Reflective Questions: Promoting Metacognition Through Discussion Board Prompts

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During two semesters, a numerical methods course for mechanical engineering students at a large US southeastern university used discussion board questions to promote reflection and metacognition. The course covered eight chapters, each with a related discussion question. The students could choose to answer these questions and receive 2% extra credit for the course. This was intended to help the students who missed some of the 30 online homework assignments that comprised 15% of the final course grade. The questions were also meant to encourage the students to think deeply and creatively. The students could see other students' responses after they posted their own. The questions ranged from making a meme, writing a nursery rhyme, and explaining a complex or easy concept. Only 64% of the total possible responses were submitted by students, and there was a small-to-medium practical but no statistical significance between the levels of participation among the high- or low-performing students. The submissions were analyzed and determined to be at the low level of Bloom's taxonomy. They identified complex topics to inform future instruction.

Keywords: metacognition, discussion, reflection, flipped classroom, Bloom's taxonomy

INTRODUCTION

This study used a discussion board in a learning management system to pose reflection questions to stimulate engineering-student metacognition in a Numerical Methods course. Metacognition, the process of thinking about one's thinking or knowing about one's cognition or knowledge, plays a pivotal role in learning and cognitive development. Through reflection studies, researchers can delve into the intricate workings of metacognition, including how individuals plan, monitor, and evaluate their cognitive activities (i.e., self-regulation). Metacognition support aligned with active learning and other forms of cognitive support can foster transformative educational practices (Vos & de Graaff, 2004). By exploring how individuals assess their knowledge, strategize problem-solving approaches, and use learning strategies, reflection studies demonstrate the importance of metacognition in enhancing and promoting academic performance, critical thinking skills, and lifelong learning.

In engineering, where complex challenges demand innovative solutions, integrating metacognitive strategies through reflective practices is critical for enhancing learning outcomes and fostering professional development. By engaging in reflection, engineering students can gain insights into their cognitive processes, identify effective problem-solving strategies, and refine their approaches to tackling engineering problems. Thus, metacognition holds profound implications for education and problem-solving across various disciplines, including engineering.

LITERATURE

Recent literature offers valuable insights into the role of metacognition in educational settings, mainly focusing on its effectiveness from an academic standpoint. Perry et al. (2019) examined the effectiveness of teaching metacognition in schools, highlighting a robust positive relationship between metacognitive instruction and pupil outcomes. Similarly, Goupil and Kouider (2019) delved into developing a reflective mind, emphasizing the transition from core metacognition to explicit self-reflection. Both research studies highlight the resourcefulness of reflection within metacognitive studies and its invaluable effect on instruction. Colthorpe et al. (2019) and Iordanou (2022) focused on promoting undergraduate students' metacognition and supporting their strategic development through reflection, respectively, underscoring the importance of metacognitive strategies in enhancing learning outcomes.

The continually growing knowledge of metacognitive research through reflection indicates various challenges and opportunities for future research and practice (Azevedo, 2020). The three primary elements of metacognition — meta experiences, meta knowledge, and meta strategies — explore a multitude of phases to consider when implementing reflective elements into metacognitive learning (Norman & Furnes, 2016). The literature on metacognition within engineering education reveals diverse approaches and contexts in which metacognitive strategies are applied to enhance learning and skill development. Studies have investigated the relationship between metacognition and self-directed learning in problem-based engineering curricula, highlighting the evolution of students' metacognitive processes over time (Marra et al., 2022). Additionally, research has demonstrated the effectiveness of reflective writing exercises in promoting metacognitive awareness and self-regulated learning behaviors among graduate students in computational science and engineering (Zarestky et al., 2022). The utilization of innovative tools, such as the web-based interactive platform "LectureTools", has been explored to assess and enhance metacognition in mechanical engineering classrooms. However, further investigation is warranted due to sample size limitations (Mazumder, 2011).

In addition to reflective activity, integrating service-based and other experiential learning initiatives has positively influenced engineering students' metacognitive strategies, particularly regarding strategic planning and task analysis skills (Lemons et al., 2011). Metacognitive skills are recognized as essential for lifelong learning and professional development in the engineering workplace, as evidenced by graduates' experiences in the Iron Range Engineering program (Spence et al., 2023). Furthermore, there is growing recognition of the importance of entrepreneurship education in fostering metacognitive abilities among engineering students, with implications for future economic impact (Ling & Venesaar, 2015). Finally, research on the effect of differently worded reflection prompts underscores the nuanced nature of metacognitive processing and its potential implications for targeted skill improvement strategies (Stratman & Diefes-Dux, 2022). Overall, these studies contribute to a comprehensive understanding of the multifaceted nature of metacognition and its significance in engineering education and beyond.

Bloom's taxonomy, which was used to classify the reflective responses in this study, has remained a cornerstone in educational research and practice due to its hierarchical model of six cognitive processes, ranging from simple recall and comprehension of facts to complex synthesis and evaluation of knowledge (Bloom et al., 1956). Over the years, research into Bloom's taxonomy has provided profound insights into how individuals learn, comprehend, and apply information across diverse domains (Cochran & Conklin, 2007; Walberg, 1972). By delving into the intricacies of each cognitive level, researchers have uncovered effective teaching strategies, assessment techniques, and learning interventions tailored to learners' cognitive development stages. While many research studies have assessed student responses and identified main themes in qualitative data, only a handful utilize Bloom's taxonomy's strategies (Crowe et al., 2008; Ullah et al., 2020; Ulum, 2016).

In educational assessment and qualitative research methodologies, recent studies have provided valuable insights into Bloom's taxonomy approach and identification of central themes. Morton and Colbert-Getz (2017) conducted a study within undergraduate medical education to measure the impact of flipped anatomy classrooms, highlighting the significance of categorizing assessments according to Bloom's taxonomy. Their findings suggested a higher mean increase in anatomy performance among students in flipped classrooms, emphasizing the importance of instructional methods in influencing learning outcomes. On the qualitative research front, Ryan and Bernard (200) discussed techniques for identifying themes in qualitative data, such as word repetitions and key-words-in-context (KWIC) analysis, which assist in uncovering the main themes among responses obtained. Similarly, Thomas and Harden (2008) presented methods for the thematic synthesis of qualitative research in systematic reviews, advocating for categorical analysis within chapters to segment and define parameters, thereby facilitating the identification of central themes. These studies contribute to a deeper understanding of assessment practices and qualitative analysis methodologies, providing valuable insights for educators and researchers alike.

IMPLEMENTATION/METHODS

Numerical Methods is a required/core course at the junior level in the Mechanical Engineering Department at the University of South Florida. It runs three times a year, with an enrollment of 40-120 students per semester. The main goal of the course is to develop and apply numerical methods for eight chapters - Introduction to Scientific Computing, Differentiation, Nonlinear Equations, Simultaneous Linear Equations, Interpolation, Regression, Integration, and Ordinary Differential Equations. The course emphasizes computing errors and their impact on the precision of numerical solutions. MATLAB programming is used to reinforce essential concepts and solve complex and real-world problems.

The discussion board questions were introduced in the Fall 2022 and 2023 semesters. There were 144 students enrolled in the course, and 119 agreed to take part in the study. The course was taught in a flipped mode (Talbert, 2017; Walkington, 2013), with online adaptive lessons used for pre-class learning (Kaw et al., 2019; Clark & Kaw, 2020; Szafir & Mutlu, 2013; Talbert, 2017; Walkington, 2013). In these lessons, through an adaptive learning platform, we provided video, textbook content, and quizzes for pre-class preparation. There were 30 online modules in the adaptive learning platform that covered the eight chapters, and each module was worth 0.5%, for a total of 15% towards the final course grade.

We offered discussion board questions as extra credit because some students would not finish all modules by the deadline. However, they were more than a compensation strategy for students, as students reflected and gave thoughtful answers. This observation prompted us to explore whether their responses to the discussion questions were related to their final course grades. There were eight discussion board questions, one for each course chapter, each worth 0.25% extra credit. The questions were posted on the CANVAS discussion board. A discussion question was opened on the Thursday after the chapter was completed, and the answer was due the following Tuesday. The instructor graded the responses using a scale of 0−5 based on the rubric in Table 1.

TABLE 1
RUBRIC TO GRADE RESPONSES 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.	
CRITERIA	**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

The instructor initially assumed that most students would eagerly take advantage of the opportunity for 2% extra credit, as it only required minimal effort (i.e., writing 50-100 words). However, this was not the case. As indicated in Table 2, the participation rate was below 71% across all chapters for both semesters, with the overall rate at 64%. However, only 11% of the students never participated.

TABLE 2
PARTICIPATION RATE (%) BY CHAPTER

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**OVERALL**
Fall 2022	63.5	63.5	69.2	65.4	55.8	51.9	48.1	53.8	58.9
Fall 2023	76.9	66.2	58.5	73.8	69.2	70.8	69.2	61.5	68.3
Overall	70.9	65.0	63.2	70.1	63.2	62.4	59.8	58.1	64.1

The discussion questions were designed to be diverse, engaging, and unique, so the responses were not perceived as repetitive or too similar. Table 3 shows the discussion questions.

TABLE 3
DISCUSSION QUESTIONS POSED

CHAPTER	**DISCUSSION 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 (Seale, 2022). 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 (Rothstein & Santana, 2011). 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 better, if not wholly.
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.

CHAPTER	DISCUSSION QUESTION
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 (Seale, 2022). 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.

The students' responses were classified using Bloom's taxonomy (Bloom et al., 1956). The instructor guided the two coders through a training session using a set of responses from Fall 2021, which were not part of the study, to classify them into three categories based on Bloom's taxonomy. By demonstrating the classification of sample responses and explaining the rationale behind each category, the instructor emphasized using specific "verbs" associated with each level of Bloom's taxonomy (Newton et al., 2020). The coders then independently classified several responses, justifying their choices and discussing discrepancies to reach a consensus. This hands-on approach continued until they felt confident in their classifications. Unlike typical thematic analysis, where themes are identified, this process involves predefined categories. The coders categorized the responses as low-level (remember and understand), mid-level (apply and analyze), or high-level (synthesize and evaluate) within Bloom's taxonomy, achieving an impressive inter-coder agreement ranging from 93% to 100%.

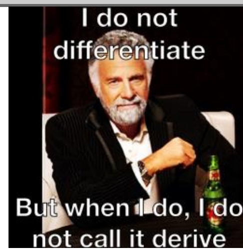
RESULTS

Response Examples to Discussion Prompts

The students provided responses to the discussion questions that exhibited varying levels of understanding. A sample of responses for each chapter is shown in Table 4.

TABLE 4
EXAMPLE RESPONSES TO DISCUSSION QUESTIONS

CHAPTER	PROMPT	RESPONSES	RUBRIC SCORE (OUT OF 5)
1	Difficult Concept	"The most difficult concept for me so far has been understanding floating point representations in base 2. Getting into it was very confusing trying to understand the style of writing base 2 in floating point representation. I think the format for the answers in this section is a little confusing since you have to think that the first digit is assumed one, and you put everything after it in the answer(mantissa)."	5
		"I felt the hardest concept in chapter 1 was part 1.05: Floating Point Binary Representation of Numbers. I felt this was rather challenging mainly because of the structure of the online assignment and videos. I personally had a hard	5

		time completing this chapter with just the videos as a guide whereas when it was gone over in class, it was much easier to understand. I feel if I was able to complete the assignment after attending the lecture, it would have been much easier.”	
2	Meme	 	5, 5
3	Tweet	“I used the bisection method the other day and by the time I finished solving the problem, I realized I forgot to check if the bracket I was given was valid. When I did, I saw that the value of the function at the lower limit times the value of the function at the upper limit was greater than zero and I did more work than I needed to!”	5
		“The most difficult concept from chapter 3 for me was the Newton-Raphson Method preliminary exercises. I was getting a little confused on how to find the x-value where the line tangent to the function at (xi, f(xi)) crossed the x-axis. However, with some practice, I got better at it.”	5
4	Weirdest Detail	“I found it weird that the identity matrix is all zeros except for 1’s in the diagonal. The identity property states that the product of any number multiplied by 1 is itself. I originally thought the identity matrix would just be a matrix full of 1’s. Then we learned how the identity matrix works with different methods such as the LU method, which made much more sense.”	5
		“The weirdest detail about Chapter. 04.06 is the issue of division by zero during the Naive Gauss elimination method. I find this out of the ordinary because I believe that it is an issue that is not rare to find and encounter, since zeros are present in many equations. Thus, one would think that that would make the method unreliable, since even when resolving the issue by applying Gaussian elimination with partial pivoting, the determinant of the resulting upper triangular matrix can still differ by sign, which is what I find strange about it.”	5

5	Formulate Question	"I think an important question to understand is "Why does polynomial interpolation break down?" I know it is similar to the question provided but I believe it is extremely critical. In order to properly solve a problem, you have to understand why it is a process in the first place. The issue the question is targeting is the reason we do most of what we do in this chapter. It is, in my opinion, the foundational question of what we learned in the chapter."	5
		"When going through quadratic spline interpolation, there are more unknowns than knowns in one equation between two points. Why would it not be useful to compare this spline to the quadratic spline between two other points in the latter end of the function in order to find the unknowns?"	5
6	Nursery Rhyme	"Linear regression, simple and clear, Fits a straight line, so no need to fear. When trends are linear, it's the way to go. When modeling data, it's a pro!"	5
		"In engineering's domain, where numbers take stage, Regression guides our path on each data-filled page. With derivatives and equations, we seek the best way, To minimize sum of square residuals, in our analysis we sway!"	5
7	Intuitive Concept	"I believe that the most intuitive method for integration is the trapezoidal rule. About it, I understand how measuring the area under the curve by measuring areas of a set number of trapezoids can give a close approximation that will work when applying this integral. what I do not understand as well is how to use it properly on functions that are not fully continuous."	5
		"I found the trapezoidal rule of integration to be the most intuitive as the name sort of explains it. The area of a trapezoid is easy to find, and I can see why approximating the area under a curve can be more accurately done with trapezoids or first-order polynomials rather than rectangles or zero-order polynomials. I can also see that it follows that using this technique, we can accurately integrate first-order functions."	5

8	Confusing Concept	"I found the Runge-Kutta method and the different combinations of methods that can be inserted into it to be a very confusing concept. It took me a while to visualize the different methods and how they work to approximate the integral, but while looking through the different variations I was able to come to an understanding of how they all work together."	5
		"I found the process of using Euler's Method to approximate the value of an integral to be the most confusing topic conceptually from Chapter 8. If we use Euler's Method to approximate the value of a function at a discrete point, then intuitively you would not think you could use it to approximate the area under the curve. However, after learning to let the derivative equal the function and set the value of the function at the lower limit equal to 0 it now makes sense why evaluating it at the upper limit will give you the approximate area."	5

Bloom's Taxonomy Coding

Although the students were not asked to give higher-level-thinking responses, we found that the responses were exclusively at the low level of Bloom's taxonomy. Specifically, 97% were coded at the low-Bloom level, and only 3% were coded at the mid-Bloom level. We did not perceive any effect of the availability of ChatGPT during the Fall 2023 semester on the responses. Although the cognitive level of the responses was somewhat disappointing, a revision towards higher expectations can be made for future semesters.

Association Between Reflective Scores and Course Grade

In Table 5, you can find the average percentage score for five groups of students who received grades ranging from A to F in the course. There does not seem to be a clear trend, but it is worth noting that students who received Ds achieved the highest score in Fall 2022. However, this may be misleading because only two (4%) students received a grade of D in that semester.

Comparing the mean score of high-performing (A and B grades) students (M=66.9, SD=33.3, N=88) with low-performing (C, D, F grades) students (M=56.7, SD=33.2, N=29) does not show statistical significance (p=0.16, t(46)=1.41) based on a two-tailed t-test with unequal variances. However, a small-to-medium effect size (d=0.36) was found, which implies that high-performing students score higher than low-performing students.

TABLE 5
PARTICIPANTS' AVERAGE PERCENTAGE SCORE (%) BY TRANSCRIPT GRADES

	A	**B**	**C**	**D**	**F**
Fall 2022	59.8	46.6	68.8	81.3	0.0
Fall 2023	74.5	80.7	48.8	54.2	0.0
Both Semesters	66.2	68.0	54.9	65.0	0.0

The students' responses were classified using Bloom's taxonomy (Bloom et al., 1956). Two coders were trained on a data set from a previous semester of Fall 2021. They were asked to classify the responses as low-Bloom (remember and understand), mid-Bloom (apply and analyze), and high-Bloom(synthesize and evaluate) taxonomy level. Although the students were not asked to give particularly higher-level thinking responses, we found that the responses were exclusively at the low-Bloom level. The responses were 97% at the low-Bloom and only 3% at the mid-Bloom levels. We did not find any effect of the open availability of ChatGPT in Fall 2023 on the level or the participation of responses. Although the low-Bloom level of responses was commonly observed in discussion posts (Garrison et al., 2001; Gilbert & Dabbagh, 2005), the instructor can impose higher expectations for future semesters. The agreement between the two coders on Bloom's levels ranged from 93%−100%.

We used the responses from both semesters to determine what students referred to in each chapter. This identifies topics where they may have struggled and informs future instruction. Table 6 gives the three most brought-up issues in each chapter.

TABLE 6
THE THREE MOST DISCUSSED TOPICS FOR EACH CHAPTER

CHAPTER	PROMPT	TOP THREE TOPICS	PERCENTAGES
1	Difficult Concept	Floating Point Format	41.77
		Biased Exponents	13.92
		Binary representation	12.66
2	Meme	FDD / BDD / CDD	34.18
		Differentiation	12.66
		Derivative of e^x	8.86
3	Tweet	Newton-Raphson Method	45
		Bisection Method	28.75
		Deciding which method	7.5
4	Weirdest Detail	LU Decomposition	30.49
		Matrix Manipulation	12.20
		Naïve Gaussian Elimination	12.20
5	Formulate Question	Different Methods of Interpolation	26.67
		Accuracy Order of Polynomial	13.33
		Number of Equations	10.67
6	Nursery Rhyme	Regression Concept	25
		Regression Equation	13.89
		Adequacy Checks	13.89%
7	Intuitive Concept	Trapezoidal Rule	39.44
		Gauss Quadrature Rule	16.90
		Single Application Trapezoidal Rule	8.45
8	Confusing Concept	Runge-Kutta Method	23.53
		Homogenous and Particular Solutions	17.65
		Solving Higher-Order ODEs	13.24

CONCLUDING REMARKS

An extra credit opportunity was offered to students in the core Numerical Methods course to compensate for missed low-stakes homework assignments and encourage their engagement and critical thinking. After completing each of the eight chapters in the course, students were given a unique discussion question. These questions varied from describing the most challenging concept to creating memes. Although the understanding levels in the responses varied, the participation rate remained below 71% for each chapter, with an overall participation rate of only 64%. There was no statistical significance in the scores of low- and high-performing students, although the latter showed a small to medium positive effect size of d=0.36. The responses were categorized using Bloom's taxonomy to analyze them further, and 97% were found to be at the low level of Bloom's taxonomy. We also coded the data to understand what students struggled the most with. This informed future homework assignments and active learning activities for the flipped classroom.

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