical ideas	4.20
Q4_8 Attendance is not necessary in this class	1.78

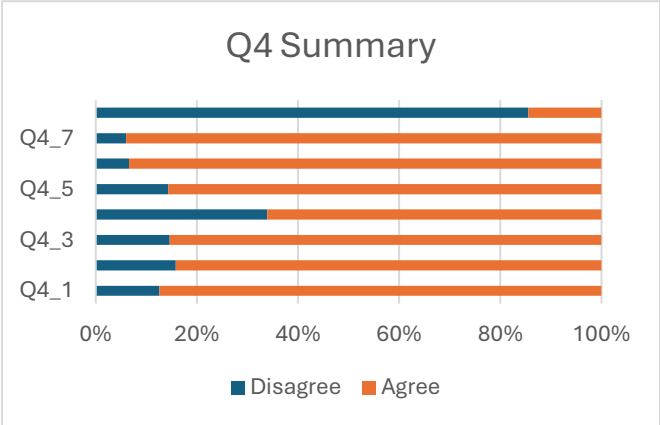
Table 6: Student perception on student collaboration. Strongly disagree = 1, Somewhat disagree = 2, Neither agree nor disagree = 3, Somewhat agree = 4, Strongly agree = 5



	SD	D	N	A	SA
Q4_1	5	14	18	73	59
Q4_2	7	15	30	71	46
Q4_3	7	13	32	69	48
Q4_4	9	32	48	45	35
Q4_5	8	12	30	71	48
Q4_6	3	7	17	69	73
Q4_7	5	4	19	66	75
Q4_8	104	32	10	13	10

Figure 8: Boxplot for Q3 and summary statistics. SD = Strongly Disagree, SD = Somewhat disagree, N = Neither agree nor disagree, SA = Somewhat agree, SA = Strongly agree

All responses in this set had a median of 4, except for questions 4_4 and 4_8. For Q4_4, the majority of respondents with an opinion felt their listening skills improved, indicating some success. Q4_8, being negatively worded, naturally received more disagreement. Overall, respondents generally agreed that IBL helped them become better collaborators, which in turn enhanced their learning.



It is interesting that approximately 14.5% of respondents with an opinion believed attendance is not necessary in this class (Q4_8). Further investigation is needed to understand the reasons behind this view, as these students may have prior knowledge of the material and feel confident in their ability to learn without additional support.

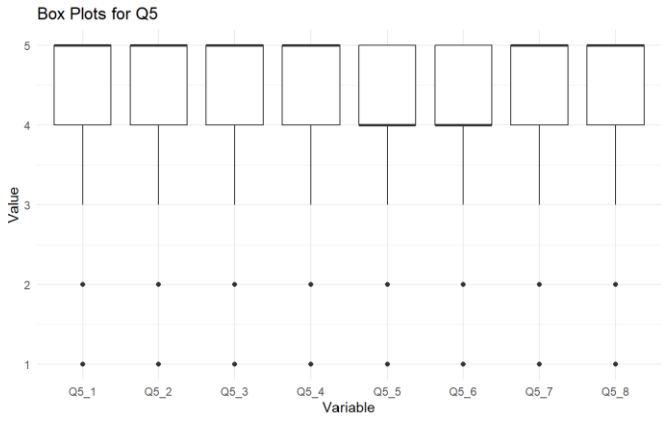
Figure 9: Stacked bar chart for student perception on student collaboration

Set 5(Q5): Instructor role and fostering equity

Question	Mean
Q5_1 My instructor was helpful in my learning process	4.33
Q5_2 My TAs were helpful in my learning process	4.50
Q5_3 My instructor's mini lectures/presentations in class helped me	4.12

Q5_4 My instructor valued and attended to my ideas	4.35
Q5_5 My instructor helped build a strong sense of community in the classroom	4.20
Q5_6 I felt a sense of belonging in the class	4.18
Q5_7 My instructor promoted equity through the design and delivery of the class	4.43
Q5_8 My instructor helped create a safe classroom climate	4.28

Table 7: Instructor role and fostering equality. Strongly disagree = 1, Somewhat disagree = 2, Neither agree nor disagree = 3, Somewhat agree = 4, Strongly agree = 5



	SD	D	N	A	SA
Q5_1	6	9	11	41	102
Q5_2	2	4	9	47	107
Q5_3	9	12	15	46	87
Q5_4	2	6	18	48	95
Q5_5	4	6	26	49	84
Q5_6	2	9	25	53	80
Q5_7	1	1	23	44	100
Q5_8	1	4	32	41	91

Figure 10: Boxplot for Q3 and summary statistics. SD = Strongly Disagree, SD = Somewhat disagree, N = Neither agree nor disagree, SA = Somewhat agree, SA = Strongly agree

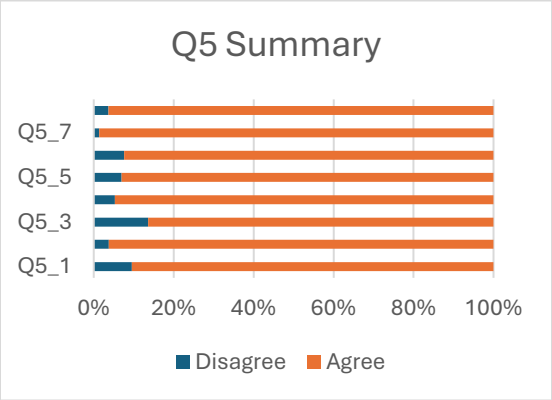


Figure 11: Stacked bar chart for instructor role and fostering equality

This set of questions appears to be the most successful, with all medians at 4 or 5, and 5 being the most common. Q5_7 was the most successful, followed by Q5_8. Both responses indicate that students felt their instructors promoted equity through the course design and created a safe learning environment. The highest mean was recorded for Q5_2, highlighting the importance of having well-trained TAs to maximize the effectiveness of the class. It is recommended to continue efforts in recruiting and training TAs. The lowest mean was for Q5_3, which assesses the balance between mini lectures and presentations. While not central to IBL, mini lectures were used as needed, reflecting student preference for a mix of traditional lectures and IBL (Q3_5). It is recommended that instructors explore more structured lectures to better support students.

Challenges of IBL

We asked students to rank their top 5 challenges in the survey, and all responses were collected and grouped into 8 categories based on similarity, regardless of ranking. The groups are listed in

order of the number of responses, with the majority focusing on challenges related to learning and understanding concepts.

A brief description of the comments for each group is provided in the following table, along with a few unedited comments for each group. Recurring issues included challenges with self-study and lack of direction, difficulty completing worksheets (especially pre-class ones), limited lectures, and a high dependency on teammates.

	Challenge	Description	Example comments
1	Learning and Understanding Concepts	Challenges included difficulty understanding complex material, such as Laplace Transforms, Eigenvectors, and Linear Algebra, especially without lectures or clear explanations, and struggling to learn from worksheets.	• Not understanding pre-class worksheets • Having to learn something entirely foreign within 50 minutes • Strongly understanding the basic concepts before continuing to very complex topics
2	Resources and Instruction	Students expressed frustration over the lack of lectures, slides, and online resources. Many felt worksheets were insufficient for learning new concepts without proper instruction, and TA support was often inadequate.	• No online sources • Lack of material to apply to questions (given questions before information) • The pre-class worksheets that introduced new topics were sometimes very difficult to follow and work through without any direction
3	Time and Workload Management	The course's fast pace, heavy workload, and strict deadlines created time management challenges. Students struggled to complete worksheets, meet deadlines, and balance study time with other responsibilities.	• The shortness of time in class to complete the worksheet • Time management (having to do a preclass and inclass every day was hard, also the in-class worksheets were often too long and I wasn't able to complete them in class and the 5 pm deadline made it difficult to complete in time)
4	Group work and Interaction	Group work posed challenges, particularly with poor team dynamics or varying work speeds. Additionally, some students struggled to stay focused or engaged in class, especially due to the lack of lectures.	• Difficulty communicating with groups that had poor team chemistry • Some of my classmates just work faster than others, and working independently at your own pace defeats the purpose of grouping up
5	Exams and Assessments	Exam preparation was challenging due to format differences between worksheets and test questions. Many students felt unprepared for conceptual exam questions.	• Studying for exams (no notes to base studying off of) • Some of the conceptual questions on the test. I felt like we weren't prepared for some of the questions since they weren't mentioned on the practice exams
6	Other	Other challenges included adjusting to college-level courses, lacking a foundational knowledge, and difficulty understanding the course structure and goals. Missed classes and misunderstandings about assignments added to the confusion.	• Remember to submit all the worksheets • Connecting concepts between units • Not knowing what the question is asking for • Finding out the overall big picture for each individual process that we're figuring out

Table 8: Challenges of IBL

Use of resources in the course

Students were asked to select and rank the following resources provided during the course: AI assistance, class discussions, class worksheets, office hours, online videos, and peer support. The

following table summarizes the percentage of students who selected each resource (regardless of rank), followed by the percentage of students who assigned Rank 1 to that resource (among those who selected it), and the percentage of students who assigned a rank between 1 and 3 to the resource (among those who selected it).

Resource	% used	% rank 1	% rank top three
AI assistance	52.1	19.3	55.6
Class discussions	82.8	20.7	70.0
Class worksheets	98.8	32.9	77.8
Office hours	62.7	11.3	56.6
Online videos	57.4	15.5	48.5
Peer support	92.3	24.4	71.8

Table 9: Use of resources in the course statistics

Almost all students but 2 selected worksheets as useful. It was also ranked as the top used/the top three used resource by the students who found it useful. A similar observation is made for peer support, followed by class discussions. These findings support our initial hypothesis that class worksheets and class discussions are crucial, as they are the main components for engaging students in the classroom.

On the other hand, the bottom three resources in terms of perceived usefulness were office hours, online videos, and AI assistance, in that order, with AI being regarded as the least useful. However, a significant number of students still found online videos and AI to be helpful (57% and 52% respectively). While these resources are not typically intended for use in a purely Inquiry-Based Learning (IBL) setting, there is little that can be done to prevent students from utilizing them. It also raises the question of how we can strive to strike a balance between these resources that can help students.

Suggestions on improving the course

Students were asked to list suggestions for the improvement of the course in the survey. We use the same format as the section of "Challenges of IBL" here to summarize the results.

	Suggestion	Description	Example comments
1	Balancing Inquiry-Based Learning (IBL) and Lectures	Feedback on balancing IBL and traditional lectures, suggesting more structured lectures to support the inquiry-based learning process.	• I think IBL worked really well for most of the concepts in the class! For some of the more challenging concepts with more complex theory involved (such as Laplace Transforms), I think a hybrid structure with some more dedicated lecturing could be used to ensure understanding. • Even in maintaining the IBL format, giving some sort of a notes sheet/structure for students to take their own notes.

2	Pre-Class and In-Class Worksheets improvement	Suggestions on improving pre-class and in-class worksheets, focusing on clarity, structure, and reducing difficulty.	• The pre-class worksheets that introduced new topics were sometimes very difficult to follow • There should be pre-class lecture videos at least once per week to help guide the learning better. • Fewer PCWs, most of my learning came from ICWs.
3	Assessment and Practice	Feedback on improving assessments, practice exams, and providing clearer examples for test preparation.	• Maybe give an initial lesson on new material so that we know why we are going certain tasks and what it can help accomplish. • More recaps after lessons to solidify key points.
4	Instructor Support and TA Involvement	Suggestions for more TA support, office hours, and instructor-led guidance during in-class work and assignments.	• Increase the number of TAs, especially for longer worksheets (maybe creating class sections with one TA per 'sector'). • More TA-led discussions or group sessions during the course.
5	Resources and Materials	Exam preparation was challenging due to format differences between worksheets and test questions. Many students felt unprepared for conceptual exam questions.	• Studying for exams (no notes to base studying off of) • Some of the conceptual questions on the test. I felt like we weren't prepared for some of the questions since they weren't mentioned on the practice exams
6	Other	Some students praised IBL and had no additional suggestions.	• I really enjoyed the way the class was taught and felt like I was able to learn all of the content in a collaborative manner. • I honestly really enjoyed this course and have no complaints. I would be happy if all of my courses were taught using this approach. • I really enjoyed the class format and would recommend it for future students.

Table 10: Suggestions on improving the course

Prior experience with IBL and ODE

These questions in the survey check if the students have had experience with IBL and/or ODE prior to this class.

The majority of the students haven't had any experience with IBL or ODE before. Out of the ones who thought that they had some experience with IBL, they have had exposure to some elements of an IBL approach like worksheets and or flipped classrooms. The statistics for this are similar to those for IBL and ODE experience.

Only 4% of the respondents had some experience with both IBL and ODE. 26% of them had experience in either IBL or ODE. The majority of them (70%) had experience with neither. This suggests that our survey provides a good representation of students who are new to both ODE and IBL.

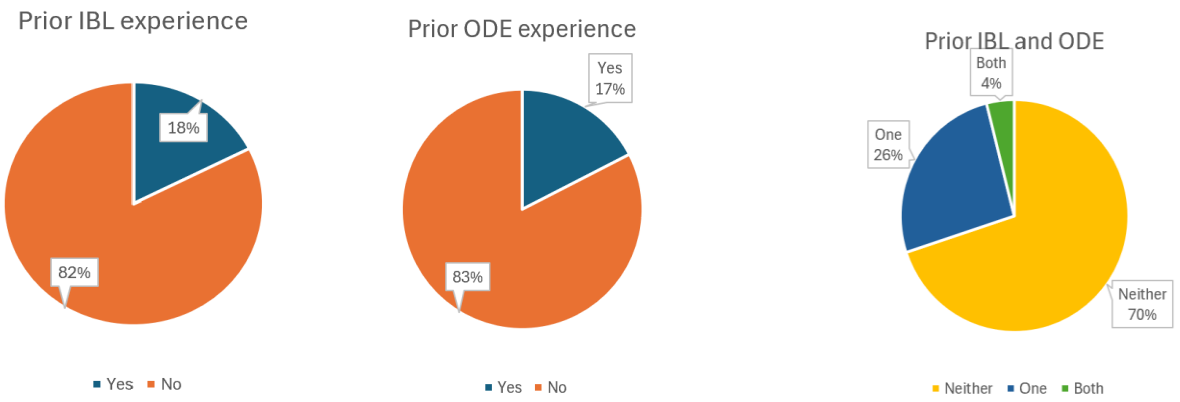


Figure 12: Pie charts for prior IBL and ODE experience

Interview results

As an icebreaker, students were asked what they thought IBL is. The majority lacked a clear understanding, mentioning pre-class and in-class worksheets with partners, instructor and TA support, and some lecture time. Only one of the seven students provided a more accurate answer.

The interview questions aligned with the survey questions, namely, Set 1 corresponds to Q1 in the interview, and so on. Below is the analysis of responses to the interview questions.

	Question	Summary
1	How did you feel in general about the ODE course using the IBL approach? Is there any benefit by using IBL approach?	Responses highlight both the benefits and challenges of inquiry-based learning (IBL) in mathematics courses. Key benefits include learning at one's own pace, asking questions, peer collaboration, and using pre-class worksheets to introduce material. In-class group activities helped reinforce concepts, and while initially challenging, the approach encouraged deeper thinking and active participation. Students valued the stronger community and the engaging nature of IBL, though some missed traditional lecture structure. Overall, they recognized IBL's value for deeper understanding and teamwork skills.
2	Were the current provided resources sufficient to success? Were the worksheets helpful? Did recap days help?	Responses reflect a mix of appreciation and frustration with the course resources and structure. In-class worksheets (ICWs) and recap days were valued for reinforcing learning, while pre-class worksheets (PCWs) and homework were seen as less helpful or overly complex. Many students felt the course offered sufficient practice materials, such as practice exams and recap sessions, but noted the limited use of textbooks and minimal in-class guidance. Some struggled with understanding the material due to a lack of comprehensive resources and sought external help. Despite these challenges, the interactive, self-directed approach fostered a sense of community and increased engagement.
3	Did the IBL approach increase your engagement with the course material?	Responses reflect a positive experience with the inquiry-based learning (IBL) approach, emphasizing its advantages over traditional lectures. Students valued the daily consistency, active engagement through worksheets, and collaboration with peers and TAs, which led to better attendance and deeper understanding. Unlike traditional classes, IBL encouraged continuous engagement and independent learning, reducing reliance on external resources like YouTube. The opportunity to explore various problem-solving methods and discuss different perspectives with classmates enhanced their comprehension and problem-solving skills.
4	Did IBL approach improve your collaboration skill with classmates? Did collaboration help you	Students found that collaborating with classmates enhanced their understanding of mathematical concepts, as discussing and explaining ideas led to deeper comprehension. Using appropriate vocabulary and gaining different perspectives made problem-solving more effective, making the IBL approach more manageable and rewarding. While challenges arose with less communicative group members, overall, increased communication and group work were seen as key to improving learning outcomes.

	understand the content better?	
5	Did your instructor create a safe and supportive classroom environment?	Responses highlight a positive and supportive relationship between students and the professor, who fostered a safe, welcoming learning environment. Students appreciated the professor and teaching assistants for being approachable, patient, and encouraging, particularly when asking questions. Many felt comfortable seeking help, with the professor taking time to explain concepts clearly and ensuring no one felt embarrassed. Even shy or reluctant students felt supported through flexibility and additional resources. Overall, the professor's approach contributed to a positive, inclusive classroom atmosphere that enhanced learning.
6	Please describe the challenges you faced in this course, ranking them from the most challenging to the least challenging. And describe how you overcame the challenges you mentioned above.	Common issues included balancing the workload, particularly when pre-class and homework assignments overlapped, and completing tasks with limited time. Some students found pre-class worksheets challenging due to unclear instructions and time constraints, while others struggled without traditional lectures. Many overcame these challenges by using office hours, online videos, and collaborating with classmates. The lack of immediate support on some worksheets led others to seek help from peers or TAs. Despite these difficulties, students appreciated the collaborative nature of the course and the support from professors and TAs.
7	Is there anything you would have done differently to improve your performance in this course?	Common strategies included better time management, such as using calendars for pre-class worksheets and planning study sessions in advance for exams. Students highlighted the importance of utilizing resources like office hours with professors or TAs to clarify concepts. They also emphasized reviewing worksheets earlier, asking more questions in class, and avoiding procrastination. Overall, the responses reflect a focus on proactive engagement with course materials and seeking timely help when challenges arise.
8	Do you have any suggestions for improving this course? Would you recommend it to others? Would a full lecture-based approach have been helpful?	Some students appreciated the hands-on, collaborative nature of IBL, finding it more effective for understanding and retaining material. They preferred working with peers and taking responsibility for their learning, though some suggested adding brief lectures or pre-lecture videos for deeper explanations. Challenges included a need for more in-depth explanations, difficulty understanding new material without structured guidance, and frustration with small mistakes affecting grades. Despite these issues, many favored IBL over traditional lectures for its engaging, interactive approach, citing better retention and understanding. Some recommended adding review days or more office hours to enhance comprehension. Overall, everyone preferred IBL over traditional method and would recommend it to others.

Table 11: In person interview findings

It's fascinating to note that all students, regardless of their performance group (A, B, C, D, F), expressed a preference for the IBL approach over traditional methods when given the choice. This unanimous preference suggests that the IBL approach could be beneficial if adopted in other courses as well.

Discussion and Conclusion

This paper primarily investigates students' perceptions of the IBL approach in ODE classes, focusing on the benefits of IBL, student collaboration, instructor roles, and engagement. Analysis of survey and interview data revealed that students had positive experiences with the IBL approach. Most students felt they had sufficient resources to succeed, and that IBL promoted their collaboration and engagement, despite some challenges, such as difficulties understanding course materials without traditional lectures.

Meanwhile, it is noteworthy that students had a vague understanding of what IBL truly entails. Their perceptions were based on the current course setup, raising questions about whether this

setup strictly adheres to IBL principles. To what extent did the course redesign implement IBL principles, and to what extent did students follow these principles in their learning? How can a course be designed to ensure strict implementation of the IBL approach?

For instance, many students found the recap worksheets very helpful, as they summarized all core course concepts. According to the survey, 52% of students used AI assistance to understand course concepts, and 57% watched online videos to learn the material. This raises the question: did students learn most effectively through exploration, discussion, and reflection, or did they still rely on passive learning methods, albeit in different formats such as reading well-written summaries or watching videos? These questions warrant further investigation on a broader scale.

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