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Improving Students' Engagement with Feedback in Mathematics Classrooms: Based on Big Data Analytics

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Abstract:

With the shift in educational paradigms from "teaching-centered" to "learning-centered", mathematics classrooms are undergoing significant transformations. Feedback is a crucial factor influencing students' learning and academic achievement, and students' active engagement is considered a key prerequisite for effective feedback. However, current research has not fully explored how students engage with feedback in mathematics classrooms or the factors that influence the engagement. Additionally, providing timely and meaningful feedback remains a significant challenge for teachers. This article examines the nature of feedback, analyzes the critical role of student engagement with it, and identifies key factors influencing this engagement in mathematics classrooms. Based on the application of big data analysis, the study proposes strategies to enhance students' engagement with feedback, aiming to promote mathematics learning and teaching. These findings provide a theoretical basis for improving students' engagement with feedback and for guiding the strategic design of interventions aimed at improving this engagement.

Keywords: students' engagement, mathematics classroom, feedback, big data analytics

INTRODUCTION

Feedback is recognized as one of the most critical factors influencing students' learning and academic achievement [1], with its distinctive features being its relation to students' performance and its evaluative nature [2]. As an integral part of the process of promoting student performance and assessment[3], effective feedback can not only reflect students' learning status but also guide their future learning improvements. This is especially crucial in mathematics education, where the development of logical reasoning and problem-solving skills is emphasized，making the effectiveness of feedback key to enhancing learning outcomes. Through timely and targeted feedback, teachers can assist students in identifying their strengths and weaknesses, thereby adjusting their learning strategies to achieve their learning objectives more effectively. However, most existing research on feedback was conducted in artificially created experiments, and the practice of feedback in everyday mathematics classes has not been fully explored [3]. In addition, traditional educational models often emphasize the unilateral provision of feedback by teachers, while neglecting the active role that students should play in this process. Although some scholars have emphasized that students' active engagement is crucial for achieving effective feedback [4], there is still limited discussion on how to guide students to become active participants in the feedback process rather than passive recipients. Therefore, it is necessary to further explore how feedback strategies can be optimized in real classroom settings to enhance student learning and development.

With the continuous advancement of information technology, the application of big data analysis in education has become increasingly widespread and profound. Big data analysis involves examining vast datasets and includes key components such as data mining algorithms, predictive analytics, data quality management, and visual analytics. As a powerful technological tool, big data analysis can process and analyze massive amounts of data, extracting valuable insights to assist teachers in making more scientific and precise teaching decisions. For instance, teachers can gain a comprehensive understanding of each student's learning profile by integrating student learning data from various sources, including homework completion, exam scores, classroom interaction records, and activity logs from online learning platforms. These data not only help educators more accurately identify which teaching strategies are most effective in enhancing student learning outcomes, but also support the design of personalized feedback strategies.

Given the aforementioned context, the objective of this study is to delve into the factors that influence student engagement in feedback within mathematics classrooms and to propose specific strategies based on big data analysis to enhance student participation in feedback. By leveraging big data analytics, we aim to drive innovative changes in mathematics teaching practices and foster improvements in students' critical thinking and self-assessment abilities, thereby significantly enhancing their

mathematical learning outcomes and personal growth. In other words, our goal is to build a dynamic and highly interactive classroom feedback ecosystem where both teachers and students are active participants, committed to the continuous optimization of the teaching and learning process. This study will provide new practical guidelines for the field of education, particularly on how to effectively implement data-driven feedback strategies in mathematics classrooms, thus laying a solid foundation for future research and practice. Ultimately, we hope that this research will stimulate further discussion and exploration of the integration of digital technology in teaching, collectively advancing innovation and development in the educational sector.

BACKGROUND

Concepts of Feedback

In the field of education, feedback has traditionally been defined as information aimed at bridging the gap between a learner's current level of knowledge and the intended learning goal [5]. This definition is rooted in a teacher-centered educational model, which emphasizes the transmission of information from the teacher to the student, while relatively neglecting how students receive, process, and apply this information[6]. With the rise of learner-centered teaching methods, feedback is further conceptualized as any information that learners can use to improve their performance or academic achievements [7]. This definition of feedback reflects the shift in understanding from emphasizing the stimulation of external information to the ability of students to change their own behavior. Winstone and Carless (2019) called this shift—from focusing on what teachers do to what students do—a new feedback paradigm that focuses on the students' activities [8,9].

Recently, researchers have acquired a new understanding of feedback as a process through which learners understand information from various sources and use such information to strengthen their work or learning tactics [7]. As mentioned above, feedback can be understood not only as providing information to students, but also as a complex process in teaching and learning in which teachers and students are both instrumental. For feedback to be effective, the information provided by the teacher must be communicated in a manner that facilitates learning improvement, while the students should actively engage in the feedback process and use the feedback to improve subsequent learning. This definition implies that learners must play an active role in seeking information, understanding it, and undertaking follow-up tasks to translate newly constructed knowledge into practice.

In the context of mathematics classroom teaching, implementing dialogue-based feedback encounters significant challenges. Teacher-student interactions often struggle to be in-depth and sustained, frequently devolving into a one-way, one-to-many communication pattern. This situation raises a complex and urgent question: how to provide timely and personalized feedback to students. With the rapid advancement of digital education, big data analytics offers powerful technical support, providing new perspectives and solutions. The core of this study is to explore how big data analytics can support teachers in refining feedback strategies and enhancing student engagement with the feedback in mathematics classrooms.

Definition and Dimensions of Students' Engagement

Students' engagement has become an important topic of research to improve the quality of teaching and learning. It is widely recognized as a key factor in promoting students' academic success and personal development. Engagement is conceptualized as the energy and effort a student invests in the learning community, observable through various behavioral, cognitive, and emotional indicators along a continuum[10]. It has a complex multi-dimensional structure and is commonly categorized into cognitive engagement, emotional engagement, and behavioral engagement [11, 12]. Cognitive engagement refers to students' intellectual activities in the learning process and their use of metacognitive strategies and self-regulation strategies [12]. At the core of cognitive engagement lies in how students think and process information, including their analytical skills, critical thinking, and creativity. The high level of cognitive engagement not only indicates that students can effectively acquire knowledge, but also reflects the ability of students to flexibly apply the knowledge to solve problems. In mathematics learning, this means that students need to master concepts, formulas, and theorems, and also be able to apply this knowledge to solve new problems. Emotional engagement relates to the emotional experience, such as interest, happiness, sadness, and anxiety of a student in learning[12]. Emotional engagement significantly influences students' motivation to learn and their persistence. Positive emotional experiences can enhance intrinsic motivation, encouraging students to invest more time and effort in their studies. Conversely, negative emotions such as anxiety and frustration can lead to decreased engagement, adversely affecting their learning. Teachers can promote emotional engagement by creating a supportive learning environment and encouraging students to express their feelings. Behavioral engagement is defined as a student's participation in classroom and school activities, which serves as the external manifestation of their individual engagement [13].High levels of behavioral engagement not only reflect students' attitudes toward learning but are also closely linked to their social interactions and teamwork skills. In the mathematics

classroom, this may manifest as students actively participating in discussions, diligently completing assignments, and engaging in group projects. In summary, cognitive engagement, affective engagement, and behavioral engagement are three components that constitute a student's overall involvement in learning. These elements work in concert to influence the student's learning journey.

ANALYSIS

The Links between Feedback and Students' Engagement

Students' engagement is a key determinant of the effectiveness of feedback because feedback will not help students to learn if they fail to engage with the feedback they receive [14]. Therefore, it is necessary to have a comprehensive understanding of how students engage with feedback and to explore teaching strategies that effectively promote their active engagement.

As recipients of feedback, students need to go through the stages of perception, acceptance, interpretation, understanding, and utilization of feedback (Figure 1) [15, 16].This process is not a simple linear progression but rather a dynamic and iterative cycle involving continuous adjustments. During the perception phase, students initially become aware of the feedback provided. However, if their emotional engagement is lacking, it may lead to resistance, which can hinder the acceptance and comprehension of the feedback. Lipnevich, et al. highlighted the three major dimensions of students' engagement in feedback, namely, cognitive, emotional and behavioral engagement, and they concluded that information, students' characteristics, and cognitive, emotional, and behavioral responses contribute to a behavior that may alter students' performance and learning [14].

When students receive feedback, they must first understand it, which requires cognitive engagement as well as emotional engagement, such as positive or negative emotional reactions. Research indicates that students' emotional states can directly influence their cognitive abilities. For instance, anxiety can diminish a student's ability to concentrate and retain information, making it significantly more challenging for them to comprehend and effectively utilize feedback. Furthermore, for feedback to be meaningful, it is imperative that students take action based on it. When students receive feedback, they must first understand it, which requires cognitive engagement as well as emotional engagement， such as positive or negative emotional reactions. Research indicates that students' emotional states can directly impact their cognitive abilities. For instance, anxiety can diminish students' attention and memory, thereby increasing the difficulty of understanding and effectively utilizing feedback information. Furthermore, for feedback to be meaningful and effective, students must take appropriate actions based on the content of the feedback. Active engagement with feedback transforms the student from a passive knowledge receiver to an active constructor of knowledge who seeks, perceives, understands, and utilizes feedback.

Such a shift not only enhances students' acquisition of knowledge but also fosters their self-regulatory abilities and critical thinking skills. To conclude, the efficacy of feedback is intrinsically linked to the extent of student involvement. Therefore, educators should strive to inspire students' cognitive, emotional, and behavioral engagement when offering feedback, ensuring that it genuinely facilitates student learning and personal growth.

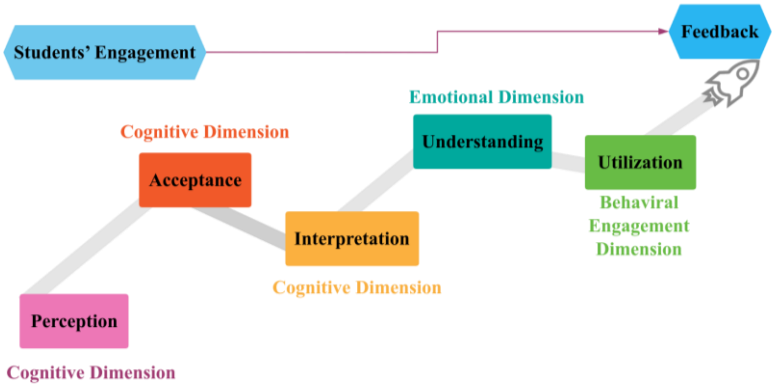

Figure 1. The stages students must go through during the feedback process

Factors Influencing Students' Engagement in Feedback in the Mathematics Classroom

In mathematics classroom scenarios, whether students engage in feedback and the extent of their engagement are influenced by the combined effect of external and internal factors. Figure 2 presents external factors influencing students' engagement with feedback in the mathematics classroom. Teachers' professional knowledge (MTSK), and teaching behavior are key variables

influencing students' participation in feedback. Research has shown that MTSK is directly related to the feedback process of mathematics teachers and determines whether they can provide enough information to improve students' learning, including students' engagement, self-perception of efficacy, and interest in mathematics [17]. Fyfe and Brown demonstrated that teachers' expectations of students influence their engagement in mathematical feedback; in particular, when teachers' expectations are low, negative emotional engagement of students may ensue [18]. In addition, the type of feedback also affects the engagement of students. Guo and Wei examined the relationship between the type of feedback provided by teachers and students' self-regulated learning in Chinese mathematics classrooms, and concluded that scaffolding feedback and praise improve students' self-regulated learning behavior [19]. Scaffolding feedback offers specific, constructive suggestions to students, helping them recognize their deficiencies and identify directions for improvement. Praise can enhance students' self-confidence, making them more receptive to feedback and more willing to strive for improvement. Validation feedback and instructional feedback can affect students' cognitive engagement, such as reducing the use of cognitive strategies while increasing the use of metacognitive strategies [19].

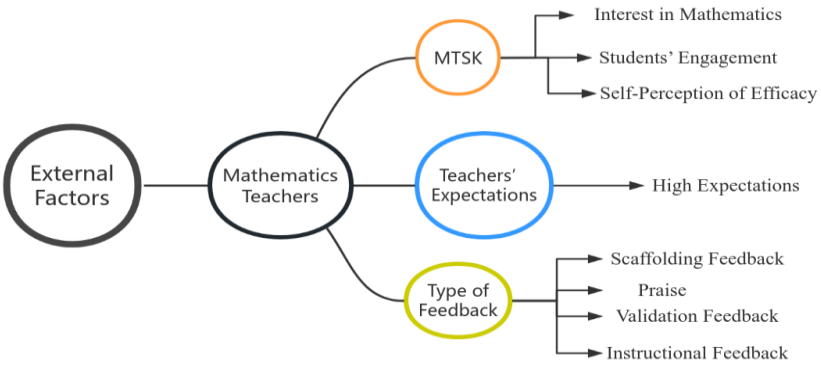

Figure 2. External Factors influencing students' engagement in feedback in the mathematics classroom

The application of big data analytics has greatly enriched the methods and strategies teachers use to enhance the effectiveness of feedback. Firstly, big data analytics can help teachers improve their level of mathematical expertise. By analyzing vast amounts of teaching resources, students' classroom learning behaviors, emotional responses, and diverse assessment data, teachers can accurately identify the knowledge difficulties and blind spots students encounter while learning mathematics. This process also helps uncover deficiencies and limitations in their own delivery of mathematical expertise. Based on this foundation, teachers can address and rectify these gaps, enhancing their mathematical knowledge system and providing students with more precise and effective feedback and guidance. Secondly, big data analytics enables teachers to form reasonable expectations for students. By deeply mining student learning data, teachers can accurately identify students' strengths, potential, and possible challenges, providing a scientific basis for setting personalized expectations. Moreover, big data analytics can reveal the characteristics of student groups who are susceptible to low expectations from teachers, guiding teachers to adjust expectations and support measures. This proactive approach helps engage students more effectively in the feedback process, enhancing their motivation and engagement in learning. Finally, big data analysis has facilitated the optimization of feedback methods. By conducting real-time monitoring and analysis of student learning data, teachers can promptly identify students' learning states and needs, providing more timely and precise feedback. Additionally, big data analysis can reveal the impact of different types of feedback on student learning outcomes, enabling teachers to choose the most effective forms and improve the quality and efficiency of feedback.

From the perspective of internal factors, the effectiveness of feedback depends to a large extent on the individual student [14].If students fail to accept or understand the feedback, the teacher's efforts may fail to achieve the desired outcomes [20]. Perceived feedback plays a critical role in fostering students' active engagement with feedback[21]. When students perceive feedback as useful and believe it enhances their problem-solving skills or work competence, their motivation and engagement are significantly boosted [10]. This perception is not only determined by the content of the feedback but also by the manner and timing of its delivery. Timely and constructive feedback is often more effective in stimulating students' interest and initiative in learning.

Big data analytics equips educators with robust tools to deeply understand students' engagement in the feedback process. For instance, sentiment analysis algorithms can track students' emotional reactions to feedback in real time, pinpointing factors that

might cause frustration or anxiety. Teachers can then quickly modify their feedback approaches to provide more empathetic and supportive responses. This real-time feedback not only increases the specificity and effectiveness of feedback but also greatly enhances students' learning experiences. Natural Language Processing (NLP) can thoroughly analyze students' written or spoken feedback to uncover their thought processes and misconceptions, helping teachers offer timely corrections and boost students' cognitive engagement. Analytical visualizations transform complex data into intuitive charts and graphs, allowing both teachers and students to clearly grasp learning progress and performance trends.

This aids teachers in assessing the effectiveness of their teaching strategies and motivates students to engage in self-reflection and self-regulation, leading to more active participation in learning. In conclusion, by utilizing big data analytics, educators can optimize feedback strategies more accurately, foster active student engagement, and improve learning outcomes.

CONCLUSION AND SUGGESTION

This study first explored the background of feedback, including the concepts of feedback, definition and dimensions of students' engagement. Existing research indicates that in the field of education, feedback has various definitions, ranging from external feedback provided by teachers to strategies that promote students' engagement. Then, we focused on analyzing the the links between feedback and students' engagement, especially the factors influencing students' engagement in feedback in the mathematics classroom. The factors influencing student participation in feedback, including both external and internal factors. The research findings indicate that student engagement is a crucial determinant of the effectiveness of feedback. Feedback can effectively promote learning only when students actively engagement in the feedback process at three levels: cognitive, emotional, and behavioral. This means that students need to perceive, interpret and understand feedback, as well as generate positive emotional responses and take practical actions to improve their learning using the feedback. The extent of students' engagement with feedback is influenced by the teacher's professional knowledge, expectation and feedback style, and is also related to students' personality characteristics and their perception of feedback. In the mathematics classroom, the role of the teacher has evolved from a traditional knowledge transmitter to a facilitator and guide of learning. They should actively encourage and promote students' proactive and active engagement in the feedback process. Based on the above, this study explores how to utilize big data analytics to optimize instructional strategies aimed at improving students' engagement with feedback. The application of big data technology can significantly enhance students' engagement in the feedback process. By employing techniques such as classroom behavior recognition, affective computing, and analytical visualization, educators can more precisely assess student engagement across cognitive, emotional, and behavioral dimensions. This capability allows teachers to adjust their teaching strategies in a timely manner and provide personalized feedback, thereby more effectively supporting students' mathematical learning.

However, this study still has certain limitations, and future research can be deepened and expanded in the following three aspects. First, it is necessary to utilize big data analytics to investigate how various types of feedback in mathematics classrooms specifically influence students' engagement. By utilizing data on classroom interactions, learning behavior patterns, and students' responses to feedback, researchers can more accurately reveal the relationship between feedback types and student engagement, thereby laying a solid foundation for developing effective feedback strategies. Secondly, future research should further explore other key factors that influence students' engagement with feedback, including students' learning motivation, cognitive development levels, and peer interactions, which have not been adequately analyzed in this study. By conducting a comprehensive analysis of these elements, researchers can more thoroughly identify the critical factors affecting students' participation in feedback processes, thereby providing more targeted strategic recommendations for teaching practices. Thirdly, harnessing big data can enhance the investigation of feedback strategies for various types of mathematical knowledge. By analyzing students' behavioral data during the learning processes of mathematical concepts, theorems, and problem-solving, teachers can more accurately identify the feedback needs for different types of mathematical knowledge. This enables them to provide targeted feedback strategies, thereby promoting a deeper understanding of concepts, flexible application of theorems, and enhanced problem-solving skills.

In summary, enhancing students' engagement with feedback in mathematics classrooms is a complex yet crucial task. The application of big data analytics provides significant support for achieving this goal. Proficiency in using big data analysis tools to deliver timely and accurate feedback is a key skill that educators must master to effectively enhance students' cognitive, emotional, and behavioral engagement. Therefore, conducting specialized training in big data applications and efficient feedback skills is highly valuable and urgently needed. Educational institutions should strengthen training and support to help teachers better utilize big data technology, thereby providing high-quality feedback and advancing students' mathematical learning.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Fang Yuan contributed to the conception, writing, and revision of the manuscript. Jingxia Wang and Yuxin Liu contributed to the revision of the manuscript. The authors approved the submitted version.

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