2023

Enhancing Engineering Students' Mathematics Learning Through Digitised Effective Feedback

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Conference Key Areas: *Innovative Teaching and Learning Methods, Fundamentals of Engineering: Mathematics and the Sciences*
Keywords: *Engineering Education, Digitised Learning, Effective Feedback, Mathematics, Polya's Heuristics*

ABSTRACT

This practice paper explores the impact of effective digitised feedback on engineering students' mathematics learning in the digital environment. By using a schematic framework, an online repository will be developed to provide effective feedback to the first-year students taking mathematics courses. The repository takes into account calculus topics and focuses on providing guidance to students who give incorrect answers to questions by incorporating sub-questions based on Polya's heuristics. The sub-questions aim to motivate students to draw on simpler connections and stimulate learning by encouraging students to check their answers and reflect on their initial responses. This study is currently an ongoing project in the Netherlands and aims to improve outcomes in calculus courses and provide a database of online exercises for digital exams, which will save teachers time, in long term.

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1 INTRODUCTION

In recent years, the integration of technology into education has become increasingly prevalent, transforming traditional learning environments and offering new opportunities for innovative instructional approaches. Engineering education, in particular, has witnessed the incorporation of digital tools and platforms to enhance the teaching and learning process. Within this context, the focus on mathematics learning and the provision of feedback have emerged as critical areas of investigation. By leveraging the potential of digital platforms, this study aims to enhance the effectiveness and engagement of students in their mathematical studies.

Recent advancements in educational technology have paved the way for the development of digitised effective feedback systems that go beyond conventional feedback mechanisms. The MAA National Study of College Calculus conducted by Bressoud, Mesa, and Rasmussen (2015) provides valuable insights and recommendations for implementing effective feedback strategies in college-level calculus courses. Their findings emphasise the importance of timely and constructive feedback in enhancing student learning outcomes.

In addition to the cognitive aspects of learning, the effective dimensions, including students' emotions and engagement, play a crucial role in the learning process. Research by Pekrun, Goetz, Titz, and Perry (2002) and Fredricks, Blumenfeld, and Paris (2004) explores the influence of effective feedback on students' self-regulated learning and engagement. Understanding and addressing students' effective experiences through digitised feedback can contribute to creating a supportive and motivating learning environment.

To guide students in their problem-solving processes, this study also draws upon the principles of Polya's problem-solving heuristics. Kilpatrick, Swafford, and Findell (2001) discuss the importance of problem-solving skills and approaches in mathematics education in their influential book "Adding It Up: Helping Children Learn Mathematics." By incorporating Polya's problem-solving heuristics, educators can empower students to develop essential problem-solving skills, fostering a deeper understanding of mathematics.

In conclusion, this paper addresses the pressing need to explore the potential of digitised effective feedback in mathematics learning within the context of engineering education. By building upon existing scholarship, including recent advancements, key papers, and notable research, and leveraging theoretical frameworks, the study aims to contribute to the field's knowledge base. The findings of this research will inform the development of an online repository of questions and exercises that integrate effective feedback, offering valuable resources to the SEFI community and advancing the learning experiences of engineering students in mathematics courses.

1.1 Research Question

Based on the above considerations and the need to enhance mathematics learning in engineering education, this study aims to investigate the impact of effective digitised feedback, incorporating sub-questions based on Polya's heuristics, on engineering students' mathematics learning in the digital environment. Therefore, the main research question is: What is the impact of effective digitised feedback on engineering students' mathematics learning and problem-solving abilities? To address this question comprehensively, this paper will undertake an exploration of the subsequent inquiries: How do these sub-questions based on Polya's heuristics contribute to the resolution of the main problem, and in what ways can their efficacy be further enhanced? Interviews were conducted with two first-year students, denoted as a student with intermediate proficiency (SIP) and a student with low proficiency (SLP), whose feedback has been presented in the results section of this paper.

2 METHODOLOGY

Since 2020, the University of Twente (UTwente) has been utilizing the Grasple online learning platform[1], which offers hint-based feedback to students through exercises sourced from other technical universities in the Netherlands. Course evaluations have consistently indicated that students are highly satisfied with the use of this online platform. However, there is a pressing need to enhance the exercises available in the Grasple repository to align them more closely with the specific learning objectives of UT's Mathline courses.

The aforementioned repository takes into consideration calculus topics, such as vectors, limits, and derivatives, which are part of an ongoing project called the 4TU Teaching and Learning Fellowship at UTwente. The aim of this project is to develop constructive feedback mechanisms for students by improving the existing repository of questions and creating new ones. The main focus is on providing sub-questions that can guide students who have given incorrect answers, serving as stepping stones to help them overcome challenges in problem-solving. These sub-questions are developed by the researcher based on relevant literature and their own teaching experience.

To guide the development of sub-questions, the framework of Polya's heuristics (1957) and Schoenfeld's metacognitive aspects of successful problem-solving (1985) are taken into account. Polya's heuristics emphasise understanding the problem, devising a plan, executing the plan, and reflecting on the solution as key steps in effective problem-solving. The heuristics offer students systematic approaches, such as working backward, drawing diagrams, making assumptions, and considering special cases, to enhance their problem-solving skills.

In Figure 1, an example from Grasple is presented, focusing on the creation of a plane equation using given vectors. The hint-based feedback is provided to students when they answer the question incorrectly, aiming to facilitate their learning process. Inspired by Schoenfeld (1985), the strategy of solving an easier, related problem first is employed as a means to support students in tackling the original problem. The sub-questions act as stepping stones and encompass concepts such as the dot product, vector construction, and visualizing components.

Another important aspect in problem-solving, as advocated by Polya, is the step of looking back. This encourages students to review their answers, analyzing them for accuracy and reasonableness. It also provides an opportunity for students to reflect on their initial responses and approach the problem with a more conscious consideration. This step will be integrated at the end of the sub-questions to further

[1] Grasple. "Homepage." Grasple. https://www.grasple.com/.

support students' learning process. Table 1 provides an overview of the sub-questions based on the guide to problem-solving techniques outlined in Polya's work (1957).

By incorporating these research-based strategies, our objective is to enhance students' mathematical learning experiences and improve their problem-solving abilities within the Grasple platform. To measure the effectiveness of our approach, we will interview a larger sample of engineering students after introducing the sub-questions in their studies. Additionally, we will compare the passing rates with the previous year's data. This expanded sample will provide valuable insights into the impact of effective digitised feedback on their mathematics learning and problem-solving abilities. Through the development of effective sub-questions and the integration of Polya's heuristics and Schoenfeld's metacognitive aspects, we anticipate creating a more comprehensive and engaging learning environment that fosters students' growth and success.

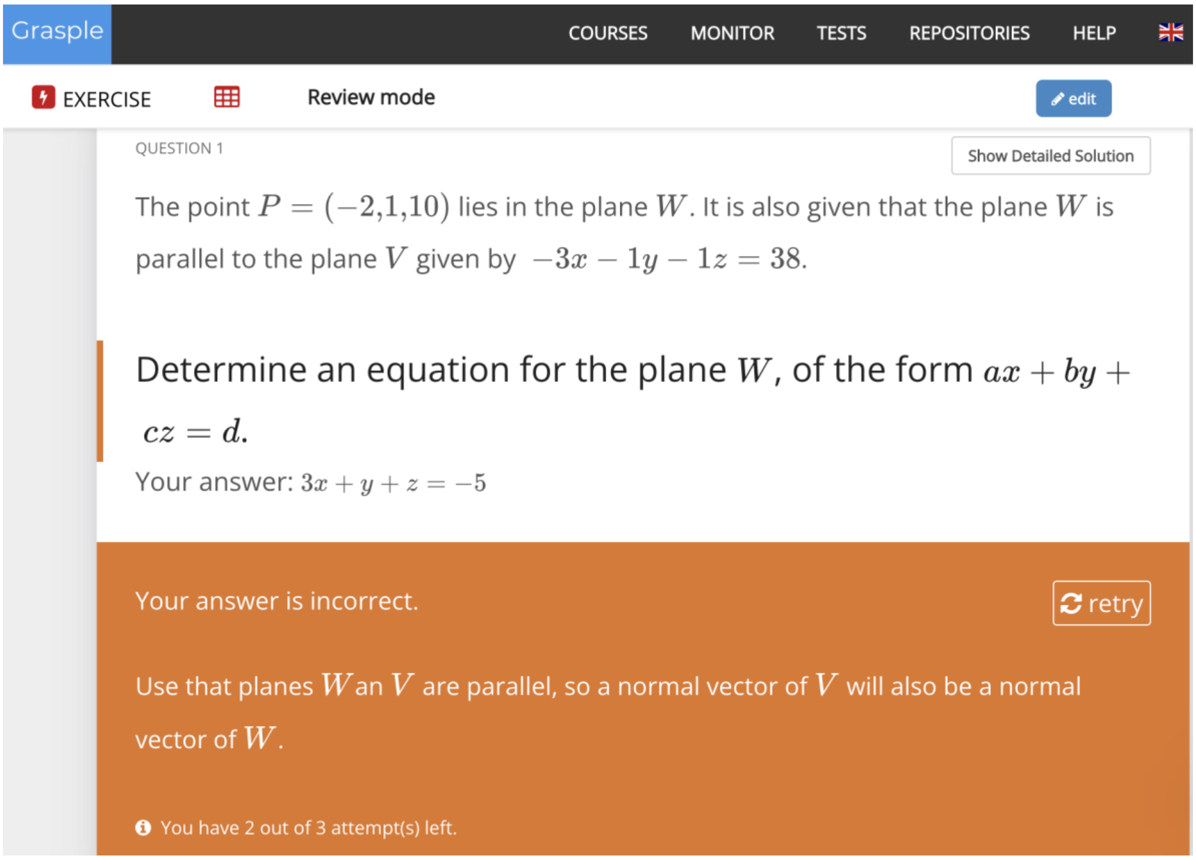

Fig. 1. The original final answer question with a hint due to incorrect answer on Grasple.

Table 1. The sub-questions by using the guide to problem-solving techniques (Polya 1957).

Phases	The sub-questions with Heuristic Approaches
1. **<u>Understanding the problem:</u>** Polya emphasises the significance of understanding the problem before attempting to solve it. This involves reading the problem carefully, identifying the given information, and clarifying the desired outcome.	**Sub-question 1: Understanding the given information (Relating Planes):** Before tackling the original problem, it is essential to determine the given information. The final answer sub-questions could be: • Which point lies in the plane W? • Which equation represents the plane V that is parallel to the plane W?
2. **<u>Devising a plan:</u>** Polya highlights the importance of devising a plan or strategy for solving the problem. This involves breaking down the problem into smaller, more manageable parts, recognizing patterns or similarities to previously solved problems, and considering alternative approaches.	**Sub-question 2: Determine the normal vector of plane V:** Understanding the concept of a normal vector and its relation to a plane equation is essential for solving the original problem. This sub-question helps reinforce the connection between normal vectors and plane equations. The sub-questions could be: • Which vector is perpendicular to the plane V? a) (-3,1,1) b) (0,-1,1) c) (-3,-1,-1) d) (1,0,-3) **Sub-question 3: Visualizing the components:** Visualise the components of the vectors and their relationship in three-dimensional space. This step helps in understanding the geometric interpretation of the plane equation.The sub-question could be: • Which of the following statements is true about the two parallel planes? a) Their respective normal vectors are parallel. b) Their respective normal vectors are perpendicular.

	Sub-question 4: Identify the relationship between parallel planes: Understanding the relationship between parallel planes is crucial for solving the original problem. By exploring this sub-question, the student will develop a deeper understanding of how parallel planes are related in terms of their normal vectors and equations. The sub-question could be: • Determine the normal vector of the plane W. a) (0,-1,1) b) (-3,-1,-1) c) (1,0,-3) d) (-3,1,1)
3. Carrying out the plan: Once a plan is formulated, Polya advises students to execute it step by step, applying appropriate mathematical concepts and techniques. He encourages students to be flexible and willing to revise their plan if necessary.	**Sub-question 5: Dot product calculation:** Calculate the dot product of the constructed vectors. The dot product is a crucial operation when working with vectors and plays a big role in defining planes.The sub-question could be: • Using the point P=(-2, 1, 10) and the normal vector of the plane W, determine the equation of the plane W. a) 2x-y-10=38 b) -3x-y-z=-5 c) -2x+y+10=38 d) 3x+y+z=-5
4. Looking back: After obtaining a solution, Polya suggests reflecting on the problem-solving process. This includes verifying the solution's accuracy, assessing the reasonableness of the answer, and considering alternative methods or perspectives.	**Sub-question 6: Reflecting on the solution:** This question prompts the student to substitute the coordinates of point P into the equation of plane W and determine if the equation holds true for the given point, without explicitly providing the direction (positive or negative) of the statement. The sub-question could be: • Verify if the point P=(-2, 1, 10) lies on the plane W represented by the equation ax + by + cz = d.

		a) Yes, the point P lies on the plane W. b) No, the point P does not lie on the plane W.

3 RESULTS AND DISCUSSIONS

In the following section, we will present the outcomes based on our interpretation of the extracts obtained from the conducted interviews. Each interview lasted approximately 45 minutes and was recorded for accurate documentation. The Grasple question depicted in Figure 1 was given to two first-year engineering students at UTwente: a student with intermediate proficiency (SIP) and a student with low proficiency (SLP). Initially, both students encountered difficulties in solving the main problem. However, upon the introduction of the sub-questions aligned with Polya's heuristics, both students successfully arrived at the correct answer. The interview encompassed a concise set of approximately two questions, namely: (1) How do these sub-questions based on Polya's heuristics contribute to the resolution of the main problem? and (2) In what ways can their efficacy be further enhanced?

<u>(1) How do these sub-questions based on Polya's heuristics contribute to the resolution of the main problem?</u>

- Overall: "*I would say in general it was a lot better than the Grasple right now. Because I know a lot of people are getting frustrated when they make a small mistake or a big mistake, whatever, and then it just says you're wrong and the explanation is not super clear. Or for example, the explanation assumes that you know something and just skips that part […] and some people just I know what we're trying to just learn how to solve what Grasple wants you to solve and that didn't seem right, but this seems a lot better […] it's like takes your hand and just follows you through the whole thing." (SIP). "I like them, because you could see it [the solution] step by step."(SLP).*

- Regarding the first phase: *"People make a lot of mistakes when reading and a lot of times you fail to solve for Grasple because you just didn't finish the sentence because you know you already know what's gonna be there. But it's not there."(SIP). "Well, these are mostly the questions that I ask myself first, so I write them down first of all.[…] That's the basic step to start any question, just write everything down that's asked from the question itself."(SLP).*

- Regarding phases 2 and 3: *"I think you can definitely see the correlation to the original equation. So we should be able to make the connection."(SIP). "So it's a good continuation on your thought process about entering question 4 from question 2." (SLP).*

- Regarding the last question: *"I like the last question because it forces you to double check your work, which people always not do, and it's a good habit to force people to do it and maybe they will actually end up doing it in their life. So* *that's nice." (SIP). "It's a nice finisher, because then you can see, OK, the point P does fit into the correct formula which you answered and if I answered [question] 5 incorrectly, then it wouldn't work."(SLP).*

(2) In what ways can their efficacy be further enhanced?

- Point of improvement: *"Maybe not these questions themselves, but like if the question is way more complex and if a person does not know the theory and he gets more like he tries, it gets wrong. Maybe it's great if it would kind of give you a short theory where referring to for example. it would be nice if it, like gives you that, but only if it's like a complicated thing […] So you make a mistake, right? You double check your work and then you saw correctly. Then you don't need the theory. But if you make two mistakes in a row, I guess then it's nice for you to get the theory." (SIP). "[In Phase 2] I would like to see some theory about it, and maybe a 3D visualisation on why the numbers are connected. […] Yes, for me it's clear, but I made a 3D visualisation in my head where I had two planes and if you have two perpendicular vectors, one from the plane downwards up or one from the plane. They [normal vectors] are parallel."(SLP).*

Based on the students' feedback, we discern a positive interpretation, highlighting the advantages associated with the implementation of the sub-questions. The interview outcomes reveal that both phase 1, involving the understanding of the given information, and phase 4, related to the reflection on the solution, play significant roles as essential stages in assisting students in resolving the main problem. In light of this feedback, we are committed to diligently considering their recommendations for enhancing the project.

This study is anticipated to yield substantial improvements in outcomes for calculus courses, which are essential components of various study programs at the University of Twente. Additionally, it aims to establish a comprehensive database of online exercises that can be utilized for digital exams, resulting in considerable time savings for teachers. The project's timeline indicates that the outcomes for larger interview sample will be available by the end of the first quarter of the upcoming academic year allowing us to address our main research question. This project introduces a practical and innovative approach to providing effective feedback to engineering students, thereby significantly enhancing their learning experience and preparing them for the challenges of a complex and sustainable world. Further research has been conducted, and additional examples will be presented and discussed during the Poster presentation of this study at SEFI 2023.

4 ACKNOWLEDGMENTS

This research was made possible thanks to funding, input and feedback from the 4TU CEE organization in The Netherlands. We gratefully acknowledge Tracy Craig for her invaluable feedback to this practice paper.

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