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Reflect, Reason, Apply: Enhancing Learning and Cognitive Engagement in Maths and Statistics

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Abstract
This study explores the effectiveness of reflective practice, implemented through an e-Portfolio assessment, in a Mathematics and Statistics course. Reflective pedagogy was employed to enhance students' engagement, comprehension, and application of mathematical concepts. Using a qualitative approach, 25 student responses were analyzed through thematic coding and sentiment analysis to evaluate their perceptions. Thematic analysis revealed students perceived the e-Portfolio as a valuable tool for reinforcing knowledge and promoting active reflection, which contributed to deeper conceptual understanding and practical application. Sentiment analysis showed predominantly positive feedback, with challenges relating to time management and the clarity of instructions. These findings suggest that while the e-Portfolio is an effective assessment tool, its implementation can be further optimized by providing clearer guidelines, structured support, and phased submission strategies to mitigate potential difficulties. The study also highlights the significance of reflective pedagogy in quantitative disciplines to enrich the learning experience and strengthen cognitive engagement.

Keywords: *Cognitive Engagement; learning experience; metacognitive regulation; quantitative learning; reflective practice; STEM education*

1. Introduction

The challenges of 21st century education systems call for types of pedagogical approaches that go beyond the memorization of information, especially in areas like mathematics and statistics where students have difficulty translating theory into practice. Mathematics education has for a long time battled with the issue of how best to ensure that students not only learn procedures, but also comprehend the concepts behind the procedures (Boaler, 2016). Most pedagogical approaches in quantitative courses focus on problem solving, which often excludes other important aspects such as requiring students to explain their thinking, confront their misconceptions or relate theories to practice (Schoenfeld, 1992). Of note, reflective pedagogy acts as a counterbalance to this pedagogical model by demanding students to engage in a process of critical reflection on their learning processes, their thought processes, and their understanding of the world (Dewey, 1933; Schön, 1983). Despite the prominence of reflective practices in the humanities education (Moon, 1999), their application in mathematics classrooms is limited and under-theorised (Pugalee, 2001) and this is the gap this study seeks to bridge through the lens of student experiences.

This paper explores the implementation of reflective pedagogy in an undergraduate mathematics and statistics course and examine how it affects learners 'metacognitive awareness and engagement in complex quantitative concepts. Using action research methodology, the study employs qualitative case study design to answer two central questions: 1) *How does the defective practices contribute to students' engagement, learning, and understanding of mathematical and statistical concepts? 2)What are the primary challenges and perceptions of students regarding the reflective process, and how can it be improved?* By centering student voices through journals, open-ended surveys, and focus group dialogues (Creswell & Poth, 2018), the research illuminates the real-life experiences of learners as they try to balance reflective thinking with learning and applying mathematical concepts. Thus, rich, descriptive accounts of student experiences are foregrounded to offer practical insights to educators seeking to personalize mathematics education while maintaining academic rigor. In doing so, it argues for reflection as not a add-on to STEM curricula, but as a vital mechanism to produce adaptable, self-aware problem solvers in a complex world (National Research Council, 2012).

Research consistently shows that metacognition—thinking about one's own thinking—plays a crucial role in mathematical learning and problem-solving (Schoenfeld 1987, 1992). This paper proposes that when reflection is structured and intentionally incorporated into course design, it can make mathematical abstraction more understandable (Pugalee, 2004), decrease anxiety (Ashcraft, 2002), and enhance intellectual resilience (Mercer, 2011). Furthermore, the cyclic approach to action research offers a replicable model for educators who want to balance curricular demands with pedagogical innovation.

2. Background

2.1. Numerical Development, Executive Functions (EFs) and Reflective Pedagogy

Siegler's (2016) Integrated Theory of Numerical Development suggests that mathematical competence is the gradual development of the representation of numerical magnitude, with a crucial shift from logarithmic (dense) to linear (proportional) understanding of number lines. This fundamental representational change underpins advanced mathematical reasoning in higher education: Linear magnitude comprehension enhances algebraic problem solving by revealing the relationships of proportions (Booth & Siegler, 2008); supports calculus through accurate interpretation of rates of change, and improves statistical reasoning by fostering natural intuition of probabilities (Peters et al., 2006). The theory's emphasis on strategy variability – learners 'use of multiple strategies (e.g., heuristic, symbolic) in a task – aligns with the strategic adaptive reasoning required in areas such as physics or computer science when students need to build models or analyze the efficiency of algorithms. Nevertheless, the existence of persistent gaps in magnitude understanding, which are typically ascribed to underdeveloped representational shifts, may hinder the understanding of abstract concepts like limits in real analysis or logarithmic scaling in data science (Weber, 2008). Interventions for these gaps, including number line visualization tasks or adaptive learning tools, show promise in closing the foundation deficits and improving outcomes in undergraduate STEM courses (Schneider et al., 2018; Hurst & Cordes, 2018).

Executive functions (EFs) - particularly inhibitory control, working memory, and cognitive flexibility - play an important role in numerical development and advanced mathematical learning of learners. These cognitive processes help learners to cope with complex numerical tasks, for instance, when solving multivariable calculus problems, interpreting statistical models or debugging algorithms by avoiding using irrelevant strategies (inhibitory control), keeping intermediate steps in mind (working memory) and shifting between the symbolic and graphical representations (cognitive flexibility) (Cragg et al., 2017; Blair et al., 2021). For example, in linear algebra, working memory helps students follow matrix transformations, while inhibitory control assists in avoiding errors such as applying logarithmic functions in the wrong context in exponential growth models. Deficits in EF are associated with numerical problems such as inadequate understanding of limits in calculus or inappropriate alignment of probabilistic understanding in data science (Weber, 2008; Obersteiner et al., 2020). Cognitive training modules, or problem solving frameworks that help to select strategies, have shown promise in improving numerical fluency and reducing attrition in STEM programs (Blair et al., 2021); however, the research has found that the development of EF skills is possible through the reflective and active re-processing of information that allows learners to maintain information in the working memory and to formulate more complex action oriented rules that provide for greater cognitive flexibility and inhibitory control (Lyons & Zelazo, 2011; Roebers, 2017).

Rooted in the work of scholars like Dewey (1933) and Schön (1983), reflective pedagogy is a theoretical and practical approach to the improvement of critical self-assessment, iterative learning, and metacognitive awareness to improve teaching and learning. Thus, the core principles of reflective pedagogy are:

- Cyclical Reflection and active Engagement – Teachers and students engage in continuous feedback loops.

- Self-Assessment & Metacognition – Help students learn to check their understanding and identify holes in their knowledge.
- Contextual Adaptation: Instruction is dynamically adjusted to meet the needs of learners, their cultural background, and the ever-changing challenges they face.
- Real-World Application – Make theoretical concepts more meaningful and applicable to real world problems to enhance motivation.

2.2. Reflective Practices in Mathematics and Statistics Education

The importance of reflective pedagogy in mathematics and statistics education cannot be overemphasized as this approach enhances metacognitive strategies and iterative feedback loops to improve conceptual mastery and critical thinking. Based on Schoenfeld's (1992) foundational work that demonstrated how guided metacognitive reflection can enhance problem solving by having students reflect on their reasoning, Kramarski and Mevarech (2003) pleaded cooperative learning combined with strategy justification to reduce procedural errors in geometry. These findings are supported by Lesser and Winsor (2009), who showed that reflective journals can help English language learners in statistics to overcome linguistic and conceptual gaps, and by Roscoe and Chi (2007), who proved that technology-enhanced peer feedback can refine data interpretation through collaborative critique. Beyond the classrooms, Savery and Duffy (1995) problem-based learning, and Gutstein (2012) socially situated pedagogy incorporated reflection in real world contexts where students could question ethical implications of statistical analyses or model societal inequities through algebra. Similarly, inquiry-oriented approaches, such as Rasmussen and Kwon's (2007) reflective discourse in calculus, demonstrate how iterative dialogue stabilizes abstract concepts like limits and derivatives. In conclusion, these studies affirm that reflective practices—whether through metacognitive prompts, peer collaboration, or culturally responsive frameworks—scaffold deeper quantitative understanding while fostering adaptive expertise and equity in STEM education.

3. Methodology

3.1. Research Approach and Participant Profile

This paper employs a mixed-methods action research design to examine the effectiveness of reflective pedagogy in a mathematics and statistics course. The cyclical approach of action research allowed for systematic inclusion of both the subjective experiences of the students and the actual outcomes in terms of student learning. A single-case study design was used to examine the outcomes in a specific course context. The participants in the study were undergraduate students enrolled in the mathematics and statistics course at University of Europe for Applied Sciences during a winter semester. A voluntary cohort of twenty-five students gave their views on the effectiveness of reflective pedagogy in their learning process.

3.2. Reflective Pedagogy Framework

- Guided reflection Exercises: Weekly reflections on conceptual understanding; problem-solving challenges and real-life applications.
- Collaborative Peer Dialogue: To share reflections and co-construct solutions in small groups.
- Individualized Feedback: Instructor critiques metacognitive growth and error analysis.
- End-of-Course Evaluation: Perceived learning outcomes in qualitative

3.3. Data Collection and Analysis

- Reflective Journals (e-portfolio): Entries documenting students 'conceptual struggles, breakthroughs, and self-assessments.
- Open-Ended Surveys: Written responses from students on their perceptions of reflective learning.
- Optional Focus Groups: Semi-structured discussions with a subgroup of students to gain deeper insights into their engagement with reflective practices.

The qualitative data from student reflections, survey responses, and discussions were analyzed using:

- Thematic analysis to identify recurring themes related to students 'perceptions of reflective learning and challenges faced in applying reflective thinking to mathematical concepts.
- Sentiment analysis to quantify the student perception and explore how they feel about the e-Portfolio—whether their feedback is positive, neutral, or negative

4. Results and Discussion

4.1. Thematic Analysis

The responses to the open-ended questions were coded thematically identifying the following three main themes:

Engagement and Learning: Students believed that the e-Portfolio was useful because it helped them to interact with the course content in a more productive way than through reading. The e-Portfolio was a good way of helping them to connect the theoretical concepts learned in class to the real world. Some students stated that through the process of creating the portfolio, they were able to determine the changes they have made and the knowledge they have gained. Students liked the practical, project-based e-Portfolio approach that encouraged them to think more critically about mathematical and statistical concepts and their applications in real world.

Challenges and Barriers: Some students did not have any major difficulties, however, some of them mentioned problems with organizing their thinking. A few responses indicated confusion with the process, which may have meant that more detailed directions were needed. Some students mentioned the problem of the time needed to develop the portfolio effectively.

Understanding and Retention: Several students stated that the e-Portfolio assisted them in consolidating the learning as they had to provide a summary of the concepts. The activity of describing their thinking process made them realize their strengths and weaknesses in mathematical reasoning. The portfolio format encouraged them to think critically and recall previously learned topics, reinforcing their retention of statistical methods they had learned in the past. Students found the e-Portfolio valuable for reinforcing learning and reflecting on their progress. While it supported concept retention, some students faced challenges related to time and process clarity.

4.2. Sentiment Analysis

The sentiment analysis of students' responses to the e-Portfolio assessment reveals a predominantly positive perception, with most of the feedback reflecting appreciation for its role helping them reinforce their mathematical and statistical knowledge, learn on their own, and retain concepts for a longer period through a systematic process of documenting them. A smaller proportion of responses were neutral, indicating that while students acknowledged the usefulness of the e-Portfolio, some may not have found it particularly transformative or impactful. These neutral responses could be used to make the assessment more definitive, for instance, by offering more specific directions or through the inclusion of other engaging elements. The negative feedback is limited; however, it highlights key challenges, primarily related to time constraints, unclear expectations, and difficulties in structuring reflections. Students who expressed negative sentiments may have struggled with the cognitive load of compiling the portfolio or found it difficult to align their reflections with course objectives. This suggests that while the e-Portfolio is generally well-received, clearer guidelines, improved scaffolding, and time management strategies could mitigate these concerns and enhance the overall student experience.

Table 1. Theoretical foundations, instructional focus, and key outcomes.

Theoretical Area	Key Focus in the Study	Observed Outcomes
Numerical Development (Siegler, Booth & Siegler)	Support numerical magnitude understanding through reflection on problem-solving and real-world math applications	Improved conceptual engagement; better linking of theoretical concepts to real-world math and statistics; strengthened strategy use
Executive Functions (Blair et al., Lyons & Zelazo)	Develop working memory, inhibitory control, and cognitive flexibility through guided reflections and adaptive tasks	Enhanced problem-solving accuracy; improved organization of thinking; recognition of procedural errors
Reflective Pedagogy (Dewey, Schön)	Foster cyclical reflection, self-assessment, and real-world application through e-Portfolio and collaborative dialogue	Increased critical thinking; stronger retention of mathematical/statistical concepts; positive attitudes toward reflective learning

Table 1 presents how the framework, informed by established theories of numerical development, executive functions, and reflective pedagogy, guided the design of instructional activities and assessments. The findings indicate that these practices not only enhanced students' engagement and conceptual understanding but also revealed areas for pedagogical refinement, particularly in relation to process clarity and time management within reflective learning tasks.

5. Concluding Remarks

The results of this study are in line with previous work on numerical development and EFs and the importance of reflective pedagogy in the development of cognitive flexibility and metacognitive regulation in quantitative fields. The e-Portfolio was used to provide students with a way of structured self-regulated learning, whereby students had to use working memory, inhibitory control, and cognitive flexibility EFs to reflect on mathematical concepts and solving strategies. The analyses of themes and sentiments showed that, in general, students benefited from the process and felt that it helped them improve their quantitative thinking and understanding of concepts, but the challenges with cognitive load and task articulation suggest that there is a need for better support. Thus, based on the current study, it is possible to suggest that enhancing the e-Portfolio approach to better support students' numerical cognition and executive functions can lead to improvements in mathematical problem-solving, critical thinking, and knowledge retention in STEM education. These findings further support the importance of developing appropriately chosen formative assessments that are informed by cognitive science for quantitative learning.

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