Evaluation of the Effect of Digital Comics on Learning: How are Students' Motivation and Emotional Reactions?

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***Abstract*—Technology-based learning media is strongly suspected of influencing students' emotional reactions and motivation to learn mathematics. However, students' emotional reactions to mathematics learning still receive less attention from teachers. This study aims to investigate the differences in emotional reactions and learning motivation between high, medium, and low levels of students' mathematical comprehension and the role of digital comic media in mathematics learning. This study involved 100 high school student respondents. Data collection is done through observation, surveys, and tests. The findings of this study indicate significant differences in emotional reactions and learning motivation between high, medium, and low levels of students' mathematical comprehension in mathematics learning assisted by digital comic media. Emotional reactions predict students' mathematical comprehension abilities in the high and medium groups in mathematics learning assisted by digital comics. However, specifically learning motivation is the strongest predictor of low group students' mathematical comprehension. The role of digital comic media in mathematics learning is to build positive emotional reactions, focus attention, visualize abstract concepts in mathematics into concrete concepts, and become good cognitive control for students when learning.**

***Keywords*—digital comics, emotions, learning achievement, motivation**

I. Introduction

Technology is growing rapidly in today's digital era. Its major influence in various areas of life is inevitable, including in education. Technological innovations in learning are starting to be used by many teachers worldwide to support the teaching and learning process [1, 2]. Technology is increasingly becoming a choice because it has proven effective in improving students' skills, motivation, and learning outcomes [3, 4].

Many educational institutions have adopted digital technology to assist in various educational activities or procedures [5]. Educational technology has not only changed the way students access information but also the way teachers deliver materials, evaluate student progress, and interact in the learning environment [6]. For teachers, educational technology opens up various opportunities to improve teaching effectiveness.

A student's mathematics learning achievement is not only influenced by cognitive intelligence factors, but other factors influence it [7]. In the learning process, emotions also play a big role in achieving learning success. Successful learning must begin with creating positive emotions in students [8]. Cognitive learning theory states that meaningful learning positively impacts students after taking lessons [9].

Several research results report that students' emotional factors often receive less attention and are ignored by teachers in mathematics learning in schools [10, 11]. Teachers hold two roles related to students' academic experiences, namely guiding students to build their knowledge and motivating them to succeed in learning. Conversely, if teachers do not provide a good academic experience, it will damage students' emotions and weaken their motivation to achieve [12]. This study contributes to the importance of teachers identifying differences in patterns of relationships between emotional reactions and learning motivation in mathematics learning where students have different mathematical comprehensions.

This study is based on the condition of mathematics learning in schools, which still gives rise to negative emotions and lacks motivation for students to learn. One cause is the minimal use of technology-based learning media. Researchers assume that mathematics learning materials packaged in the form of digital comics can improve students' comprehension and build positive emotional reactions and learning motivation. Therefore, we focus on five research questions that will guide this study.

RQ-1: Is there a significant difference in emotional reactions between low, medium, and high levels of students' mathematical comprehension in mathematics learning assisted by digital comic media?

RQ-2: Is there a significant difference in learning motivation between low, medium, and high levels of students' mathematical comprehension in mathematics learning assisted by digital comic media?

RQ-3: Is there a correlation between emotional reactions, learning motivation, and students' mathematical comprehension in mathematics learning assisted by digital comic media among low, medium, and high levels of students' comprehension?

RQ-4: How do emotional reactions and learning motivation predict students' mathematical comprehension in mathematics learning assisted by digital comic media among low, medium, and high levels of student comprehension?

RQ-5: How is the role of digital comic media in the relationship between emotional reactions, learning motivation, and students' comprehension in mathematics learning?

This study is intended to stimulate discussion and coordinated research efforts on how emotional reactions relate to students' motivation and learning achievement in mathematics learning assisted by digital comic.

II. Literary Review

A. Digital Comics as Learning Media

Comics are a form of visual communication media that has

the power to convey information in a popular and easy-to-understand way. This is possible because comics combine the power of images and writing, which are arranged in a picture storyline making information easier to absorb. Comics provide a unique opportunity to explore character development, plot structure, and visual narrative techniques. Students learn to sequence events, create dialogue, and convey emotions through a combination of images and text.

Learning technology is a communication, information, and technology tool to enhance learning, teaching, and assessment. It can be hardware or software, such as computers, tablets, online learning platforms, and mobile applications. In mathematics learning, computers are widely used to deliver materials that require movement (animation), images, text, and color. The role of technology (digital comic media) as an effective and efficient alternative learning media in helping students understand abstract mathematical concepts [13].

Digital comics are illustrated stories with certain characters that present information or messages through electronic media [14]. Some applications that can be used to create digital comics include Canva, Clip Studio Paint, MediBang Paint, Procreate, and Photoshop. The use of digital comic media has an advantage because of its advantages compared to other forms of advertising, namely time and cost efficiency, more efficient to carry than printed comics, and easy to access. Through teacher guidance, comics can function as a bridge to foster students' interest and motivation in learning. The researcher hopes that using this digital comic media can arouse positive emotional reactions and increase learning motivation so that student's comprehension of mathematics also increases.

B. The Student's Emotional Reactions

Emotion is an expression of the true feelings that he feels, which are shown to someone or something that makes him emotional [15]. Emotion is a unique feeling and thought, a psychological state, and a series of tendencies to act that is more directed at the characteristics and expressions of emotion [16]. Emotional reactions are changes that can prevent someone from acting, which are sometimes out of control [17]. Therefore, we need to control emotional reactions so that the reactions that appear are not destructive, but constructive.

Emotions are one of the factors that influence individual behavior. A person's ability to direct and adjust emotions to a situation will affect behavior and social relationships [18]. This emotional aspect greatly influences children's behavior towards themselves, others, and their environment [16]. Therefore, teachers need to understand emotions and their impact on student behavior and know how to control them. It should be noted that managing emotions is important because it will make us better understand our own condition and our surroundings [15].

Emotions play an important role in the learning process because they can enhance or inhibit learning, depending on how they are felt. Positive emotions can help students achieve better learning outcomes, while negative emotions can slow down or stop learning. Emotional feelings associated with situations when students learn mathematics are joy, satisfaction, enthusiasm, boredom, anxiety, and frustration [10]. Satisfaction and joy may not be common emotional feelings among students when learning mathematics at school. However, often the emotional feelings that arise when students learn mathematics are negative emotions, namely boredom, anxiety, and frustration [19]. If teachers can arouse positive emotional feelings among students, it will be able to encourage student motivation and success in learning mathematics.

C. The Role of Motivation in Learning

Motivation is an urge that arises within a person to do or think with a certain purpose, either consciously or unconsciously [20]. Motivation causes a person to do something and persist in doing it, marked by the emergence of reactions and feelings to achieve goals [21]. Learning motivation is basically the acceptance of a relationship between oneself and something outside oneself [22]. Students who are motivated to learn a particular subject tend to pay more attention to that subject [23]. Intensive focus on learning materials can enable students to study harder and ultimately achieve the desired learning outcomes [22, 24].

Intrinsic and extrinsic motivation are very much needed by students to raise their enthusiasm for learning [25]. We summarize from several expert opinions [25–28], that good learning motivation is manifested in student behavior as follows: diligent in facing tasks, persistent in facing difficulties, does not require external encouragement to achieve, has a high enthusiasm for learning, and likes new knowledge.

D. Mathematical Comprehension

Mathematical comprehension is the foundation for thinking in solving mathematical problems and problems in everyday life. The ability to understand will help students better understand the mathematical concepts they are learning so that they no longer learn by memorizing [29, 30]. Indicators that show students' abilities in mathematical comprehension include (a) restating a concept that has been learned and applying the concept algorithmically; (b) classifying objects based on the requirements that form the concept; (c) presenting concepts in various forms of mathematical representation; and (d) various concepts in mathematics and outside mathematics [31]. The object of learning mathematics is abstract, so it has the potential to be difficult for some students to understand. To bridge students' mathematical comprehension, students need to be assisted with learning media, including digital comics that contain mathematical material.

E. Trends in Mathematics Learning Research

In this decade, the trend of research approaches in mathematics learning has focused more on cognitive processes [32]. Research on mathematics learning media (2019–2023) has been reviewed by Hanifah *et al.* [33] with 15 articles on the use of technology in mathematics learning (2013–2022) has been reviewed by Kurnia *et al.* [34] with 24 articles, and the influence of game-based learning in mathematics learning (2018–2022) has been reviewed by Mahmud and Hui [35] with 64 articles. Several studies have also discussed the influence of motivation and ICT in mathematics learning [36, 37]. However, we have not found any attention from researchers to the role of emotions

in the process of comprehension knowledge, especially in digital technology-based mathematics learning. Our research is one of the first to explore differences in emotional reactions and learner motivation among students with high, medium, and low mathematical comprehension.

III. Methodology

A. Research Design

This study focuses on quantitative descriptive research by combining a one-shot case study research design and survey methods with a cross-sectional design. A one-shot case study research design [38] is applied to measure mathematical comprehension ability (dependent variable) based on the treatment given. Meanwhile, the cross-sectional design was chosen to provide a snapshot of the behavior and attitudes of respondents during the survey [39]. The aspects surveyed were about emotional reactions and students' learning motivation in mathematics learning assisted by digital comic media (independent variable) [40, 41].

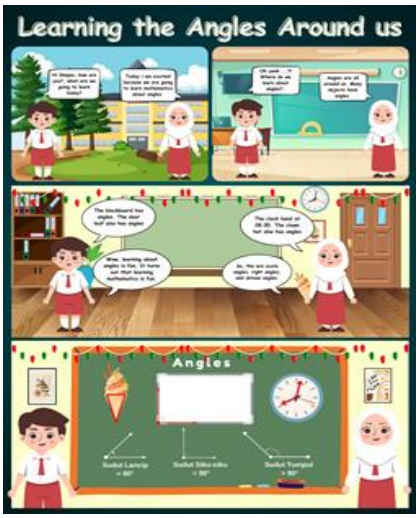
B. Participants

This study involved 100 respondents of seventh-grade junior high school students and a mathematics teacher. The sample (respondents) was selected using a purposive sampling technique based on certain characteristics or attributes [42]. Respondents consisted of 50 male students and 50 female students. In general, students are between 11 and 12 years old. The form of teacher participation is implementing mathematics learning assisted by digital comic media, and teachers conduct cognitive assessments.

C. Material

The mathematics learning materials used in this study are packaged in the form of digital comics with angle material. This digital mathematics comic was developed through the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) stages [43]. Before being used in the study, this digital comic had been evaluated and passed the validity, practicality, and effectiveness tests of the media through trials in classes of the same level. The following is an example of an illustration of a digital mathematics comic and its conversation in Table 1.

Table 1. Digital comic content and characters with angle material

Digital Comic Illustration	Characters	Conversation in Digital Comic
	Andrew:	Hi Shopia, how are you? What are we going to learn today?
	Shopia:	Today I am excited because we are going to learn mathematics about angles.
	Andrew:	Oh yeah….?! Where do we learn about angles?
	Shopia:	Angles are all around us. Many objects have angles.
	Andrew:	The blackboard has angles. The door leaf also has angles
	Shopia:	The clock hand at 08.00 The clown hat also has angles.
	Andrew:	So, there are acute angles, right angles, and obtuse angles.
	Shopia:	It turns out that learning mathematics is fun.

D. Instruments

The researcher collected research data using a test instrument (T-1), questionnaire (T-2), and observation sheet (T-3). The test instrument (T-1) consisted of 4 items to collect data on students' mathematical comprehension of angle material. The researcher developed the test instrument according to the mathematical comprehension indicators.

The reliability of the test instrument was tested using the internal consistency method, namely the Cronbach's alpha method. The results of Cronbach's alpha test obtained a reliability coefficient of 0.74 (r_1 > 0.70) with a high-reliability category [44].

The questionnaire instrument (T-2A) was used to obtain data on students' emotional reactions in mathematics learning assisted by digital comic media. The questionnaire instrument (T-2) was modified based on Measuring Emotional Reactions (MER) developed by Demirkol *et al.* [12]. The number of questionnaire items (T-2A) is 12 questions with a 5-point Likert scale assessment (1 = "Strongly disagree", to 5 = "Strongly agree").

Questionnaire instrument (T-2B) to obtain learning motivation data. The questionnaire (T-2B) was modified based on the Motivation Assessment Scala (MAS) developed by Ferland *et al.* [45]. The number of questionnaire items (T-2B) is 24 questions with a 5-point. Likert scale assessment (1 = "Strongly disagree", to 5 = "Strongly agree"). The questionnaire instrument (T-2B) includes open-ended questions that must be answered by respondents.

The reliability of the questionnaire instruments (T-2A) and (T-2B) was tested using the internal consistency method, namely the Cronbach's alpha method. The test results obtained a Cronbach's alpha reliability coefficient for the questionnaire instrument (Q-1) of 0.78 (r_1 > 0.70) and the questionnaire (Q-2) of 0.76 (r_1 > 0.70), so the instrument is said to have high reliability [44].

Guidelines for observing (T-3) emotional reactions

(positive emotions and negative emotions) were modified from the work of Meyer *et al.* [46]. Positive emotional reactions include satisfaction (e.g., relieved, relaxed, satisfied) and pleasure (e.g., interested, happy, excited). Negative emotional reactions include anxiety (e.g., angry, frustrated, embarrassed, afraid) and sadness (e.g., sad/tired, bored).

The observation sheet was evaluated and validated by two experts in the field of psychology. The evaluation process includes: the suitability of the aspects and statements observed, the language used in the observation sheet, and the clarity of the instructions for filling out the observation sheet. Observations were conducted openly and documented on a video recorder.

E. Data Analysis

The quantitative data analysis of this study was conducted in four stages. First, the classical test through initial analysis related to the requirements of normal distribution and multicollinearity test [47]. Second, the one-way ANOVA test followed by a post hoc test [48] to investigate differences in emotional reactions and learning motivation among students with high, medium, and low mathematical comprehension. Third, zero-order correlation analysis to test the relationship between (emotional reactions and mathematical comprehension) and (motivation and mathematical comprehension) among the high, medium, and low groups.

Third, the Fisher Z-r test [49] to investigate whether there are significant differences in the correlation pattern between (emotional reactions and mathematical comprehension) and (motivation and mathematical comprehension) among the three different groups. Fourth, multiple linear regression analysis to test whether there is a correlation between (emotional reactions and mathematical comprehension) and (motivation and mathematical comprehension) among the three different groups. The "Exclude cases list wise" method was adopted to handle missing data in this study [50].

Qualitative data from the results of open-ended questions and observation results were analyzed selectively through an inductive approach with thematic content analysis [51]. To maintain the credibility of the research results, a final analysis was carried out through a group discussion forum attended by psychology experts (psychologists), teachers, and researchers.

F. Procedure

The lecturer designs assignments in a based learning project in realistic mathematics education courses. The expected product of this project is a mathematics learning video.

The implementation of research data collection was carried out at one time. One-shot case study research. was carried out by providing treatment of mathematics learning assisted by digital comic media, and then a post-test was carried out in the form of a mathematical comprehension test. When the sample was given treatment, the researcher observed students' attitudes and learning practices to support the survey results. The sample was surveyed through a questionnaire about students' emotional reactions and motivations in mathematics learning assisted by digital comic media. In the end, the post-test and survey data will be analyzed together to test the correlation and research variables that predict other variables. This research procedure is described in the form of a research workflow, as in Fig. 1.

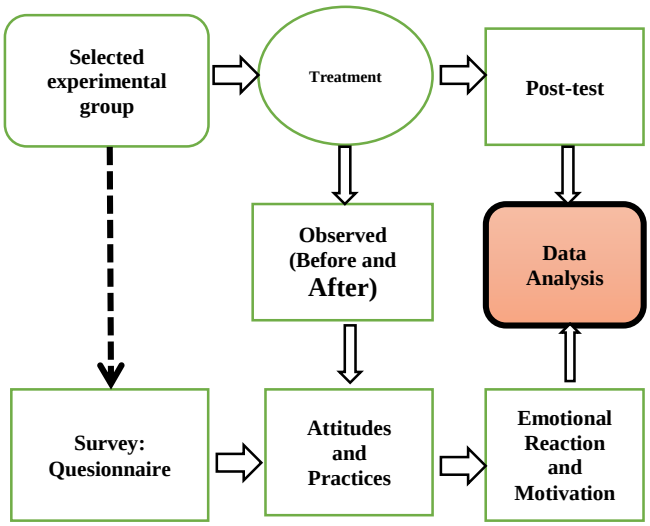


Fig. 1. One-shot case study combined with cross-sectional research design.

IV. Results

Initial analysis was carried out by testing normality by reviewing the skewness and kurtosis values. The results of testing the data on emotional reactions, learning motivation, and students' mathematical comprehension showed a normal distribution. Skewness and kurtosis values between –2 and +2 (see Table 2) are acceptable to prove a normal univariate distribution [52].

Table 2. Normality test for initial data analysis

Statistics	Emotional reactions	Learning motivation	Mathematical comprehension
N(Valid)	100	100	100
Missing	0	0	0
Skewness	0.187	0.412	0.187
Std. Error of Skewness	0.338	0.338	0.438
Kurtosis	1.056	0.955	1.109
Std. Error of Kurtosis	0.705	0.762	0.568

In the statistical test of collinearity, the tolerance value of emotional reactions and learning motivation was 0.274, greater than 0.10. While the VIF value of emotional reactions, and learning motivation was 2.359, less than 10, proving that there was no case of multicollinearity [53, 54]. The following is a statistical description of students' mathematical comprehension in mathematics learning assisted by digital comics. The grouping of students into three levels (high, medium, and low) is based on the range of mathematical comprehension scores in a normal distribution with x = 72.675 and σ = 11.719 (see Table 3).

Table 3. Statistic descriptive of mathematical comprehension

Statistic Descriptive	Mathematical Comprehension		
	High (n = 20) ($\bar{x}+1\sigma <$ score)	Medium (n = 62) ($\bar{x}-1\sigma \leq$ score $\leq \bar{x}+1\sigma$)	Low (n = 18) (score < $\bar{x}-1\sigma$)
Minimum	85.0	65.0	58.0
Maximum	85.0	80.0	60.0
Mean score per group	87.21	72.59	59.11
Standard Deviation	8.61	8.54	5.93

In this study, indicators of emotional reactions are shown in the form of positive emotions and negative emotions when students gain mathematics learning experiences assisted by digital comics. Positive emotions are emotions that present positive feelings, namely satisfaction and happiness. Negative emotions are emotions that are identical to unpleasant feelings and create negative feelings, namely anxiety and sadness [55, 56]. The following report data on students' emotional reactions that have been grouped according to the level of students' mathematical comprehension (high, medium, and low) as in Table 4.

Table 4. Students' emotional reactions to mathematics learning with digital comics

Indicators of emotional reaction	Mathematical Comprehension		
	High (n = 20)	Medium (n = 62)	Low (n = 18)
Satisfaction	3.65	3.84	3.90
Pleasure	3.79	3.65	3.80
Anxiety	1.40	2.20	1,60
Sadness	1.27	2.00	1,10
Information: (a) Positive emotions: Satisfaction, Pleasure; (b) Negative emotions: Anxiety, Sadness			

The researcher also took data on students' learning motivation in mathematics learning assisted by digital comic media. The reported student motivation data has been grouped according to the level of students' mathematical comprehension (high, medium, and low) as in Table 5.

Table 5. Students' Learning motivation to mathematics learning with digital comics

Indicators of motivation	Mathematical Comprehension		
	High (n = 20)	Medium (n = 62)	Low (n = 18)
Diligent in facing tasks	3.95	3.59	3.75
Persistent in facing difficulties	3.80	3.82	3.78
Does not require external encouragement to achieve	3.65	3.70	3.65
High enthusiasm for learning	3.43	3.68	3.00
Likes new knowledge	3.70	3.35	3.40
Mean score	**3.70**	**3.63**	**3.51**
Standard Deviation	**0.92**	**1.03**	**1.29**

To answer research questions RQ-1 and RQ-2, a one-way ANOVA test was conducted. Descriptive statistics and differences in emotional reactions and learning motivation between low, medium, and high levels of students' mathematical comprehension in mathematics learning assisted by digital comic media are reported in Table 6.

Table 6. One-way ANOVA for emotional reaction and motivation

Statistics	Emotional reactions	Motivation to learn
F(ANOVA)	812.95[a]	904.37[a]
Post-Hoc Test (Bonferroni's correction)	L1 > L2[a]	L1 > L2[a]
	L1 > L3[a]	L1 > L3[a]
	L2 > L3[a]	L2 > L3[a]
Partial η^2	0.16	0.12

Note: a is corrected model coefficients; [a]$p < 0.001$; L1 = High-students' mathematical comprehension; L2 = Medium-students' mathematical comprehension; L3 = Low-students' mathematical comprehension.

Table 5 shows that there are significant differences in emotional reactions among students' mathematical comprehension at different levels, F(ANOVA) = 812.95, $p < 0.001$, partial η2 value = 0.16. The Post Hoc test with Bonferroni correction [48] showed that students' emotional reactions to high mathematical comprehension were significantly higher than students with medium and low mathematical comprehension. Students' emotional reactions to medium mathematical comprehension were significantly higher than students with low mathematical comprehension (all $p < 0.001$). In addition, there were also significant differences in learning motivation among the three groups of students, F(ANOVA) = 904.37, $p < 0.001$, partial η2 value = 0.12. The Post Hoc Test with Bonferroni correction shows that the learning motivation of students with high mathematical comprehension is significantly higher than students with medium and low mathematical comprehension (L1 > L2, and L1 > L3). The learning motivation of students with medium mathematical comprehension is significantly higher than students with low mathematical comprehension (L2 > L3) (all $p < 0.001$).

To answer research question RQ-3, zero-order correlation was conducted. The relationship between emotional reactions and learning motivation on mathematical comprehension is reported in Table 7. In Table 7, for students with high mathematical comprehension, the correlation coefficient

between emotional reactions and mathematical comprehension (r = 0.64, p < 0.001) is higher than between learning motivation and mathematical comprehension (r = 0.51, p < 0.001). In students with moderate mathematical comprehension, the correlation coefficient between emotional reactions and mathematical comprehension (r = 0.47, p < 0.001) is higher than the correlation coefficient between learning motivation and mathematical comprehension (r = 0.34, p < 0.001. For students with low mathematical comprehension, the correlation coefficient between emotional reactions and mathematical comprehension (r = 0.39, p < 0.001) is higher than the correlation coefficient between learning motivation and mathematical comprehension (r = 0.28, p < 0.001).

Table 7. Correlation among variables for high-, medium-, and low-mathematical comprehension

Variables	High-mathematical comprehension					Medium-mathematical comprehension					Low-mathematical comprehension				
	ER	LM	MC	SES	Gender	ER	LM	MC	SES	Gender	ER	LM	MC	SES	Gender
ER	-	0.58[c]	0.64[c]	0.15[c]	−0.02	-	0.50[c]	0.57[c]	0.35[c]	0.01	-	0.41[c]	0.39[c]	0c	0.05
LM		-	0.51[c]	0.19[c]	0.07[c]		-	0.34[c]	0.09[c]	0.02[c]		-	0.28[c]	0.22[c]	0.17[c]
MC			-	0.21[c]	0.04			-	0.01[c]	0.07			-	0.12[c]	0.14
SES				-	−0.03[b]				-	−0.10[b]				-	−0.02[b]
M	3.60	3.70	87.21	0.28	0.68	3.32	3.63	72.59	0.27	0.50	3.75	3.51	64.11	0.67	0.36
SD	1.03	0.92	8.61	0.86	0.46	1.08	1.03	8.54	0.43	0.71	1.10	1.29	5.93	0.25	0.40
Skewness	−0.15	−0.64	−1.03	1.03	−0.47	0.22	−0.37	0.19	1.08	−0.69	0.65	0.24	−0.75	0.53	0.85
Kurtosis	−0.28	0.21	0.04	0.09	−0.38	−0.07	0.62	−1.08	−0.02	−0.44	0.28	−0.51	−0.46	−0.19	−0.10

Note: ER = Emotional Reactions; LM = Learning Motivation; MC= Mathematical comprehension, b, c is corrected model coefficients; $^{b}p < 0.05$, $^{b}p < 0.01$, $^{c}p < 0.001$.

For the correlation between emotional reactions and learning motivation in high group students, the correlation coefficient value is higher than the correlation coefficient between emotional reactions and learning motivation in medium and low group students.

While in medium group students, the correlation coefficient value is higher than the correlation coefficient between emotional reactions and learning motivation in low group students.

Next, the Fisher Z-r test to find the r-confidence interval and the difference between the correlations. The Fisher Z test is useful for testing the difference in correlation between two variables being compared [57, 58]. In this study, the Fisher Z-r test was conducted to investigate significant differences in the correlation pattern between emotional reactions and motivation between students with high, medium, and low mathematical comprehension.

The results showed that emotional reactions and high and medium levels of mathematical comprehension did not have a significant difference in correlation (Z = 0.98, p = 0.586), but there was a significant difference in the correlation of emotional reactions and mathematical comprehension between the high and low groups (Z = 4.98, p = 0.004). In addition, there was a significant difference in the correlation between emotional reactions and mathematical comprehension of the medium and low groups (Z=3.67, p < 0.001).

Furthermore, we report that there is no significant difference in the correlation between motivation and mathematical comprehension of the high and medium groups (Z = 0.84, p = 0.201). However, there is a significant difference in the correlation between motivation and mathematical comprehension of the medium and low groups (Z = 3.56, p = 0.001), and there is a difference in the correlation between the high and low groups (Z = 5.27, p = 0.004).

Research question RQ-4 is answered through the results of statistical tests presented in Table 8. The results of statistical tests reported in Table 8 investigate whether emotional reactions and learning motivation can predict students' mathematical comprehension in mathematics learning assisted by digital comic media among low, medium, and high levels of student comprehension. Table 7 shows the correlation between emotional reactions, learning motivation, and students' mathematical comprehension among three groups (high, medium, and low) after controlling for gender and Single Exponential Smoothing (SES). The regression model explains 7, 3, and 9% of the variance of students' mathematical comprehension in the high, medium, and low groups. Interpreting the statistical results, we report that the parameter estimates as an increase of one standard deviation.

Table 8. The relationship between emotional reactions and learning motivation in students with high, medium, and low mathematical comprehension

Variables	High-mathematical comprehension					Medium-mathematical comprehension					Low-mathematical comprehension				
	B	SE	β	t	p	B	SE	β	t	p	B	SE	β	t	p
Gender	4.12	1.08	0.05	4.69	0.014	4.05	1.81	0.01	3.97	0.000	12.12	1.35	0.19	14.37	0.000
SES	9.05	1.27	0.06	9.32	0.002	6.05	1.29	0.02	8.72	0.000	−7.02	1.09	−0.07	−1.94	0.015
ER	3.74	1.59	0.02	3.45	0.568	3.44	1.25	0.03	3.61	0.002	−1.59	1.74	0.02	−1.32	0.000
LM	4.97	1.37	0.08	4.78	0.004	4.23	1.52	0.04	5.44	0.004	6.38	1.89	0.08	5.56	0.002
Adjusted R^2 (SE)	0.07(45.63)					0.05(40.66)					0.08(31.56)				

Note: ER = Emotional Reactions; LM = Learning Motivation.

For students with high mathematical comprehension, the standardized emotional reaction coefficient is 0.10 after controlling for SES and gender. That is, if emotional reactions increase by one standard deviation, then students' mathematical comprehension achievement will increase by 0.10 standard deviations, followed by learning motivation (β = 0.08, p = 0.004). In addition, the relationship model between emotional reactions and mathematical comprehension of students in the medium group is consistent with the learner model (students) in the high group. That is, after controlling for SES and gender, emotional reactions become the strongest predictor of mathematical comprehension (β = 0.03, p = 0.002), followed by learning motivation (β = 0.04, p = 0.004). However, the relationship

model for students with low mathematical comprehension is different from students with high and medium mathematical comprehension (see Table 8 in the appendix). Specifically, learning motivation becomes the strongest predictor for students with low mathematical comprehension (β = 0.02, p = 0.000), followed by emotional reactions (β = 0.08, p = 0.002).

Research question RQ-5 is answered by thematic analysis of student response data answering open-ended questions and observing emotional reactions in student learning experiences using digital comics. The questionnaire instrument (T-2B) includes open-ended questions answered by respondents. Each answer is coded based on the questions answered and the themes that emerge in the responses. The codes used are descriptive labels [59]. The answers that appear indicate that the respondents' answers have similarities in terms of meaning and content. While answers that are not the same are referred to as other answers (See Table 9).

Table 9. Students' response in answering open questions

No.	Questions and Answers
Q-1	***Why do you feel satisfied in learning mathematics with digital comics?***
A-1	I successfully complete math tasks
A-2	I got satisfactory test scores
A-3	I can understand math well
A-4	Other answers (e.g., feeling calm, not anxious, students can focus on learning, etc.)
Q-2	***What makes you feel happy when learning mathematics with digital comics?***
A-1	The comic images are interesting
A-2	The material in the comics is very clear and I understand it
A-3	I study happily without fear and anxiety
A-4	Other answers (e.g., overcoming boredom and saturation, students prefer reading, etc.)
Q-3	***What causes you to experience math anxiety?***
A-1	I was asked to do math problems in front of the class
A-2	I haven't finished my math assignment yet
A-3	I have a math exam
A-4	Other answers (e.g., the teacher was angry, I didn't do my homework, I had trouble comprehension math formulas, etc.).
Q-4	***Why do you feel sad when studying math?***
A-1	I got a bad grade on a math test
A-2	I got yelled at by my teacher for not doing my math homework
A-3	I study math, but I still have trouble comprehension the math material
A-4	Other answers (e.g., I don't have anyone to help me study math, there is a challenging assignment that I can't do, etc.)
Q-5	***When did you have the motivation to learn math?***
A-1	If I find easy math problems
A-2	If I get tutoring from my teacher and friends
A-3	If my teacher provides interesting learning resources, such as math comics, math games, etc.
A-4	Other answers (e.g., when I get good grades, there are no difficult assignments, etc.)
Q-6	***How is your experience learning mathematics with digital comic media?***
A-1	This comic helps me understand mathematical concepts more clearly
A-2	The comic images and illustrations are interesting and relevant to mathematics lessons
A-3	Learning activities with comics are fun and full of joy
A-4	Other answers (e.g., the characters are funny, the characters and characters in the comic are very similar to me, etc.)

Table 10. Students' learning experiences and emotional reactions

Code	Learning Experience	Emotional Reaction	Positive Emotions	Negative Emotions
S-F1 S-M1	Students learn mathematics related to the outside world through digital comics	Smiling facial expression, Relaxed body language, Cheerful and pleasant tone of voice, Mouth open: eyes wide, surprised, and showing joy and happiness beyond expectations.	√	-
S-M1	Comic characters and characters help understand mathematics material	Eyes staring intensely: showing attention, smiling and laughing	√	-
S-M2 S-F1	Students view mathematics as a fun activity	Corners of the mouth raised: showing feelings of happiness, pleasure	√	-
S-F4 S-M1	There is support and motivation to learn from teachers and fellow students	Lips spread: showing motivation or even passion and satisfaction	√	-
S-F2	Students face complex mathematics tasks	Lip biting: a sign of anxiety, bowed head	-	√
S-F3	Students achieve poor mathematics learning outcomes	Corners of the mouth pulled down: conveying sadness, writing a diary	-	√
S-F3 S-M1	Students do not understand the purpose of learning mathematics	Blinking rapidly: Feeling stressed or uncomfortable and frustrated	-	√
S-F4 S-M3	Students face difficult situations and do not find solutions	Shaking their head and mumbling angry	-	√

The learning experiences and emotional reactions of students when participating in mathematics learning assisted by digital comics and when students complete mathematics assignments have been observed and recorded in Table 10. The emotional reactions observed were in the form of changes in behavior, facial expressions, and body movements as a form of expression of positive or negative emotions.

V. Discussion

The mathematical comprehension test results are divided into three groups based on the area (probability) of the normal distribution value. The high mathematical comprehension group is in the range ($\overline{x}+1\sigma <$ score) of 20 students. The medium mathematical comprehension group is in the range ($\overline{x}-1\sigma \leq$ score $\leq \overline{x}+1\sigma$) of 62 students. The low mathematical comprehension group is in the range (score < $\overline{x}+1\sigma$) of 18 students.

In learning mathematics, emotions play a major role in achieving learning success [60]. As experts in previous studies revealed, students' attitudes and emotions are reflected in their mathematics learning experiences [61, 62]. Positive emotions emerge when students (Table 10: S-F1 and S-M1) feel that mathematics learning can be connected to new learning experiences through digital comic media, and students feel satisfied with their learning achievements.

This study reported significant differences in emotional reactions among students with high, medium, and low levels

of mathematical comprehension in digital comic-assisted mathematics learning (see Table 6). However, the effect of emotional reactions on low-group students did not significantly predict mathematical comprehension abilities. However, learning motivation remains a strong predictor of their mathematical comprehension abilities.

The difference in emotional reactions between students' mathematical comprehension (in the high, medium, and low groups) is due to differences in learning readiness and differences in perception between students. Students in the high and medium mathematical comprehension groups are more ready to learn than students in the low group. Students in the high group have good initial abilities about angle material and positive perceptions to support their learning process so that students understand the material in digital comics faster.

Students' perception of feedback in the form of positive emotional reactions helps increase learning motivation [63]. Students with low mathematical understanding may receive feedback from less positive emotional reactions from others (teachers and peers), which can lead to lower motivation [64]. Students with low mathematical understanding receive more learning experiences in the form of negative feedback than those with high and medium mathematical understanding.

This study also revealed significant differences in learning motivation among students with high, medium, and low levels of mathematical understanding in mathematics learning assisted by digital comics. Different motivations in each learner can affect the achievement of their learning goals. Differences in motivation for each student are due to various factors. In the low mathematical understanding group, students are more influenced by pleasure and interest in digital comic media. Meanwhile, the motivation of students in the high and medium mathematical understanding groups is influenced by students' emotions and aspirations to succeed in learning. The different relationship patterns between motivation and mathematical understanding of these different achievement groups directly compare variations in these groups [25] as a meta-analysis study conducted by Kriegbaum *et al.* [65] showed that there is a positive correlation between motivation and students' academic achievement in school.

Zero-order correlation analysis showed that emotional reactions and learning motivation were positively correlated with mathematical comprehension among students in the high, medium, and low groups. The Fisher Z-r test revealed that the pattern of the relationship between motivation and mathematical comprehension was not the same among the three groups. The different relationships between motivation and mathematical comprehension in the three groups were reflected in the correlation coefficient.

Relationship patterns for learners (students) where students' emotional reactions to digital comic-assisted mathematics learning predict students' mathematical comprehension in high and medium groups. However, the relationship model of low-group students' mathematical comprehension differs from that of high and medium-achievers. Specifically, learning motivation is the strongest predictor of low-group students' mathematical comprehension, but emotional reactions do not predict low-group students' mathematical comprehension.

In general, students experience learning difficulties due to emotional factors and learning motivation. When emotions are unstable, the impact of the learning process is less than optimal because students feel less motivated, which hinders their comprehension of mathematics learning materials [61]. In Table 10, there is a learning experience when students experience anxiety (negative emotions) in lessons; it will encourage the motive for the emergence of the behaviour of not daring to ask (lowering their heads) when getting math assignments [66, 67]. On the other hand, students who feel satisfaction (positive emotions) and feel appreciated by their peers and teachers will be enthusiastic about completing their assignments. So, it can be stated that emotions will provide energy or strengthen motivation, which will affect student learning achievement [68].

This study also reported that students' experiences of learning mathematics with the help of digital comics affected students' emotions over time. Successful performance in mathematics increased students' positive emotions and decreased their negative emotions over the years. On the other hand, digital technology (computers) has been utilized by teachers to visualize abstract concepts in mathematics into concrete ones.

Based on the thematic analysis of the data in Tables 9 and 10 of open-ended questions, it can be described that students get meaningful experiences when learning mathematics with the help of digital comic media. The use of digital comics in mathematics learning impacts students' psychology. One psychological impact is an emotional reaction, which suggests that digital comics can build positive perceptions namely overcoming students' boredom and saturation in learning mathematics so that learning mathematics becomes fun without pressure [69, 70]. Regarding motivation, it can be reported that digital comics can help increase students' learning motivation and interest in learning [71]. In terms of learning aspects, comic media can make it easier for educators to convey material to students and help improve the quality of mathematics learning [14].

The results of the data analysis in Tables 4, 7, and 10 can be assumed that students' mathematical comprehension is related to students' learning experiences, namely positive emotions in the form of satisfaction and pleasure. The presence of fun learning media, namely digital comics, creates positive emotions to focus students' attention and reduce anxiety [3]. The decrease in mathematical anxiety when learning with comic media impacts the growth of students' learning motivation [4], which ultimately affects mathematical comprehension.

Mathematics learning assisted by digital comics can help students become emotionally involved through the characters in the comics and create fun and cheerful learning activities [72]. Digital comics facilitate comprehension of mathematical concepts more clearly, strengthen memory, increase student interest, and positively influence learning motivation [73]. Previous studies [74, 75] stated that digital comics can improve students' comprehension of lesson content and increase students' desire to explore and improve critical thinking skills. Summarizing from the discussion of this study, the role of digital comic media in mathematics learning is to focus attention and become good cognitive control for students while learning.

This study reveals empirical evidence of unique patterns of

relationships between emotional reactions and motivation among students with different mathematical comprehensions. The results of this study are very important for teachers to intervene through the implementation of differentiated learning. For example, by emphasizing the specific motivational needs of different students, targeted motivational interventions can be carried out for students with low levels of mathematical comprehension to build positive emotions and improve their learning achievement.

VI. Conclusion

This study concluded that there were significant differences in emotional reactions and learning motivation between high-, medium-, and low-level students' mathematical comprehension of mathematics learning assisted by digital comic media. Zero-order correlation analysis showed that emotional reactions and learning motivation were positively correlated with mathematical comprehension among students in the high, medium, and low groups. The relationship model of emotional reactions in mathematics learning assisted by digital comics predicted students' mathematical comprehension abilities in the high and medium groups. However, the relationship model of students' mathematical comprehension in the low group differed from the high and medium groups. Specifically, learning motivation became the strongest predictor of students' mathematical comprehension in the low group, but emotional reactions did not predict students' mathematical comprehension abilities in the low group. The role of digital comic media in mathematics learning is to build positive emotional reactions, focus attention, visualize abstract concepts in mathematics into concrete concepts, and become good cognitive control for students while learning.

This study has several limitations, including (a) The number of participants in this study was limited to 4 junior high schools and may not represent all high school students in a broad scope; (b) This study is limited to one-shot case study research so that there is a lack of a stronger experimental design with a comparison of pre-and post-testing and has not involved a control group; (c) The phrase "students with low mathematical comprehension" in this study is not as passive learners, but only for the purpose of revealing more specific and appropriate strategies when helping different students. Future research should involve more samples to increase its generalization and researchers can develop digital comic media on other mathematical materials that are more interactive and fun for students.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Imam Kusmaryono contributed to the research concept and design, data analysis, interpretation of research results, and final approval. Hevy Risqi Maharani conducted data analysis, interpretation, critical revision of the manuscript, manuscript grammar, and supervision. All authors had approved the final version.

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