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ASSESSMENT OF MATHEMATICS STUDENTS' KNOWLEDGE AND SKILLS

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This article is dedicated to dear Professor Mirjana Vuković on the occasion of her 75th birthday

ABSTRACT. Evaluating and assessing university students' knowledge and skills is a complex process and for many professors it is the most challenging aspect of their job. Mathematics curricula highlight the learning outcomes and competencies that students will acquire at the end of an educational cycle, which should guide professors in designing assessments of students' knowledge and skills. When designing assessments, consideration should be given to the objectives of the assessment - what is to be assessed or measured. In addition, questions and tasks should be relevant, varied in form, varied in difficulty, clear and understandable, without double meaning or confusion, with clear and precise instructions. Any test should be reliable and valid. The scoring of the results and their interpretation should be clear. Combining the above will ensure that the test is of high quality and measures what needs to be assessed. Teachers should ask themselves what exactly the tasks and questions they use in exams are measuring. Are they using tests and are they made up of questions and tasks that meet all the criteria for a test? Do these tests, questionnaires and sets of objective tasks provide answers about the results obtained? The aim of this paper is to provide an overview of recent research on the assessment of mathematics students' knowledge and skills with a particular focus on the assessment of student performance in proving mathematical statements, and e-assessment in mathematics at university level.

1. INTRODUCTION

The landscape of assessment in university level mathematics education is undergoing significant change, driven by advances in educational theory, technology and changing educational goals. Traditional assessment paradigms are being re-evaluated in the light of student-centered approaches to learning, and online learning environments have introduced new challenges and opportunities for assessing mathematical understanding. This paper explores different assessment paradigms, methods and the current state of research on assessment in university-level mathematics. In particular, we focus on online environments and the assessment of mathematical proofs.

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2. Assessment paradigms in university-level mathematics

Assessment paradigms in education serve as basic frameworks that guide the evaluation of student learning and the effectiveness of teaching. In the context of university mathematics, these paradigms are central to aligning assessment practices with educational goals and learning outcomes. Traditionally, the assessment of learning has been the norm, predominantly through summative means such as standardized tests and final examinations, emphasizing the measurement of learning outcomes against pre-defined standards [6]. However, such traditional methods, including written and multiple-choice tests, have been criticized for their limited ability to inform teaching and promote deeper understanding [36], [35]. They often focus on procedural knowledge rather than conceptual understanding and may not fully capture students' reasoning or creativity [34]. Over the past three decades, a paradigm shift has been advocated, emphasizing assessment for learning rather than assessment of learning [5], [8].

Assessment for learning, characterized by formative approaches that focus on continuous feedback to students and teachers, has been shown to have a significant positive impact on student achievement [6]. It encourages self-assessment, reflection and autonomy in the learning process [13]. In mathematics education, this shift could include iterative problem-solving sessions with feedback not only on the correctness of solutions but also on the underlying reasoning [7]. In addition, alternative assessment methods such as portfolios, projects and collaborative assessments have been proposed to promote student autonomy and responsibility [55], [57], [1]. These learner-centered approaches promote deeper engagement, collaboration and increased interaction between students and teachers [64]. They are consistent with the aims of initiatives such as the Bologna Process, which emphasize student autonomy and responsibility in learning [44]. Research suggests that learner-centered methods, such as the use of portfolios, lead to deeper learning outcomes compared to traditional assessments [57], [47].

Furthermore, learner-centered methods aim to develop students' autonomy and sense of responsibility, in line with the aims of initiatives such as the Bologna Process [44]. They promote autonomous learning and enable students to take responsibility for their learning process [51]. Research suggests that the use of portfolios for student assessment, as opposed to methods such as multiple-choice tests, leads to deeper learning outcomes [57], [47]. Overall, these findings highlight the potential benefits of moving towards learner-centered assessment methods to improve student engagement, learning outcomes and self-regulation in higher education.

3. Research of assessment in mathematics at university level

In general, research on assessment in mathematics at university level has taken several directions, such as research on tasks/problems given in written examinations, case studies of single classroom assessment methods, assessment practices, impact of assessment on learning, e-assessment, assessment of evidence. Much of the research has focused on a single classroom case study exploring a less traditional form of assessment (e.g. [16], [33], [54].

Another subset of the literature on assessment in mathematics education focuses specifically on the items included in traditional written examinations. These studies typically take a sample of written exams and analyze the items within each assessment. These studies consistently show a tendency for such exams to prioritize procedural knowledge over conceptual understanding. Notable findings include those of [4], [22], [56], [65] and [42]. Tallman et al. [56] found that the majority of Calculus I final exams sampled across the US required minimal cognitive demands, focusing primarily on recall and application of procedures. Furthermore, they showed that there has been little change in exams that require students to use higher-order thinking (e.g., applying understanding) over the course of approximately 25 years. Mac an Bhaird et al.'s [22] analysis of calculus exams in Irish universities echoed this trend, indicating a lack of emphasis on conceptual understanding. Despite calls for alternative assessment methods, such as those advocated by [21], there has been little evolution in exam design over time. Reed et al. [42] proposed criteria for high quality exam items, emphasizing the importance of assessing conceptual understanding and higher order thinking skills, a recommendation supported by findings from Mac an Bhaird et al. [22] and Tallman et al. [56].

Only a few studies address the observation of assessment practices. Iannone and Simpson's [19] study offered a comprehensive examination of assessment in undergraduate mathematics courses in England and Wales, providing valuable insights into the assessment methods used in these settings. Through careful data collection from 43 representative courses and in-depth interviews with 27 senior members of mathematics departments, Iannone and Simpson [19] uncovered notable trends in assessment practices. The study revealed a striking prevalence of closed-book examinations, with over a quarter of modules assessed entirely in this format.

Furthermore, almost 70% of modules allocated a significant proportion of the final mark to closed-book examinations, indicating the widespread use of this assessment method across different mathematics courses. The research also elucidated the perspectives of heads of mathematics departments on assessment practices. These senior members expressed support for closed-book exams, but also raised concerns about alternative assessment methods. Key concerns included issues of fairness, plagiarism, collusion, satisfaction with existing assessment patterns, institutional pressures, employability and promoting student learning. A decade later, Iannone and Simpson [21] revisited their seminal research to assess whether significant changes had occurred in assessment practices across the UK higher education landscape. Despite the intervening years being marked by changes at a policy level and an increased emphasis on training and supervision in higher education teaching, the findings revealed a surprising continuity in assessment practices. Closed-book examinations continued to be the predominant method of assessment in universities, suggesting a remarkable persistence of traditional assessment methods despite changing educational contexts.

Moreover, the prevalence of traditional exams in mathematics education reflects broader trends observed in various disciplines worldwide. Studies by researchers such as Meyer et al. [27], Postareff et al. [38] and Rawlusyk [39] have documented a similar dominance of traditional assessment methods in higher education institutions worldwide. This comparative perspective underscores the pervasiveness of traditional assessment practices, and highlights the need for further research and potential reform of assessment methods to better align with contemporary educational goals and student needs.

In their study, Zheng et al. [70] conducted a comprehensive review of syllabi from courses offered during the spring 2021 semester at a large university in the southwestern United States. Their findings provide valuable insights into the prevailing assessment practices at this educational institution, building on previous research [19], [21] conducted by Iannone and Simpson in 2012 and 2022. The study shows that written tests were the most commonly used form of assessment, used in approximately 91.9% of the sampled courses. This was closely followed by traditional homework, which was used in 93% of courses. Quizzes were the third most common form of assessment, although significantly less common than written tests and homework, used in 64% of courses. In addition, participation in the final assessment was included in approximately 53.5% of course sections. Further analysis of the data revealed variations in assessment practices across subjects, years and class sizes, with patterns generally in line with practical expectations. For example, applied mathematics courses tended to include projects more frequently than pure mathematics courses. In addition, lower-division undergraduate courses had the greatest variety of assessment methods, with an average of 3.8 methods per course. In contrast, upper-division undergraduate and postgraduate courses tended to use fewer assessment methods, with an average of 2.7 and 3.0 methods respectively. The study also highlighted the relatively low use of learner-centered approaches to assessment. For example, portfolio assessment, oral exams, case studies, peer assessment, self-assessment and reading notes/questions were rarely used in the sampled courses, indicating a potential gap between current assessment practices and the principles of learner-centered education. Overall, the study provides a nuanced understanding of assessment practices within a large university setting, highlighting the prevalence of traditional assessment methods such as written tests and homework, as well as providing insights into variations by subject area, year level and class size. It also highlights the limited adoption of learner-centered approaches to assessment and suggests potential areas for further research and development of assessment practices in higher education.

4. Research on impact of assessment on learning

Early studies such as [29] ”found unexpectedly that what influenced students most was not the teaching but the assessment” [12]. Snyder [53] suggested that assessment dominates how students budget time and effort to focus on the more point-bearing learning activities. He brought the term ”hidden curriculum” to the attention of the higher education community. Rowntree [43] described, ”if we wish to discover the truth about an educational system, we must first look to its assessment procedures.”

Research by [23] and [9] had firmly established assessment as a central element in higher education, with a significant impact on students’ perceptions of learning and their study priorities. Assessments play a crucial role in directing students’ focus, potentially leading them to superficial learning strategies aimed at passing exams rather than fostering deep understanding and knowledge retention. Brown and Knight [10] highlight the dual nature of this influence, emphasizing that assessment can either help or hinder student learning, depending on the design and implementation of assessment methods.

Building on this foundational research, more recent studies have provided empirical evidence of the profound impact of assessment on students' learning strategies. Researchers such as [57], [46], [60] and [15] have contributed to our understanding of the complex relationship between assessment practices and student learning outcomes. The collective literature underlines the urgent need for educators and curriculum designers to reassess their assessment strategies. On the other hand, in contrast to the message of the general literature, Iannone and Simpson's study [20] showed that mathematics students perceive traditional assessment as the best discriminator of ability. Meyers and Nulty [28] argue that students' perceptions of assessment shape their understanding of the curriculum, highlighting the importance of designing assessments that are aligned with educational goals. Furthermore, trust in assessors, as emphasized by [67], highlights the importance of transparency and expertise in the assessment process.

Another important aspect of assessment is feedback. Beaumont, O'Doherty and Shannon [2] suggest the need to improve the quality of feedback to students in higher education, with implications for curriculum redesign. Scholars argue for a 'new culture at university' that includes faculty competencies that encompass methodological, evaluative and supportive dimensions, as proposed by [68]. The study [14] sheds light on undergraduate students' perceptions of assessment methods and feedback, providing insights for improving assessment practices in higher education. In Education, learner-centered methods are more prevalent than in other disciplines, which often rely on traditional assessment methods. In addition, the study finds that engineering students have distinct preferences for assessment methods, especially those related to team projects. Participants who frequently use learner-centered assessment methods perceive assessment as fairer and more effective than those who prefer traditional methods. However, there were no statistically significant differences between the two groups in the importance attached to feedback or the reliability of its sources.

In summary, studies of the impact of assessment on learning highlight the critical role of assessment in shaping student learning experiences and outcomes in higher education. It calls for a re-evaluation of assessment practices to ensure that they effectively support deeper learning and are aligned with educational goals, emphasizing transparency and expertise in the assessment process to foster trust and meaningful learning experiences for students.

5. E-ASSESSMENT IN MATHEMATICS AT UNIVERSITY LEVEL

The advent of online education has necessitated a re-evaluation of assessment strategies in mathematics at university level. Online assessment offers unique opportunities for scalability, flexibility and innovative assessment methods. However, it also poses significant challenges, including issues of academic integrity, accessibility, and the adequacy of the technology to fully capture students' mathematical understanding. Online assessment has evolved from simple quizzes and automated grading systems to sophisticated platforms that incorporate adaptive learning technologies, real-time feedback and collaborative problem-solving tasks. Studies [25] and [3] have highlighted the growth of online assessment tools that can accommodate a wide range of mathematical tasks, from basic arithmetic to complex calculus problems.

Methods used in online assessment include computer-assisted assessment (CAA), which often includes automated feedback mechanisms, and dynamic assessment tools, which adjust the level of difficulty based on the student's performance. A large body of research emphasize the importance of these tools in providing immediate feedback and personalized learning experiences, which are crucial for mastering mathematical concepts (e.g. [50], [11], [59]).

E-assessments offer several advantages, especially when teaching large cohorts: they offer the possibility of automatic marking and feedback. However, most e-learning systems are poorly adapted for use in mathematics, a language in its own right [17]. According to [52], current e-learning systems do not adequately support the necessary notations and diagrams, "the very building blocks of mathematical communication". The effectiveness of online assessment is measured by its ability to accurately assess student understanding, promote engagement and support learning outcomes. A meta-analysis [25] suggests that online and blended learning environments, when properly designed, can be as effective as traditional classrooms in terms of student achievement in mathematics. However, the transition to online assessment requires careful consideration of assessment design, technological infrastructure, and pedagogical strategies to ensure that assessments are fair, reliable, and aligned with learning objectives. Research [41] suggests that well-designed online assessments can enhance the teaching and learning of complex mathematical skills by incorporating interactive simulations, visualizations and problem-solving tasks.

Despite its potential, online assessment faces several challenges. Academic integrity is a major concern, with research [61] exploring the prevalence of cheating in online environments and strategies to mitigate this problem. In addition, technical difficulties, accessibility issues and the digital divide can hinder the effectiveness of online assessment, potentially exacerbating inequalities between students [49]. The assessment of higher order thinking skills, such as mathematical reasoning and proof construction, remains a complex area in online environments. Traditional assessment methods may not translate well to digital formats, and innovative approaches are needed to accurately assess these skills [63].

6. Assessment of mathematical proof

The foundation of pure mathematics lies in mathematical proofs. At university level, the assessment of a mathematics student's performance revolves primarily around evaluating their ability to construct proofs [62]. However, assessing proofs is challenging, as mathematicians need to assess not only the quality of the written proof, but also the depth of understanding behind it [30]. Furthermore, there is a noticeable lack of assessment tools specifically designed to assess the understanding of proofs [26].

Several studies have been conducted to measure proof comprehension skills. In the study [66], authors refer to it as "reading proof comprehension" because understanding proof is more dominant in the reading aspect. Yang and Lin [66] attempted to compile instruments to measure reading proof comprehension skills for secondary school students. They conceptualized proof comprehension on the basis of previous studies [18] and [48]. Yang and Lin [66] formulated five facets in reading proof comprehension: basic knowledge, logical status, integration or summation, generality, and application or extension.

Nevertheless, the question of how to effectively assess a student's understanding of proofs remains open [26]. Feedback is emerging as an important tool for supporting students' learning of proof construction [31], [32]. However, students often fail to understand feedback from lecturers and rarely receive further feedback on their revisions [37]. Furthermore, proof validation, which involves critically evaluating proofs to determine their correctness [48], has been shown to have a positive impact on students' ability to construct their own proofs [40]. This process requires students to engage deeply with their learning material, such as asking and answering questions, constructing subproof, and interpreting definitions and theorems [48].

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7. CONCLUSION

The landscape of assessment in mathematics at university level is complex and diverse, encompassing a range of paradigms and methods that reflect the diverse goals of mathematics education. As the field continues to evolve, particularly with the increasing prevalence of online learning environments, educators and researchers must continue to explore innovative assessment strategies that not only measure mathematical knowledge and skills, but also foster deeper engagement with the material. Central to these efforts will be the development of assessment methods that are equitable, inclusive and capable of capturing the nuanced and sophisticated thinking that characterizes advanced mathematics. Ultimately, the aim of assessment in mathematics at university level should be not only to evaluate learning outcomes, but also to enhance the educational experience by promoting a deeper understanding and appreciation of mathematics.

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