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The effectiveness of AI-based emotional feedback in an online mathematics game on fractions for junior high school students

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Abstract

Mathematics learning often triggers anxiety and motivation loss when students encounter persistent failure. The present study examines the impact of an online math game featuring AI-based emotional feedback on students' learning outcomes in fraction topics. Specifically, it analyzes the effectiveness of real-time AI emotional feedback in improving academic performance among junior high school students. A sequential explanatory mixed-methods design was employed. The study involved 119 eighth-grade students aged 13–14 years, with balanced gender representation across two research sites. Participants were assigned to an intervention group (n=61) receiving AI feedback and a control group (n=58). Quantitative analysis using t-tests revealed that the intervention group significantly outperformed the control group in both School X ($t = -5.43$, $p < .001$, $d = 1.42$) and School Y ($t = 2.22$, $p < .033$, $d = 0.57$), indicating medium-to-large effect sizes. System log data showed that "Neutral" was the most frequent emotional state, while "Sadness" emerged as the primary negative emotion during challenging tasks. Qualitative findings further indicated that AI feedback supported cognitive reappraisal and refocusing strategies, enabling students to transform negative emotions into persistence. Overall, AI-based emotional feedback functions as effective affective scaffolding, mitigating the impact of negative emotions on mathematical performance.

Keywords: AI feedback; emotion regulation; fractions material; online math game; student emotion patterns

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Introduction

Mathematics learning is often a dilemma for students, on the one hand, it offers intellectual satisfaction, but on the other hand, it is prone to triggering anxiety and feelings of helplessness when students encounter cognitive dead ends.(Hascher et al., 2024). This shows that teaching strategies and the use of media that are not enjoyable directly affect students' feelings or emotions in learning mathematics. Torres-Peña et al. (2025) explain that mathematics learning is a crucial foundation for the development of students' logical, analytical, and problem-solving skills. Various topics taught in fractions are often one of the most challenging fundamental concepts and cause significant learning difficulties for students (Simon et al., 2018).

One of the root causes often identified in learning difficulties with fractions is students' suboptimal ability to communicate, organize, and interpret mathematical ideas (Schons et al., 2022; Simon et al., 2018). These skills are not merely complementary, but rather core competencies that enable students to transfer information from one form to another, such as from verbal to visual, visual to symbolic, and vice versa (Schoenherr et al., 2024). These abilities become more complex when students have to perform operations on fractions, such as addition, subtraction, multiplication, and division, which require students to not only understand the visual representation but also manipulate the procedures in fractions (Karika & Csíkos, 2022; Simon et al., 2018; Syed Ismail et al., 2024). One effort that can overcome this problem is online math games. Through online math games that are more interactive and fun, it is hoped that motivation can be increased, anxiety reduced, and conceptual understanding deepened (Steinkuehler & Squire, 2014).

The use of online math games has emerged as an innovative solution to mitigate this problem by creating an interactive and motivating learning environment (Russo et al., 2025). However, the majority of conventional digital learning media still have critical weaknesses, they only provide cognitive-based feedback (right or wrong) and often ignore the emotional conditions underlying the student's failure. This is where Affective Computing, through AI-based emotional feedback, offers superior theoretical advantages over conventional methods (D'Mello et al., 2018; Picard, 1997). Unlike conventional feedback, which is static and delayed, AI-based feedback is capable of real-time and adaptive intervention. This system not only responds to incorrect answers, but also detects "impasse-driven frustration" before students decide to give up, thereby enabling self-regulated emotions that maintain cognitive persistence (Pekrun & Linnenbrink-Garcia, 2014).

To bridge this gap, Affective Computing offers a sophisticated alternative by providing AI-based emotional feedback that adapts to a student's real-time state (Picard, 1997). Grounded in Pekrun (2011, 2024), Control-Value Theory (CVT) which posits that achievement emotions directly dictate cognitive resources and persistence, this study moves beyond static interventions. While prior affective computing studies have explored general emotional responses in digital learning, there is a distinct lack of research integrating real-time facial emotion detection specifically within the high-anxiety context of fraction learning. This study fills that gap by providing contextually appropriate affective scaffolding that detects frustration before a student disengages. By combining facial expression analysis with adaptive interventions in fraction-based games, this research examines how such technology can maintain cognitive persistence and improve learning outcomes.(Alsaiari et al., 2025).

This study aims to answer several research questions regarding the effectiveness of AI-based feedback on student emotions through online math games on fractions:

1. To what extent does the use of online math games with AI-based emotional feedback significantly improve student learning outcomes in fractions compared to methods without emotional feedback?
2. How do students' emotional fluctuations develop during interaction with AI-based math games?
3. How do teachers and students perceive the role of AI feedback in helping to regulate emotions and overcome cognitive difficulties in fraction operations?

Methods

Research type

The research method used in this study is a mixed-methods approach, with a sequential explanatory design(Creswell & Creswell, 2018; Tashakkori & Teddlie, 1998). In this study, Data quantitative was collected through game scores and AI interaction logs. Statistical analysis (t-tests and multiple linear regression) was used to identify patterns of effectiveness and significant emotional influences. The results of quantitative analysis formed the basis for determining interview participants through purposive sampling. Specific findings, such as the significant impact of anger at School X or the stability of scores at School Y, were used to develop a focused interview protocol. The qualitative phase was conducted through in-depth interviews to explain the quantitative findings. Qualitative data revealed the psychological mechanisms behind the numbers, such as how students used AI messages to perform cognitive reappraisal when faced with cognitive failure.

Research population and sample

The research population consisted of all junior high school students in the city of Banda Aceh. The research sample was taken from two junior high schools and selected based on accessibility and willingness to participate. It is acknowledged that the use of this non-probability sampling method may limit the generalizability of the findings to the broader population of students in Banda Aceh. To ensure internal validity within the selected sites, 119 Year 8 students (aged 13–14 years) were involved. The gender distribution in this study was evenly balanced between male and female students in both schools. School X consisted of 31 students and school Y consisted of 30 students in the experimental group who used online math games with AI-based emotional feedback. School X consisted of 30 students and school Y consisted of 28 students in the control group, which used an online math game without AI-based emotional feedback

Research procedures

The media used in this study was an online math game called Fraction Heroes, designed to help students master fractions (see Figure 1). This media was developed by the Indonesian Realistic

Mathematics Education Research and Development Center (PRP-PMRI) in 2024. This game covers fraction concepts and operations, from basic to more complex levels. The game can only be played on Android smartphones. In 2025, this online math game was developed with the addition of a unique feature in the form of AI-based emotional feedback that responds to students' emotional patterns in real time and can be applied on a personal computer (PC).

The emotion AI system was developed using Unity (C#) for the gaming environment and Face++ (Megvii) Python-based API as the emotion recognition engine. Technically, emotion sampling was conducted with a temporal resolution of every 15 seconds while students were playing to ensure consistent affective monitoring without burdening system performance. Regarding validity, Face++ is a leading computer vision platform with reported facial expression recognition accuracy rates of 90-95% on various standard emotion benchmark dataset (Chiou et al., 2024; Jung et al., 2018). The use of this commercial API provides robust and reliable technical validation compared to manual coding (human coders) for real-time affective detection.

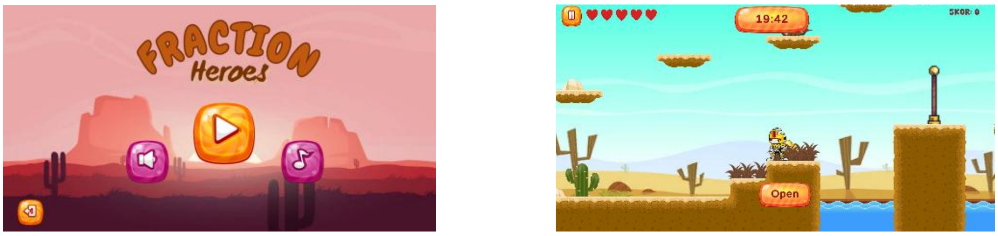

Figure 1. Fraction heroes game screen (left), Challenge and features in game (right)

The challenges and features found in online math games are:

1. Lifepoint (heart icon): A visual indicator that shows the player's remaining lives. Each time the player makes a serious mistake (e.g., falling into a hole or being hit by a cactus) or fails to solve a problem, one heart is lost. Losing all lifepoints signals the end of the game session or the need to restart at that level.
2. Time (top center): a countdown timer that shows the time remaining for players to complete the level. The presence of this timer serves to spur players to respond quickly to questions and complete challenges, as well as providing pressure that can naturally trigger an emotional response.
3. Star: When the player reaches and presses the star, a math problem interface will appear, requiring the student to solve the problem before continuing the character's movement.
4. Pole: checkpoint. When players pass this pole, their progress will be saved. If students fall into a water hole or get hit by a cactus, they can continue from the last pole they passed.
5. Water holes and cacti: Obstacles or traps in the game designed to provide physical challenges that can reduce lifepoints.
6. Score: A cumulative number representing the player's total achievement or success in completing questions. This score increases each time the player successfully completes a fraction question correctly.

Students must register before they can play the online math game. The registration process requires students to fill in personal data such as username, password, full name, school, grade, and classroom. After the registration process is successful, students can immediately log in to the online math game using the username and password they have registered.

In this study, once students have registered and completed a game session, all of their game activities are recorded in the dashboard. The website http://fractionheroes.my.id:8000/dashboard is for feedback, and http://heroesnonfd.my.id:8000/dashboard is for no emotional feedback. This dashboard also contains data on the number of sessions completed, the percentage of correct answers in each session, emotional patterns captured by the camera, and the student's recent gaming history (see Figure 2).

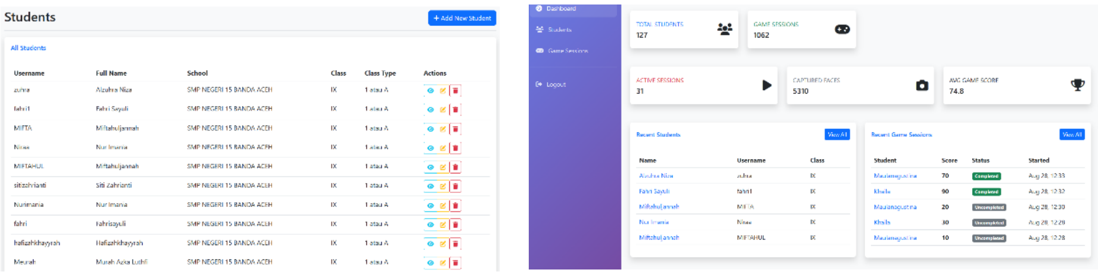

Figure 2. List of registered students (left), dashboard with emotional feedback (right)

The dashboard also automatically records data related to student emotions through an AI-based student emotion feedback feature. This system works by detecting student emotions through a computer camera, then responding with relevant notifications or emotional feedback aimed at helping and motivating students. The data recorded in this interaction log is very important because it provides a direct and objective picture of students' emotional responses to challenges and difficulties in the game (see Figure 3.). The accumulation of recorded emotions can then be visualized through an emotion diagram, which presents a summary of students' emotional patterns during the playing session.

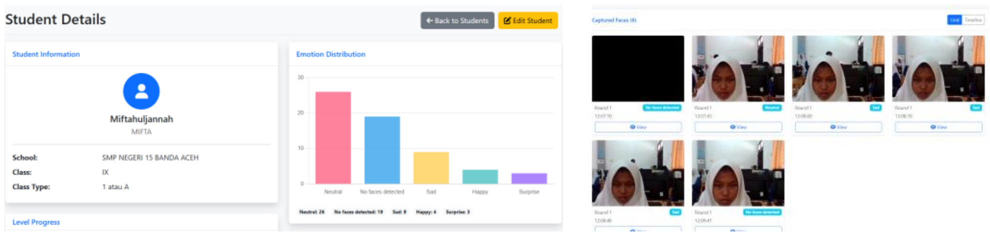

Figure 3. Emotion capture data diagram (left), Emotion capture example (right)

The study began with an introduction to the Fraction Heroes online math game for all students. The students were divided into two groups: one group used the game with AI-based emotional feedback, while the other group used the game without this feature. During the meeting, students had to register themselves to obtain a username and password within 10 minutes. After registering, students logged into the game to play the online math game for 60 minutes. After playing the online math game, all students were asked to complete a questionnaire about their emotional experiences. Next, some students and teachers participated in in-depth interviews lasting five to ten minutes, where they were asked to share their experiences and perceptions in more detail regarding the use of this online math game.

This study has met all applicable ethical standards. Prior to implementation, the research procedures were reviewed and approved by the Research Ethics Committee. To protect the rights and privacy of participants, written informed consent was obtained from the parents or guardians of all underage students who participated. Specifically, participants and guardians were explicitly informed about the activation and purpose of using cameras to detect facial emotions during play sessions. In addition, data anonymisation was applied; video recordings or facial data were used only for emotion score extraction and were immediately anonymised and separated from student identity information to ensure complete confidentiality.

Data collection techniques

Quantitative data was collected to measure the effectiveness of AI-based feedback on students' emotions and learning outcomes in fractions through game scores and automatic log recordings on the system dashboard. The emotion categories used by the AI system included seven basic dimensions, namely Neutral, Sad, Happy, Surprised, Fearful, Disgusted, and Angry, which were based on Ekman (1992) basic emotion theory. The selection of this category was prompted by the system's ability to detect universal expressions that correlate directly with achievement emotions such as frustration, confusion, and learning satisfaction. The log data was reinforced with an emotional experience questionnaire adapted from the Achievement Emotions Questionnaire (AEQ) developed by Pekrun et al. (2011). The adaptation process followed four systematic steps to ensure its relevance to the specific context of AI-based math games was dimension selection, contextualization, language adaptation and translation, and validation.

In addition to being validated by five experts, this instrument has undergone field testing that proves the statistical validity of the items using Pearson Product-Moment correlation analysis, in which all items are declared valid for measuring students' emotional constructs. This measurement tool demonstrates Very good internal consistency with a Cronbach's alpha value of 0.878. Meanwhile, qualitative data was collected through in-depth interviews with teachers and students to provide contextual explanations for the quantitative findings, focusing on subjective experiences and AI feedback mechanisms in helping to regulate emotions when facing cognitive difficulties.

Data analysis techniques

Data analysis in this study was conducted quantitatively and qualitatively, focusing on the presentation and interpretation of data collected from various instruments. Quantitative data analysis was performed to measure the effectiveness of the treatment between the experimental group (with AI-based student emotion feedback) and the control group (without AI-based student emotion feedback) using an independent t-test preceded by a normality and homogeneity of variance test. The hypothesis in this study is:

$$H_0: \mu Experiment = \mu Control$$
$$H_a: \mu Experiment > \mu Control$$

If H_a is accepted, then the average learning outcome score for fractions of students who use online math games with AI-based emotional feedback is better than that of students who use online math games without AI-based emotional feedback. Thus, it can be concluded that AI-based emotional feedback is effective for learning outcomes in fractions.

Second, to understand emotional patterns, data from student emotional experience questionnaires and student emotional logs contained in the dashboard were analyzed descriptively to determine the frequency and percentage of answer choices. The results were presented to illustrate general trends in student responses to emotions.

To deepen this understanding, qualitative data from in-depth interviews was also analyzed. Qualitative data analysis was conducted through systematic steps to gain a deeper understanding. Students' perceptions of online math games were analyzed qualitatively to gain a deeper understanding of their experiences. Data was collected from open-ended questionnaires and interview protocols, which included questions about liked or disliked features, whether they felt they were learning, and suggestions for improvement.

Results

The research results are presented in two main sections: quantitative analysis and qualitative analysis, in accordance with the sequential explanatory mixed-methods methodology used. Quantitative data was obtained directly from online math games and presented to provide an empirical picture of student learning outcomes, including a comparison of scores between the experimental and control groups, as well as an analysis of students' emotional patterns recorded automatically. This data is then followed by qualitative analysis, which involves in-depth interviews with teachers and students, to explain and provide their responses to feedback on AI-based student emotions in playing online math games.

The effectiveness of AI-based feedback on student emotions through online math games

The effectiveness of AI-based feedback on student emotions was tested through an intervention using an online math game on fractions. The data was categorized into three levels: low, medium, and high. These categories were determined based on the number of sessions completed by students and the number of correct answers given by students. Table 1 below presents data on students' average scores by school, which provides an initial overview of student learning outcomes in the game. This data compares the achievements between the Experimental Class and the Control Class, presenting the Mean and Std scores obtained by students from each school.

Table 1. Online math game score data

School	Group	*M*	*SD*	*df*	*t*	*p*	*Cohen's d*
School X	Experiment	77.61	5.59	59	5.58	$< .001$	1.43
	Control	59.29	17.41				
School Y	Experiment	76.79	21.09	56	2.19	$.033$	0.58
	Control	64.33	22.23				

The prerequisite test showed that the data were normally distributed in both schools. However, Levene's test showed non-homogeneous variance in School X ($p < .05$), so Welch's t-test (equal variances not assumed) was used. In contrast, School Y showed homogeneous variance, so the pooled t-test (equal variances assumed) was used. The t-test results at School X show a very clear and significant difference, $t(59) = 5.58, p < .001, d = 1.43$. This proves that AI intervention has a large effect on improving student scores. Similarly, at School Y, a significant difference was found, $t(56) = 2.19, p =$

$.033, d = 0.58$, with a medium effect on the middle category. Collectively, these results indicate that H_0 is rejected and H_a is accepted in both schools. It can be concluded that the use of online math games with AI-based emotional feedback is proven to be more effective in improving learning outcomes in fractions compared to without AI intervention.

Students' emotional patterns use online math games

In addition to analyzing the experimental and control classes, this study also investigated students' emotional patterns while playing online math games. Data on these emotions was automatically recorded through an AI-based feedback feature and collected in a dashboard. The analysis of these emotional patterns aimed to identify the most dominant types of emotions and map how those emotions changed. The emotions detected at School X and School Y were neutral, sad, surprise, fear, disgust, and angry, as shown in Table 2.

Table 2. Students' emotional patterns

School	Emotion	Sum	*M*	*SD*
School X ($n = 31$)	Neutral	309	9.96	5.1
	Sad	111	3.58	3.37
	Happy	34	1.1	1.4
	Surprise	38	1.23	3.09
	Fear	6	0.19	0.53
	Disgust	14	0.45	0.29
	Angry	9	0.29	1.02
School Y ($n = 30$)	Neutral	466	16.64	7.55
	Sad	146	5.2	5.5
	Happy	93	3.32	2.39
	Surprise	66	2.35	1.34
	Fear	22	0.79	1.32
	Disgust	72	2.57	3.25
	Angry	34	1.21	2.04

Table 2 presents statistics on students' emotional patterns recorded automatically in the form of frequency of occurrence during online math game sessions. The emotion with the highest frequency in both schools was neutral, indicating a predominance of focus while students completed the game. Among negative emotions, sadness was the most frequently detected emotion, especially at School Y, which represented a response to the level of difficulty of the questions. Conversely, fear recorded the lowest average in both schools, indicating that even though students faced challenges or frustration, the game did not trigger significant anxiety or stress responses. Overall, these data show that the AI intervention successfully kept the intensity of negative emotions at a low level, allowing students to continue their games with stable focus.

To strengthen empirical evidence and deepen analysis of automatically recorded emotional pattern data in the dashboard (Table 2), a questionnaire instrument on students' emotional pattern experiences was used as supporting data. Table 3 specifically measures students' perceptions and intensity of feelings through self-report, which forms the basis for interpreting quantitative findings in the context of students' emotional pattern experiences.

Table 3. Students' emotional pattern experiences (Pekrun et al., 2011)

	Question	*M*	*SD*
1	I feel happy and excited when I successfully solve fraction problems.	4.17	0.97
2	I feel frustrated or upset when my answers are wrong.	3.41	1.1
3	I feel confused or anxious when faced with difficult fraction problems.	3.59	1.08
4	I feel bored or uninterested in the game.	1.62	0.94
5	I try again more diligently after receiving feedback or error notifications.	3.97	1.03
6	I feel helped and motivated by the feedback provided by the AI when I feel frustrated or sad.	2.84	1.34
7	I feel that feedback from the AI helps me refocus on the problem.	3.66	1.27
8	I feel that feedback from the AI matches my feelings at that moment.	3.36	1.27
9	I feel more confident in doing fraction problems after playing this game.	3.97	1.02
10	I feel that this game makes learning fractions more enjoyable.	4.29	0.97
11	I feel that the feedback from the AI helps me manage my negative emotions.	3.43	1.27
12	I feel challenged and motivated to move on to the next level.	4.14	1.11
13	When I fall into a hole or get hit by a cactus in the game, I feel like trying again.	4.31	1.05
14	I feel that the AI feedback reinforces my positive feelings, such as when I feel happy or satisfied.	3.81	1.02
15	The notifications and audio in the game make me more excited to play.	3.81	1.21
16	I feel I can solve problems faster after using this online math game.	3.9	0.96
17	I find it easier to understand fractions after playing the game.	3.5	1.19
18	I feel I can control my emotions better when there are problems in the game.	3.62	1.06
19	I feel that feedback from the AI helps me find solutions when I am confused.	3.41	1.29
20	I feel that this game is an effective tool for learning fractions.	4.28	0.94

Note: 1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Often, 5 = Very often.

Table 3 shows that students have high grit and motivation toward online math games, with the highest average scores achieved by the statements "want to try again" after failure and "this game makes learning fractions more fun." Although students admitted to often experiencing negative emotions such as confusion or anxiety, they rated AI-based feedback on student emotions as effective in helping them manage negative emotions and refocus on the problem. Overall, this self-report data proves that AI-based feedback on student emotions successfully transformed emotional challenges into motivation to continue trying to complete the game, rather than boredom.

Teacher and student responses to ai-based student emotional feedback

Qualitative analysis was based on in-depth interviews with mathematics teachers who had become the subject of the study. The interviews with teachers aimed to obtain their perspectives on learning challenges, the role of student emotions, the potential of technology-based learning media, and factors that influence emotions while playing online math games. The results of this analysis provided important insights that complemented the quantitative findings.

Table 4. Interview dialogue with teachers about AI-based emotional feedback

Interview points	Researcher	Math teacher
The Main Triggers of Negative	P: "In your opinion, what factors most often cause frustration, sadness, or	G1: "The main factor is the difficulty of remembering the fraction material itself, such as equalizing denominators, changing

Interview points	Researcher	Math teacher
Emotions	confusion for students when they learn fractions, even in games?”	forms, and division operations. When students make mistakes at the beginning, they quickly become frustrated and tend to give up immediately because they feel they cannot do it.”
The Impact of AI Feedback	P: “Did you observe any changes in the students’ emotions or behavior, especially in the experimental group, after receiving emotional feedback from AI?”	G2: “Yes, I see the difference. It’s the feedback from the AI. When students start to get upset, a notification pops up asking them to stay calm and refocus. Their attention shifts from their emotions to the instructions. They get back to trying more quickly and waste less time getting angry.”
The Role of Games in Motivation	P:” “What factors keep students motivated even though the material is difficult?”	G1: “Educational game factors. Graphics, success notifications, and encouragement to try harder. When they successfully complete a problem, the feeling of joy and satisfaction makes them forget their previous frustration.”

Interviews with mathematics teachers provided qualitative validation regarding the emotional triggers and regulatory mechanisms induced by AI-based emotional feedback interventions for students. Teacher (G1) identified that the main triggers of negative emotions, such as frustration and the tendency to give up, were difficulties with fractions, including equalizing denominators and other fraction operations. Regarding the effectiveness of the intervention, teacher (G2) observed that feedback from AI acted as an effective emotion regulator. When students became upset, AI notifications served as a distraction, asking students to remain calm and refocus. This significantly made students try again more quickly and reduced time wasted due to anger. In addition, teacher (G1) emphasized that educational game factors were very important in maintaining students’ immediate motivation, allowing them to forget their previous frustrations and maintain engagement.

Another qualitative analysis was also based on in-depth interviews with six students who used online math games with AI feedback features. These interviews aimed to determine students’ responses to AI-based emotional feedback through online math games, explore students’ direct experiences and perceptions of AI feedback, and examine the role of games in regulating their emotions during learning. This analysis provided important insights that complemented the quantitative data.

Table 5. Interview dialogue with students regarding AI-based emotional feedback

Interview points	Researcher	Students
The Main Triggers of Negative Emotions	P: “What frustrates or annoys you the most when playing this game?”	S3: “The most frustrating thing is when you’ve been calculating for a long time, but the answer is still wrong or the denominator is wrong. I feel like quitting, especially when I make the same mistake over and

Interview points	Researcher	Students
		over again in the same place.”
Triggers for Positive Emotions	P: “When do you feel the happiest, most excited, or most satisfied while playing?”	S4: “It feels good when you successfully get past the cactus obstacle or when you get the answer right and the ‘Good job’ notification pops up. That feeling of joy is fleeting, so you forget that you were confused or frustrated by the difficult question.”
AI Feedback Effect	P: “When you start to feel annoyed or confused, do the emotional notifications from AI bother you or help you?”	S6: “At first I was surprised, but eventually it helped. When I was upset, the AI notification was like a reminder to relax. So, my anger subsided a little, and I immediately looked at the instructions in the question again instead of getting angry.”

Interviews with students provide in-depth subjective validation of their emotional experiences when interacting with online math games. Students consistently report that the main triggers of negative emotions, such as frustration and the desire to quit, are repeated failures due to errors in complex fraction calculations, especially those involving denominators. Conversely, positive emotions, such as joy and satisfaction, are triggered by success notifications (“Good job”) and successfully overcoming game obstacles, which serve as instant reinforcements that can erase memories of previous frustrations. Most importantly, students emphasize that emotional feedback from AI, although initially surprising, eventually becomes very helpful. These notifications serve as effective cognitive interruptions when students start to get upset, reminding them to relax, thereby successfully diverting negative emotions and encouraging students to immediately refocus on the problem instructions instead of wallowing in anger. These findings underscore the crucial role of AI-based emotional feedback in facilitating self-emotional patterns to maintain engagement and persistence. Overall, student interviews confirm that AI emotional feedback is a contextually appropriate intervention that plays an important role in facilitating self-emotional regulation, transforming negative emotional momentum into momentum for persistence and refocusing on the task.

Discussion

The results of this study indicate that the use of AI-based emotional feedback in online math games is positively associated with higher learning scores compared to the use of media without this feature. These findings provide an indication of the potential role of emotional regulation in learning, where high-quality feedback not only serves to identify technical errors but also provides constructive information that encourages independent learning strategies (Alsaiari et al., 2025). Unlike conventional feedback that merely identifies errors, this system provides affective scaffolding that encourages cognitive reappraisal (Han et al., 2024). When the AI detects “impasse-driven frustration” captured in the log data as “Sad” expressions, the timely intervention prevents a “frustration-boredom” loop, allowing students to maintain cognitive persistence (Baldassarri et al., 2021).

These findings align with and extend major international studies beyond the Southeast Asian context. For instance, the results mirror research conducted in the United States by Arroyo et al. (2014) on the *Wayang Outpost* system, which demonstrated that students receiving affective support from digital tutors showed higher perseverance in mathematics. Furthermore, our findings resonate with a meta-analysis from Germany by Vogl et al. (2020) which posits that technology-mediated learning is most effective when it directly targets achievement emotions. However, while Woolf et al. (2009) in North America found that emotional AI significantly benefits low-achieving students, our data suggests a broader impact across diverse ability levels in the fraction material, indicating that the complexity of fractions makes affective support universally beneficial.

Pedagogically, the findings regarding the dominance of neutral emotions in this study have significant meaning. In the context of affective computing, the high frequency of neutral emotions is often interpreted not as an absence of emotion, but as an indicator of engaged concentration or a state of flow(D'Mello & Graesser, 2012). These findings are similar to those of Baker (2010), which show that students in a state of deep concentration tend to display flat or neutral facial expressions when processing complex information. This indicates that the AI system successfully kept students in an optimal concentration zone, preventing them from slipping into extreme negative emotions. Nevertheless, the effectiveness of this technology must be viewed critically. Previous literature, such as McQuiggan et al. (2008), warns that emotionally sensitive feedback can be counterproductive if given at the wrong time or if it is too general. In this study, the effectiveness of the system is likely to be influenced by timeliness and contextual appropriateness. Qualitative data supports this, with students perceiving the AI intervention as particularly helpful precisely because it appeared adaptively only after the system detected signs of persistent negative emotions when dealing with complex fraction calculations.

This study expands the scope of affective computing research in mathematics education by providing a practical model of how facial detection can be transformed into a tangible pedagogical intervention. While most previous studies have focused solely on the accuracy of emotion detection Picard (1997), this study goes further by integrating the detection results into the instructional design of fraction material. This contribution emphasises that the development of future educational technology must consider adaptive learning environments that are capable of transforming negative affective responses into persistence, as demonstrated in the use of these online maths games.

Conclusion

AI-based emotional feedback in online math games significantly improves learning outcomes in fractions by facilitating students' emotional regulation. Findings demonstrate that the dominance of neutral emotions reflects stable cognitive concentration (engaged flow), while the system effectively mitigates negative emotions such as sadness by providing timely affective scaffolding. Internationally, this research offers a scalable model to address "math anxiety" in complex STEM subjects. The findings suggest that global AI learning systems should move toward "proactive scaffolding," where algorithms detect early signs of frustration to prevent disengagement. Furthermore, designers should prioritize maintaining the "flow zone" (neutral affect) as a key metric for instructional success. The main limitations lie in the short duration and technical factors like lighting. Future research should integrate the facial detection models with the emotional experience instruments used in this study to create robust multimodal systems across different cultural contexts.

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Declarations

Conflicts of Interest	:	The authors declare no conflict of interest regarding the publication of this manuscript. In addition, the authors have completed the ethical issues, including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies.
Generative AI Statement	:	Grammarly was used for language editing and clarity. The tool was not involved in the research process, including data analysis or interpretation. The authors reviewed all content and take full responsibility for the manuscript.
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Author Contributions	:	**Razid Ananda Siregar:** Developed feedback on students' emotions based on artificial intelligence (AI) through online math games; **Rahmah Johar:** Coordinated all stages of the study; **Mailizar:** Guided RS in analyzing and discussing the study findings.

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