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# Discussion Questions As Metacognitive Exercises

**Prof. Autar Kaw, University of South Florida**

Autar Kaw is a professor of mechanical engineering at the University of South Florida whose scholarly interests include engineering education research, adaptive, blended, and flipped learning, open courseware development, composite materials mechanics, and bascule bridge design. His work has been funded by the National Science Foundation, Air Force Office of Scientific Research, Florida Department of Transportation, and Wright Patterson Air Force Base. Under Professor Kaw's leadership and funding from NSF, he and his colleagues from around the nation developed, implemented, refined, and assessed online resources for open courseware in Numerical Methods. This courseware receives over 1 million page views (https://nm.MathforCollege.com), 1.6 million views of the YouTube lectures, and 90,000 visitors to the "numerical methods guy" blog annually. This courseware is also used to measure the impact of flipped, blended, and adaptive settings on how well engineering students learn content, develop group-work skills, and perceive the learning environment. Professor Kaw has written over 120 refereed technical papers, and his opinion editorials have been featured in the Tampa Bay Times, the Tampa Tribune, and the Chronicle of Higher Education. He has earned several teaching awards at the national level, including the 2012 U.S. Professor of the Year Award (doctoral and research universities) from the Council for Advancement and Support of Education and the Carnegie Foundation for Advancement of Teaching. His work has been covered, cited, and quoted in many media outlets, including Chronicle of Higher Education, Inside Higher Education, U.S. Congressional Record, Florida Senate Resolution, ASEE Prism, Times of India, NSF Discovery, and Voice of America.

**Dr. Renee M Clark, University of Pittsburgh**

Renee Clark serves as the Director of Assessment for the Swanson School of Engineering at the University of Pittsburgh. She received her PhD from the Department of Industrial Engineering, where she also completed her post-doctoral studies. Her research has primarily focused on the application of data analysis techniques to engineering education research studies as well as industrial accidents. She has over 20 years of experience in various engineering, IT, and data analysis positions within academia and industry, including ten years of manufacturing experience at Delphi Automotive.

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## Abstract

In a core mechanical engineering course on numerical methods at the University of South Florida in the fall of 2022, students were presented with discussion questions to serve as metacognitive activities. The course consisted of eight topics, and after each topic, the students were asked a single discussion question. While answering these questions was optional for the students, it served as 2% extra credit for the eight questions of the course. This initiative was initially taken to offset any occasional missed 30 online homework assignments, which accounted for 15% of the grade for the semester. These questions were designed to elicit thoughtful and unique responses from the students. To promote learning from others, students were allowed to see posted responses from other students only after they had submitted theirs. The questions ranged from making a meme to describing a difficult or intuitive concept. Despite the opportunity for extra credit and the unique prompts, the participation rate was only 59% of the possible submissions, and no clear trend was observed between the participation of high- or low-performing students.



## Keywords

Flipped classroom, active learning, metacognition, reflection.


## 1 Introduction

Reflection [1-3] is crucial for fostering metacognition, supporting effective learning, academic success, and lifelong learning beyond college. It is not only about absorbing information but also about actively thinking about one's thinking. By engaging in metacognitive practices, students can set learning goals, evaluate their understanding of course material, and select study methods that align with their cognitive strengths. This approach empowers students to become self-regulated learners. It helps them identify areas of difficulty and adjust study strategies, ultimately enhancing their comprehension and retention of course content and ability to be lifelong learners. Metacognition is a valuable skill that enables students to navigate the complexities of their academic journey and cultivate a deeper, more meaningful understanding of the subject matter.

STEM education requires effective pedagogical strategies that go beyond the mere transmission of information. Reflective practices have gained prominence in STEM disciplines as educators strive to cultivate content knowledge, critical thinking skills, and problem-solving abilities. This paper explores the application of reflection questions in a college-level engineering course, aiming to view the quantity and examples of responses. The article gives an example of using well-crafted and targeted reflection questions to catalyze deeper learning in a STEM course. It aims to contribute to the ongoing conversation about effective teaching practices in STEM education by focusing on the role of reflection questions.

Reflection questions were asked via a discussion board on a learning management system to invoke metacognition in a course in Numerical Methods. This core course is taught in the Mechanical Engineering Department at the University of South Florida at the junior level. It is offered thrice a year, with typical enrollment varying from 40-120 students per semester. The course's main objective is for students to develop and use numerical methods for the following eight topics: Introduction to Scientific Computing, Differentiation, Nonlinear Equations, Simultaneous Linear Equations, Interpolation, Regression, Integration, and Ordinary Differential Equations. Throughout the course, emphasis is placed on calculating errors and their relationship to the accuracy of the numerical solutions. MATLAB programming reinforces the course's fundamentals and solves intractable and real-life problems.

## 2 Implementation

The semester the discussion questions were implemented was the fall of 2022. The number of students registered for the course was 62, but only 52 opted to participate in the study. The course was taught in a flipped modality [4-7] with pre-class adaptive learning [8-10], and one of the grading components (15% of the grade) was the online adaptive lessons. Here, we delivered video and textbook content and asked questions via an LMS or an adaptive learning platform for pre-class preparation. There were 30 online lesson modules in the adaptive learning platform that covered the eight topics of the course, with each module worth 0.5% points.

Since there were 30 modules, it was inevitable that students would miss the completion deadline for a few of them. We added some discussion questions as extra credit to compensate for these missed deadlines. However, it was more than a compensation mechanism, as students actively reflected and gave serious responses. This observation led us to investigate whether these discussion questions were associated with students' final grades.

There were eight discussion questions, one on each topic or chapter of the course, worth 0.25% extra credit each. The questions were posed through the CANVAS discussion board. A discussion question was released on Thursday when the chapter was completed, and the answer was due on the Tuesday of the following week. Per the rubric in Table 1, the answers were graded on a scale of 0, 2.5, and 5.

**Table 1**. Rubric to Grade Answers to Discussion Questions

| Submissions will be graded on a simple rubric for thoughtfulness, thoroughness, and completeness. Students are expected to answer all prompts with care and in good faith. | |
|---|---|
| | Points |
| A thoughtful, thorough, and complete answer. | 5 |
| An attempt that mainly misses one of the above requirements. | 2.5 |
| An attempt that mainly misses two of the above requirements or is irrelevant or generic. | 0 |

Each chapter question was different to add variety, promote engagement, and avoid otherwise similarly worded answers. These questions are given in Table 2.

**Table 2**. Discussion Questions Posed

| Chapter | Question |
|---|---|

| | |
|---|---|
| **1.** | In 50-100 words or more, describe in complete sentences the most difficult concept or exercise for Chapter 01 (Introduction, Approximation & Errors) for you or a classmate. Include categorically why one would struggle with it. Limit yourself to one concept. |
| **2.** | Make a meme to illustrate anything related to Chapter 02 (Numerical Differentiation) |
| **3.** | In up to 280 characters (NOT 280 words), as one would do in a tweet, describe the most difficult concept or exercise for Chapter 03 (Numerical Methods for Solving Nonlinear Equations) for you or a classmate. Include categorically why one would struggle with it. |
| **4.** | In 50-100 words or more, describe in complete sentences the weirdest detail in Chapter 04 (Numerical Methods for Solving Simultaneous Linear Equations) for you or a classmate. Describe anything that stands out as weird, strange, or unusual [11]. Include categorically why one considers it to be weird. |
| **5.** | "All students should learn how to formulate their own questions" - Dan Rothstein and Luz Santana [12]. Choose the concept that gave you or would give a fellow student the most trouble to understand in Chapter 05 (Interpolation). Now think about a question that answering would help them to understand it better, if not completely. |
| **6.** | Write a nursery rhyme of 4 lines to describe a concept in Chapter 06 (Regression). The nursery rhyme should rhyme. It can be an original or a parody of an existing one. |
| **7.** | In 50-100 words or more, name the most intuitive concept or topic for Chapter 07 (Numerical Integration), and describe what you do and don't understand about it. Limit yourself to one concept or topic. This assignment is extra credit for 5 points on the "Online Assignments." |
| **8.** | In 50-100 words or more, name the most confusing concept or topic for Chapter 08 (Numerical Methods for Solving Ordinary Differential Equations), and describe what you or your fellow student would consider confusing [11]. It could be a concept or procedure whose details do not add up, sound contradictory, ideas that feel wrong, or arguments that are not appropriately reasoned. Limit yourself to **one** concept or procedure. |

## 3 Examples of Answers to Discussion Questions

To the discussion questions, the students gave answers that were of varying understanding. Some of the typical responses are shown in Table 3 for each chapter.

**Table 3**. Typical Responses to Discussion Questions

| Chapter | Question Asked | Answers |
|---|---|---|
| **1.** | Difficult Concept | "I personally struggled with the section 1.05 which covered Floating point binary representation of numbers. The main issue I have with this concept was initially understanding the format in which numbers were written. I had difficulty understanding the mantissa and the exponent because I have never represented numbers this way. I still need to work on the finding the error caused by the floating point format."<br><br>"I personally struggled with section 1.05. I am not sure if I missed something on the videos but there was a question where it asked for the smallest positive mantissa number and they gave the bits of the sign of the number, the sign exponent, mag of exponent, and the mag of mantissa. I had trouble figuring out this section from 1.05 and am still confused about it. I know that 0 indicated a positive sign but I didn't know how and where to place 0's and 1's on the chart. But I believe after you get the smallest values, you then convert it to decimal format for the final answer. |
| **2.** | Meme |  <br>  |

| | | |
|---|---|---|
| **3.** | Tweet | "Most of the Newton-Raphson method was easy, but the questions where we had to geometrically find where the tangent intersects the x-axis take a while. There's a lot of room for error; it can be so annoying!"<br><br>"Finding where the tangent line crosses the x-axis with the Newton-Raphson Method was hard to grasp. After understanding that the function over its derivative is the slope of the tangent line, I was able to use slope intercept form to find the answer." |
| **4.** | Weirdest detail | "I found the weirdest detail from Chapter 4 to be the Partial Pivoting Method, since it is so specific and it can avoid all pitfalls encountered in the Theory of Gaussian Elimination problems. The Partial Pivoting Method requires numbers to be switched after taking the absolute value, which I thought was confusing at first."<br><br>"If i am to be honest, the weirdest part to me was putting all of this in matrix formation. I already knew the Gaussian elimination method before this class. But trying to put it all in as a matrix and doing the math in matrix form made is seem so much weirder to do for me since it makes it seem so different even though its still the same process." |
| **5.** | Formulate Question | "Spline interpolation is a highly accurate method of interpolation covered in this course, however, it is relatively complex when compared to Vandermonde interpolation. What advantages are there in using spline interpolation instead of higher order Vandermonde interpolation that make the process worth the extra complexity?"<br><br>"It is easy to estimate the length of a curve given by a continuous function. Y'(x) is required to be continuous, y(x) is required to be differentiable and the integrand needs to be integrable. Why would you not use the analytical way of finding the length." |
| **6.** | Nursery Rhyme | "When the data tries to teach a lesson<br>But you cant get a confession<br>apply regression<br>the method is at your own discretion"<br><br>"Twinkle, twinkle little regression line<br>How I wonder your display<br>Up above, below, or on the given points you stay<br>As long as you are the smallest sum of the square residuals you're fine" |

| | | |
|---|---|---|
| **7.** | Intuitive Concept | "I found the 2-point Gauss Quadrature Rule of Integration to be most intuitive because it is like taking a more accurate combination of Riemann Sums since it is not solely using the left, right, or center points. It is intriguing to obtain an accurate answer after only finding 4 unknowns and adding / multiplying them together. This is certainly more beneficial for certain functions as they become more complex."<br><br>"I found Single Application Trapezoidal Rule the most intuitive topic because it is very easy to understand how you can estimate the value of an integral by multiplying the sum of the length of the parallel sides and the perpendicular distance between the parallel sides of the trapezoid that you draw under the curve (between the two interval points). Later you just divide that by two. This concept was straightforward to grasp as when it is sketched it is very intuitive to visualize what points/areas you are using to calculate the integral. Also, you can visually see the amount of true error which is the section above the trapezoid, but under the curve." |
| **8.** | Confusing concept | "The most confusing part of this chapter to me was the different versions of doing the Runge Kutta method because it was easy to mix up. At first I felt like a had a good understanding of it until I was doing practice problems and realized the question wanted a different method then the Heun's method and then I felt completely lost because I had forgotten the different parameters for the other two ways."<br><br>"The most confusing concept in Chapter 8 was analyzing the error associated with using Euler's method and Runge-Kutta, as the absolute relative true error was often over 2000%. This made me confused as to why these numerical methods would be acceptable to use, as such a high error would suggest that the values they produce would not be usable." |

## 4 Statistical Findings

At first thought, the instructor figured that most students would jump at the chance for extra credit of 2% as it required minimal effort (i.e., writing of 50-100 words). That was not the case. As shown in Table 4, the participation rate for each chapter was below 70%, and the overall rate was only 59%. However, only 11% of the students never participated.

**Table 4**. Participation rate by topics

| Topic | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| **Participation Rate (%)** | 63.5 | 63.5 | 69.2 | 65.4 | 55.8 | 51.9 | 48.1 | 53.8 |

The next question to ask is, who participated in the discussion questions? Were these lower-performing students trying to pass the course, or were they higher-performing students? Table 5 shows the average percentage score for five groups of students who earned grades of A-F in the course. One does not notice any trend, except that the students who received Ds earned the highest score. However, that may be skewed because only two (4%) students got a grade of D.

**Table 5**. Participants' average score by transcript grades

| Grade | A | B | C | D | F |
|---|---|---|---|---|---|
| **Participant Average Score (%)** | 69 | 61 | 69 | 81 | N/A |

## 5 Concluding Remarks

An extra credit opportunity was presented to students to encourage their engagement and critical thinking in a core Numerical Methods course. After completing each of the eight topics in the course, students were prompted with a unique discussion question. These questions ranged from prompting students to describe the most challenging concept to creating memes. While the levels of understanding in the responses varied, the participation rate remained below 70% for each topic, and the overall participation rate was only 59%. Interestingly, there was no clear association between the participation average score and the end-of-semester grade in the course. To further analyze the responses, future work could involve organizing them into categories using a taxonomy such as Bloom's [13] and coding the data using content analysis to understand what students struggle with the most. The latter would be used to structure homework assignments and the active learning activities of the flipped classroom.

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