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AN ANALYSIS OF PROSPECTIVE MATHEMATICS TEACHERS' KNOWLEDGE ABOUT ZENO'S PARADOX OF MOTION

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ABSTRACT

Paradoxes are catalysts for innovation or new findings in mathematics. One of them comes from Zeno's thoughts, namely Zeno's paradox. Zeno's paradox of motion remains relatively unknown among students. This study aims to describe Zeno's paradox of motion to readers and explore the extent of knowledge of prospective mathematics teacher students about Zeno's paradox of motion. This qualitative study employs a literature review and case study approach, while the instrument used is an open-ended interview. The literature review was conducted by reviewing articles to find out the paradox of Zeno's motion. Case studies were conducted by interviewing ten 2023 students as research subjects, taken randomly from five available classes in the mathematics education study program. The literature review provided a foundational understanding of the paradox, and the case studies offered empirical insights into its cognitive implications within a specific educational context. The data analysis used was thematic. This study reveals that there are 2 categories of student knowledge about Zeno's paradox of motion, including *1) Unknown of Zeno Motion Paradoxes, and 2) Known of Zeno Motion Paradoxes.* This underscores the importance of incorporating historical mathematical paradoxes into teacher training to enrich students' understanding of mathematical evolution and critical thinking.

Keywords: *Paradox, Zeno, Motion, Mathematics Teacher, Case Study*

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INTRODUCTION

The process of deep abstraction often reveals paradoxes or logical fallacies (Nasution, 1984). Mathematical paradoxes have presented a new perspective in the study of mathematics, by shifting the focus from the calculation process to an in-depth analysis of the process of forming solutions to various mathematical situations (Adi Wibawa, 2015; Umar, 2009). Zeno was the first philosopher to make mathematicians think more deeply about space and time with paradoxes (Boe, 2023). Zeno's paradox of motion such as Achilles and the tortoise, the dichotomy, the arrow, and the stadium have been a springboard for the development of philosophy and mathematics, especially in understanding concepts such as continuity and infinity (Gultom, 2014; Setiawan et al., 2008).

In his youth, Zeno of Elea developed a series of paradoxes aimed at justifying the philosophy of his teacher, Parmenides, who rejected the existence of change and motion (Mustansyir, 2007; Silagadze, 2005). Through the dichotomy paradox, Zeno attempted to show that the concept of motion is contrary to logic (Nasution, 1984; Srinivasan, 2019). Zeno also considered the concept of infinity too abstract and difficult to explain logically, so he rejected

it by using the paradox of the race between Achilles and the tortoise as a proof of infinity (Prabowo, 2009). In addition, Zeno also developed the arrow paradox and the stadium paradox (Boe, 2023; Kay, 2019).

It is important for students to know Zeno's paradox of motion which has a great influence on science, especially in the field of mathematics (Hrp et al., 2024). Zeno's paradox of motion remains relevant for understanding the evolution of modern mathematical concepts (Wahyu & Mahfudy, 2016). By understanding Zeno's paradox of motion, students can better appreciate the importance of mathematics (Adi Wibawa, 2015; Susilo & Agustin, 2015). Zeno's paradox of motion also sharpens thinking skills by questioning basic assumptions about space, time, and motion (Naharuddin, 2024; Nurgiansah, 2020).

In reality, there are still many students who do not know the paradox of Zeno's motion. The history of mathematics, especially those that discuss the paradox of Zeno's motion, tends to sound foreign among prospective mathematics teacher students (Asril et al., 2023). In fact, the paradox of Zeno's motion can be a powerful tool to arouse the awareness of prospective mathematics teachers in conveying complex ideas (Jayantini et al., 2020). Given the importance of knowing the history of Zeno's paradox of motion, this research is expected to open new insights by presenting paradoxes related to the concept of motion from Zeno.

Referring to previous research by (Stefanov, 2013) which aims to suggest a new view in the form of a solution regarding the paradoxical nature of Zeno's motion. The research produced a formal solution by drawing philosophical attention to the way humans have motion phenomena as a result of space-time perception. This research leads to three famous paradoxes by Zeno, namely "Achilles and the Tortoise", "Dichotomy", and "The Arrow". Referring also to research (Sabirin, 2016) which aims to discuss the history of the concept of infinity and examples of application in the computer field. The study found that Zeno's four paradoxes of motion became one of the thoughts on the concept of infinity. Furthermore, the study also produced some thoughts from other scientists and the application of infinity in computers.

In contrast to research by (Stefanov, 2013) which focuses on providing a new view of Zeno's paradox of motion and research by (Sabirin, 2016) which focuses on the history and application of infinity with Zeno's paradox of motion as one of the concept references, while the current researcher will describe the four paradoxes of Zeno's motion and analyze the knowledge of prospective mathematics teacher students in the 2023 entry year at Padang State University.

In fact, students tend to prefer practical learning over theoretical ones (Efendi et al., 2021). Given the significance of Zeno's contribution, further studies need to be conducted to introduce Zeno's paradox of motion among prospective mathematics teachers (Adi Wibawa, 2015; Naharuddin, 2024). In-depth research on Zeno's paradox of motion will not only enrich the reader's understanding of the history of mathematics, but can also inspire new research. Therefore, the researcher aims to describe Zeno's paradox of motion and explore the extent of prospective mathematics teachers' knowledge of Zeno's paradox of motion.

METHOD

This research adopted a qualitative approach by combining literature review and case study methods. The data obtained is descriptive and non-numerical. The literature collection process is carried out by reading, critically analyzing, and evaluating various scientific publications relevant to the research topic (Hadi & Afandi, 2021; Ridwan et al., 2021). Case study is a research method that intensively analyzes one specific case to reveal the reality underlying the phenomenon that occurs (Assyakurrohim et al., 2022).

This research adopted a basic qualitative research design, aiming to explore and describe the understanding of Zeno's paradox of motion among prospective mathematics teacher

students at Padang State University. Within this broader qualitative framework, case studies were conducted to provide focused and detailed insights into the knowledge of ten selected students. The use of case studies, informed by semi-structured interviews, allowed for a rich examination of individual perspectives, complemented by a literature review that provided the necessary theoretical and historical context for the phenomenon under investigation. This approach facilitated a nuanced understanding of the students' current knowledge and potential misconceptions regarding Zeno's paradox.

The literature review establishes a comprehensive understanding of Zeno's paradoxes. It outlines the various formulations of the paradox, their historical context, philosophical implications, and mathematical interpretations. This provides a baseline against which to compare the students' understanding. The literature review also details the significance and relevance of Zeno's paradox in the history and development of mathematics. This provides context for understanding the importance of whether or not the students have heard of it. It also helps to develop a standard for what constitutes "hearing" or "knowing" about the paradox.

The case studies explore the students' actual understanding of the paradoxes. This goes beyond simple familiarity, delving into the nuances of their comprehension, revealing potential misconceptions, and providing insights into their cognitive processes when grappling with abstract mathematical concepts. The case studies directly gather empirical data on the students' familiarity with the paradox, revealing the extent to which this concept has reached them.

In this qualitative research, the data is in the form of interview results of 10 students in the entry year 2023 as research subjects taken randomly from five available classes in the mathematics education study program at Padang State University. The research aims to understand the "extent of knowledge" and "how" students understand Zeno's paradox. This requires a deep dive into individual cognitive processes and interpretations, which is best achieved through in-depth interviews and qualitative data collection. Open-ended interviews were chosen as the main instrument in this research to obtain accurate and relevant data.

Case studies allow researchers to delve into the students' reasoning, thought processes, and potential misconceptions. Case studies provide detailed data from a small group, revealing insights beyond typical surveys. Random sampling removes the researchers' subjective judgment in participant selection, minimizing the potential for bias to influence the study's findings. By randomly selecting from multiple classes, the researcher is more likely to recieve different answers, and therefore get a better grasp of the overall student body's knowledge.

This research uses data obtained from various written sources. Scientific journals, books, and other online sources about Zeno's paradox of motion became references in collecting data for this study. By synthesizing information from various sources and references, the author forms a framework of understanding that is innovative and leads to original discussions and discoveries. This research relies on secondary sources as data sources. Secondary sources provide information or references that are indirect to the researcher, serving as a foundation for analysis. The scope of secondary sources in this research includes biographical books of mathematicians, journal articles, and historical documents that specifically discuss Zeno's Paradox, as well as other aspects related to the research topic.

In selecting data sources, the author is guided by four main categories, namely: (1) Credibility, which measures the level of trust in the author and the validity of the research underlying the data in the book or journal; (2) Transferability, which assesses the suitability of the data with other sources in similar contexts; (3) Dependability, which ensures the essential consistency of the data presented; and (4) Confirmability, which ensures the objectivity of the data through agreement between subjects (Mahanum, 2021; Maskar & Dewi, 2020).

Analysis was carried out after collecting data from various sources and interview results by researchers. Data was collected through structured interviews. This structured approach was

chosen to ensure consistency in data collection and facilitate direct comparison of responses across the ten participants. The responses were then analyzed through a thematic analysis approach. Thematic analysis method is used to identify, analyze, and present themes or patterns contained in the data (Sitasari, 2022). Thematic data analysis was carried out by deconstructing raw data, grouping data by category, and drawing conclusions to answer research questions. Naming the categories of interview results refers to research by (Harisman et al., 2023).

The research questions posed to the research subjects were as follows:

1. Have you ever heard of Zeno's paradox of motion?
2. Do you know what are the paradoxes of Zeno's motion?

RESULT

Zeno's Paradox of Motion

Zeno's paradox has been a mystery that has puzzled philosophers for more than 2000 years (Thomson, 1985). As a disciple of Parmenides, Zeno developed paradoxical arguments to show that the notions of motion, change, and the multiplicity of things in the world are merely illusions that mask a single, eternal reality (Silagadze, 2005). Zeno argues that the notions of change and movement themselves contain unsolvable contradictions, proving that change and movement are mere illusions (Mulyono, 2014).

Zeno's four paradoxes imply the impossibility of motion and have been the subject of intense study by philosophers throughout history, including Aristotle, Hegel, and Russell (Groarke, 1982). Although Zeno proposed four paradoxes of motion, the paradox of the race of Achilles and the tortoise is the most frequently discussed and studied (Sabirin, 2016). At the heart of the history of Zeno's paradoxes is a long debate over fundamental philosophical and mathematical concepts, particularly regarding continuity and infinity (Baş, 2005). Zeno sought to demonstrate that the human perception of motion is not real, but rather an illusion that appears in the mind (Stefanov, 2013).

When exploring Zeno's paradoxes and their implications for time, space, and motion, there are concepts such as infinity and infinitesimals, which have been central to the evolution of calculus. The history of calculus shows the development of this understanding, especially about limits. The Dichotomy paradox, involving an infinite series, illustrates the difficulty of conceptualizing infinity (Baş, 2005).

The Achilles and the Turtle Paradox

In Greek mythology, there is a paradox involving Achilles, a legendary war hero (Mulyono, 2014). The paradox tells the story of a race in which Achilles, no matter how fast he ran, was unable to overtake a tortoise that started the race first (Kay, 2019; Sabirin, 2016). By the time Achilles reached the point where the tortoise started, the tortoise was already slightly ahead (Thomson, 1985). Achilles then runs again to the turtle's new point, but by then the turtle has already taken another step (Feng, 2023; Gunawan, 2020).

This process repeats over and over again, and Achilles can never overtake the tortoise (Misselbrook, 2015). The claim is that the distance between the two will continue to shrink, but will never become zero (Stefanov, 2013). This paradox defies the common prediction that the faster one will inevitably overtake the slower one (Baş, 2005). Zeno rejected the concept of infinity by using this paradox as his argument (Gunawan, 2017). Figure 1 illustrates the Achilles and the Tortoise paradox.

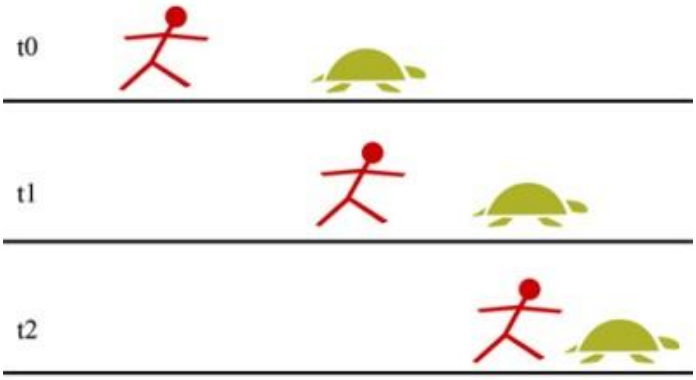

Figure 1. The Achilles and the Tortoise Paradox

The Dichotomy Paradox

The Dichotomy Paradox states that every movement must go through an infinite number of steps (Groarke, 1982; Kay, 2019). A runner will never get to the finish line because he or she must always go through half the remaining distance, creating an endless series of steps (Herberg-Rothe, 2024; Silagadze, 2005; Stefanov, 2013). This paradox suggests that if we continue to divide the distance in half, the runner will be trapped in an endless cycle and will never reach his goal (Baş, 2005; Sabirin, 2016). The concept of infinity proposed by Zeno in this paradox seems to prove that movement is impossible (Groarke, 1982; Srinivasan, 2019). Figure 2 illustrates the Dichotomy paradox.

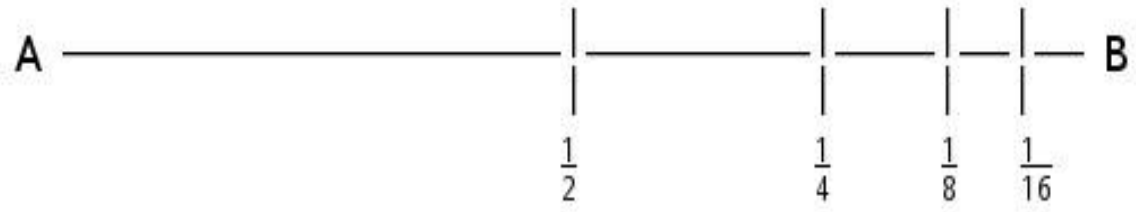

Figure 2. Dichotomy Paradox

The Arrow Paradox

The arrow paradox states that if an object is always in a certain position at every moment, then it is not moving (Herberg-Rothe, 2024; Stefanov, 2013). According to this paradox, time is divided into very small moments, at each moment the arrow will be at one specific point (Kay, 2019; Silagadze, 2005). An arrow in flight occupies only one point in space (Thomson, 1985). This means that the arrow never actually moves (Baş, 2005; Silagadze, 2005). Zeno argues that the arrow is stationary because time consists of an infinite series of moments (Baş, 2005; Thomson, 1985). Therefore, the movement is an illusion (Sabirin, 2016). Figure 3 displays an illustration of the Arrow paradox.

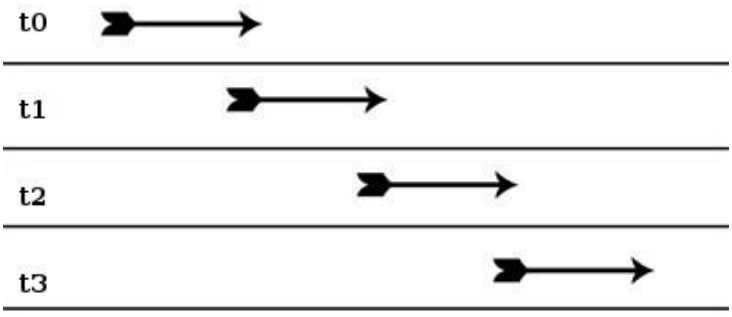

Figure 3. The Arrow Paradox

The Stadium Paradox

This paradox argues that in order to reach a goal, we must first achieve half the distance towards that goal, then half of the remaining distance, and so on (Kay, 2019). Since this process never ends, movement becomes impossible to start (Baş, 2005). As a result, we seem to be trapped in an endless process of division (Thomson, 1985). This paradox points to a fallacy in understanding movement (Kay, 2019).

Imagine three lines of soldiers in a stadium (Sabirin, 2016). Two rows are moving against each other at the same speed, while one row is stationary (Sabirin, 2016). Every time they take a step, the moving soldiers will pass the soldiers in the stationary row and the two soldiers from the opposite moving row (Silagadze, 2005). Surprisingly, the time it takes for a soldier to pass one person is equal to the time it takes to pass two, which is like saying that one equals two, which is clearly absurd (Baş, 2005).

The argument suggests that before an object can move to a point, it must traverse half the distance, then a quarter, and so on, leading to an infinite number of required steps, which makes starting movement logically impossible (Thomson, 1985). In other words, t = 2t, this is impossible (Baş, 2005). Figure 4 illustrates the Stadium paradox.

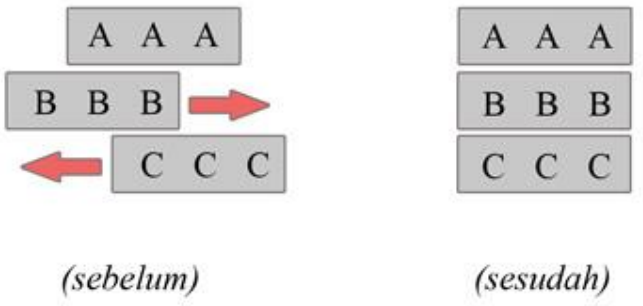

Figure 4. Stadium Paradox

Interview Results of Mathematics Teacher Candidate Students from 5 Classes İn 2023

Stratified random sampling was employed to ensure representation from each of the five available classes within the mathematics education study program at Padang State University. This method involved creating a roster for each of the five classes. Subsequently, two students were randomly selected from each class's roster, resulting in a total sample size of ten participants. This approach was chosen to maintain proportional representation across the different classes and to enhance the likelihood that the sample reflected the diverse perspectives and knowledge levels within the overall student population. By grouping the samples by class, the researcher aims to minimize potential bias and increase the transferability of the findings to a wider group of mathematics education students of class 2023.

Through interviews and observations, the researcher was able to detail each participant's responses to the research questions. From five different classes, a total of 10 students were recruited as participants. This study successfully revealed the level of knowledge of prospective mathematics teachers in:

1. Knowing the paradox of Zeno's motion
2. Knowing what are the paradoxes of Zeno's motion

The interview results from the International class show that student 1 and student 2 do not know the paradoxes of Zeno's motion and what these paradoxes are. The following is one of the interview results.

Researcher: *"Have you ever heard of Zeno's paradox of motion?"*

Student 1: *"Never, because I just found out about Zeno's paradox from this question."*

Researcher: *"Do you know what Zeno's paradox of motion is?"*

Student 1: *"I don't know, but I think this material is quite important to know."*

Based on the interview results from class A, the researcher realized that student 3 and student 4 had just heard of Zeno's paradox of motion for the first time. The following is one of the interview results.

Researcher: *"Have you ever heard of Zeno's paradox of motion?"*

Student 3: *"I never heard of it before."*

Researcher: *"Do you know what are the paradoxes of Zeno's motion?"*

Student 3: *"I don't know about Zeno's motion either."*

The interview results from class B showed that student 5 did not know anything about the paradox of Zeno's motion, while student 6 knew the paradox of Zeno's motion and could mention one of the paradoxes of Zeno's motion. The following is presented the results of the interview with student 6.

Researcher: *"Have you ever heard about Zeno's paradox of motion?"*

Student 6: *"I have."*

Researcher: *"Do you know what Zeno's paradox of motion is?"*

Student 6: *"Paradox comes from Greek which means contradictory opinions. Zeno's paradox is a famous paradox in Greek history and mathematics. The race of Achilles and the tortoise is one of the 8 most famous paradoxes of Zeno."*

Based on the interview results from class C, the researcher saw that student 7 had knowledge of two paradoxes of Zeno's motion, namely arrows and dichotomy. This is inversely proportional to student 8 who did not know about Zeno's paradox of motion at all. The following presents the results of the interview with student 7.

Researcher: *"Have you ever heard about Zeno's paradoxical motion?"*

Student 7: *"I have, I heard it from a group of presenters who were discussing Zeno's paradox of motion."*

Researcher: *"Do you know what Zeno's paradox of motion is?"*

Interviewee: *"A few, namely the arrow paradox and the dichotomy paradox."*

The interview results from class D, the researcher saw that student 9 did not know the paradoxes of Zeno's motion, while student 10 could express specific answers and mention one of the paradoxes of Zeno's motion. The following are the results of the interview with student 10.

Researcher: *"Have you ever heard of Zeno's paradox of motion?"*

Student 10: *"Yes, I have knowledge about the paradox of Zeno's motion."*

Researcher: *"Do you know what are the paradoxes of Zeno's motion?"*

Student 10: *"Zeno's paradox of motion is a series of arguments put forward by the Greek philosopher Zeno of Elea. These arguments aim to challenge the traditional understanding of*

motion and space. Zeno uses a series of postulates that seem logical but lead to unintuitive or paradoxical conclusions, such as: The Argument of Achilles and the Tortoise."

Based on the answers of ten prospective teacher students in the year 2023 from five classes available in the mathematics education study program at Padang State University, the author can make two categorizations regarding their knowledge of the mathematician Zeno's paradox of motion. The categorization of the knowledge of prospective mathematics teachers can be seen in Table 1.

Table 1. Categorization of Mathematics Teacher Candidates' Knowledge of the Zeno Motion Paradox

No.	Categorization	Description
1	Unknown of Zeno Motion Paradoxes	Math teacher candidates who do not recognize and cannot name any paradoxes of Zeno's motion.
2	Known of Zeno Motion Paradoxes	Future teacher students who know the paradox of Zeno's motion.

DISCUSSION

Unknown of Zeno Motion Paradoxes

The researcher's finding based on the results of the interviews that have been conducted is the *Unknown of Zeno Motion Paradoxes* shows that many prospective mathematics teacher students do not know about the Zeno motion paradox. The lack of knowledge about the history of mathematics is an obstacle in developing the quality of mathematics teachers. The history of mathematics, which is not really discussed at the secondary school level, is one of the main factors. In addition, although these paradoxes are crucial to understanding the development of mathematics, they are usually not part of the standard undergraduate mathematics curriculum. Therefore, knowledge of the history of mathematics is important for prospective teachers in order to better understand the roots of thought behind the mathematical concepts to be taught.

This finding is in line with research by (Woei et al., 2021) entitled *"Integration of Word Wall Media Games in History Education"*: history as a boring thing has become a common assumption by most students. This is also supported by research by (Mujyati & Sumiyatun, 2016) entitled *"Construction of History Learning Through Problem Based Learning (PBL)"*: the assumption that history is boring and irrelevant to life is still inherent today.

History is the study of the past to understand the present and design the future (Herdi, 2021). Without historical knowledge, students will lose understanding of the struggles of mathematicians in coming up with their ideas (Printina, 2017). Important events in history have the potential to motivate individuals to develop constructive attitudes towards mathematics (Hardjasaputra, 2019). The teaching of history by educators has great potential to be a catalyst in the development of mathematics (Prayogi et al., 2022).

The condition of students, including their interest in learning, is one of the causes of low interest in the history of mathematics (Almahera et al., 2023). Learning interest is one of the important factors that can increase students' motivation in learning the history of mathematics (Ratnasari, 2017). When students are interested in history, they will be more motivated to learn and understand the thoughts of past mathematical figures (Fatimah et al., 2021). Interest serves as an intrinsic motivation that encourages students to be actively involved in mathematics learning innovation (Friantini & Winata, 2019).

Known of Zeno Motion Paradoxes

The last research finding is *Known of Zeno Motion Paradoxes*, which shows that only three prospective mathematics teacher students know about Zeno's motion paradoxes. This lack of knowledge is due to the lack of literacy interest of prospective mathematics teacher students in the thoughts of historical figures. Therefore, the knowledge of prospective teacher students needs more intensive support with knowledge provision by those closest to them, especially educators. Educators should move beyond rote memorization of formulas and procedures, instead fostering a learning environment that encourages critical thinking and historical inquiry.

This is supported by research (Buchari, 2018) entitled *"The Role of Teachers in Learning Management"*: educators as the spearhead of the educational process have a crucial role in the successful achievement of history learning objectives for prospective mathematics teachers. This statement is also supported by research by (Fimansyah, 2015) entitled *"The Effect of Learning Strategies and Learning Interest on Mathematics Learning Outcomes"*: continuous development of the competence of prospective mathematics teacher students by educators is the key to success in improving the quality of learning history of mathematics.

Research by (Kurniawan & Parnawi, 2023) entitled *"Benefits of Literacy to Improve Education Quality"* suggests that literacy is a very important basic capital for the younger generation in the learning process and facing challenges in the modern era. Literacy skills, especially reading and writing, are a strong foundation in obtaining various information needed to compete in various fields of life (Kharizmi, 2015). With good literacy skills, prospective teachers' understanding of the history of mathematics becomes deeper (Komalasari & Riani, 2023).

Students' low interest in reading also has a negative impact on their cognitive and intellectual development (Paluvi et al., 2023). Low student reading interest goes hand in hand with low frequency of visits to the library (Ilmi et al., 2021). Further efforts from educators are needed to increase students' interest in reading, one of which is by improving library management (Anisa et al., 2021).

CONCLUSION AND SUGGESTIONS

Zeno's paradox, presented by the ancient Greek philosopher Zeno of Elea, demonstrates the apparent impossibility of motion when analyzed through infinite division, as illustrated by paradoxes such as Achilles and the tortoise, the Dichotomy, the Arrow, and the Stadium. This study revealed a significant lack of awareness of these paradoxes among prospective mathematics teachers, highlighting a critical need for intervention. Comprehensively mapping their understanding enables the identification of knowledge gaps and the design of targeted educational programs. A deep understanding of Zeno's paradoxes is important to enrich prospective teachers' insights into the history and philosophy of mathematics, fostering a belief that mathematics is a dynamic and constantly evolving discipline, ultimately influencing their teaching practices and the way mathematical concepts are delivered in the classroom.

In the research results above, the researcher explains the various information that can be obtained about the Zeno motion paradox. The results of research on prospective mathematics teacher students show a variety of answers to knowledge about Zeno's motion paradoxes which are then grouped into two categories, including *1) Unknown of Zeno Motion Paradoxes, and 2) Known of Zeno Motion Paradoxes.* After getting the conclusion of this research, it would be nice if prospective mathematics teachers have an interest in studying history and for further researchers can conduct a deeper analysis of the knowledge of mathematics teachers.

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