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EPISTEMOLOGICAL AND ETHICAL PHILOSOPHY OF MATHEMATICS IN 21ST CENTURY MATHEMATICS LEARNING PRACTICES

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ABSTRACT
21st century mathematics education has made use of science and technology while maintaining the philosophy of mathematics from an ethical and epistemological standpoint. This paper examines the goals of the philosophy of mathematics from an epistemological and ethical perspective. It also investigates the relationship between these perspectives and the practice of studying mathematics in the twenty-first century. This article was written using the Publish or Perish software and a systematic literature review approach. 41 initial articles were found by inputting keywords. Following review, fifteen articles were found to be in agreement. This study reveals that the goal of mathematics philosophy is to understand truth, meaning, certainty, and the nature and sources of mathematical knowledge, as well as how to interpret mathematics, from an epistemological perspective. Analyze and reflect on the ethical implications of mathematical practices. Its epistemological application in 21st century learning practices guides the way concepts are positioned, logical arguments are made, and mathematical problems are solved. Next, ethical considerations include maintaining student privacy, establishing learning agreements in every class, and avoiding creating group distinctions. by utilizing an interactive, student-centered learning paradigm like PBL, inquiry, contextual learning, use of technology, STEM, and others. Such behaviors will subsequently cultivate the values of critical, communicative, creative, and cooperative character. Therefore, we must uphold the fundamentals of learning in the 21st century, both in terms of epistemology and ethics.
Keywords: Epistemology, Ethics, Learning Characteristics, Philosophy of Mathematics, 21st Century Mathematics Learning

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PRELIMINARY

Philosophy comes from two Greek words, namely Philo which means love/desire and Sophia which means wisdom. If put together it becomes (Φιλοσοφια), namely philosophy which means love or wisdom. Literally, philosophy is a science used to understand the nature of existing reality using reason and reason.

Philosophy of mathematics is a branch of philosophy that studies the philosophical assumptions, foundations and influences of mathematics. The philosophy of mathematics provides notes about the nature and methodology of mathematics so that mathematics can be understood. The philosophy of mathematics has its own goal of making decisions and

analyzing events ethically in the practice of learning mathematics. Apart from that, it provides important notes regarding the nature, methodology of mathematics and understanding the role of mathematics in human life (Zulhendri & Jamaris, 2021). Ethically, the philosophy of mathematics is the application of norms, values and moral principles regarding mathematical principles and their use in everyday life (Buchanan et al., 2022). By involving various ethical aspects such as justice, equality, freedom and responsibility related to the mathematical context. Applying different mathematical philosophies has different impacts on educational practice.

The development of mathematics learning in the classroom is in line with the development of science and technology in the 21st century. Where all types of information can be accessed and obtained easily and provide different interpretations for each individual. In 21st century mathematics learning practices in the classroom, the use of technology and information is linked to the application of mathematical concepts in everyday life (David, 2023) by providing teaching instructions (Fadlelmula, 2022). Strengthening this concept cannot be separated from the epistemological foundations of the philosophy of mathematics education.

The philosophy of mathematics education as a field of science provides a clear foundation and direction for mathematics to become a means of thinking in discovering and developing various new knowledge and then communicating the results of this knowledge so that it becomes useful and beneficial (Telaumbanua et al., 2023). With an epistemological basis, it can be mapped the subjective-objective character of mathematical knowledge, its role in a socio-cultural context, the transfer between one knowledge and another, the relationship between the main principles of constructivism, socio-cultural views and didactics (Ernest, 2018).

Apart from the epistemological basis, the ethical perspective in learning must also be taken into account by both teachers and students in learning practices in the 21st century. Ethics in mathematics education takes the form of looking at concern for values, approaches to justice and social equality. Learning mathematics can be a revolutionary activity that causes people to think critically. This criticality does not highlight deficiencies in education such as gender, ethnicity, disability, economic conditions and others (Ernest, 2021).

By adhering to strong philosophical principles in the practice of mathematics learning in the classroom, certain characters will be formed in the practice of mathematics learning in the 21st century. Such as negotiating the ethical challenges of mathematics in

the classroom (Tanswell & Rittberg, 2020; Dubbs, 2020) take a collective approach (Wagner, 2022) and stimulate epistemic thinking in mathematics (David, 2023). Furthermore, to express the epistemological and ethical relevance of the philosophy of mathematics in 21st century learning practices is the focus of renewal in this article.

METHODS

The literature review method used in this research is systematic literature review (SLR), where the selection of reading material is chosen clearly and can be accounted for (Newman & Gough, 2020) to provide evidence, retrieve information and make a plan (Cohen et al., 2008). The SLR steps in this research include:

1. Develop Research Questions

The research questions developed based on the background include: 1) What are the aims of the philosophy of mathematics epistemologically and ethically? 2) How is the philosophy of mathematics related epistemologically and ethically to 21st century learning?

2. Article Selection Criteria

The articles used in this research were selected based on predetermined criteria in the form of a set of inclusion and exclusion criteria so that they correspond to the research statement used, presented in table 1.

Tabel 1. Selection Criteria

No	Criteria	Inclusion	Exclusion
1	Publication Type	The articles used come from journals	Theses, short reports and types of non-empirical studies
2	Journal Specifics	The minimum accredited journal is Sinta 2 and an international journal indexed by Scopus	Unaccredited journals, or journals from Sinta 3-6 and international journals not indexed by Scopus
3	Year of Publication	Articles published from 2019 to 2023	articles published outside the specified time period
4	Language	In English language	Doesn't speak English
5	Fields	Mathematics, Mathematics Education	Not mathematics, Mathematics Education
6	Research Subject	Formal education	Informal education

3. Developing a Search Strategy

The next process in searching for articles is to use existing electronic database sites, including Scopus and Crossef, which are assisted by the Publish or Perish application. The

keywords used to obtain the research database include "epistemological and ethical philosophy of mathematics in 21st century learning".

4. Article Selection Process

After obtaining articles in the search strategy, a review is carried out to see their relevance and compliance with the predetermined selection criteria, if they do not meet the criteria they will be excluded for the next process.

5. Assessing Article Quality

The articles will be analyzed if they comply with the assessment criteria of the questions presented, including: 1) Does the article discuss epistemologies and ethics in the philosophy of mathematics?; 2) Does the article have any relevance to 21st century learning?

6. Synthesis Results

This synthetic analysis was carried out by reviewing all articles obtained from search results for the publish or publish application by entering predetermined keywords. Then the search results are filtered based on existing criteria so that you get something like the image below

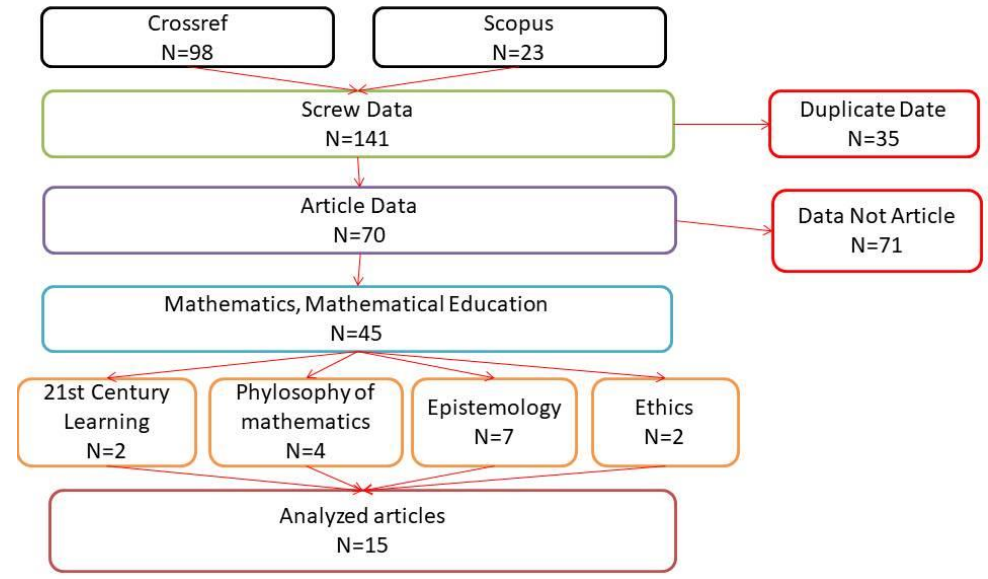


Figure 1. Article Selection Flow

RESULT AND DISCUSSION

Based on search results from Publish or Peris and having gone through various selection criteria, a total of 15 articles were obtained from 2019-2023 with a distribution as in Figure 2.

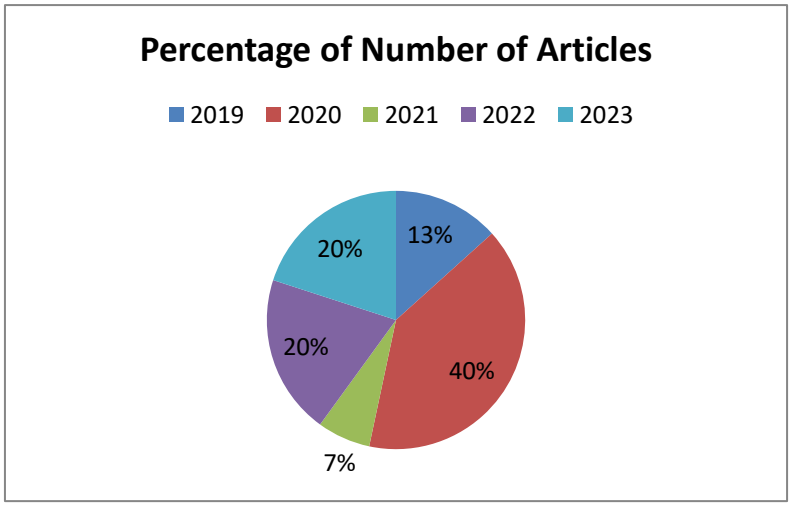


Figure 2. Percentage of Number of Articles

Furthermore, to make the work easier, the articles being analyzed will be given a code as in table 2.

Table 2. Articles Analyzed

Code	Author	Method	Research subject	Country
A1	(Chronaki et al., 2022)	Case study	Multilingual mathematics students and lecturers in Greece, Catalonia, and Sweden	Swedan, Eropa
A2	(Dubbs, 2020)	Literature review	-	United Stated, Amerika
A3	(Guillemette & Radford, 2022)	Literature Analysis	-	Canada, Amerika
A4	(David, 2023)	Literature Analysis	-	Austria, Eropa
A5	(Luecke & Sanders, 2023)	Case Studies, Literature Analysis	D/Lakota Math Connections" at Bull College	United Stated, Amerika
A6	(Tanswell & Rittberg, 2020)	Case Study with a philosophical approach	Mathematics Education Student, Loughborough University	United Kingdom, Eropa
A7	(Wagner, 2022)	qualitative, based on case studies	Math Teachers' Collective of the Popular Education Project and the 2015 student movement in São Paulo, Brazil.	Brazil, Amerika
A8	(Khasawneh et al., 2023)	Survey	Mathematics Teacher in Abudabi	United Arab Emirad, Asia
A9	(Berghofer, 2020)	Study of literature	-	Austria, Eropa
A10	(Buchanan et al., 2022)	qualitative and literature analysis	Lecturer at Australian University	Australia, Australia
A11	(Hußmann et al., 2019)	Experiment	Students Studying Mathematics	German, Eropa
A12	(Haule & Johnson, 2023)	Literature Analysis	-	Tanzania, Afrika
A13	(Uzuriaga López, 2021)	quantitative with a descriptive approach	A group of mathematics teachers at Columbia University who teach	Colombia, Amerika

Code	Author	Method	Research subject	Country
			mathematics courses to engineering and technology students	
A14	(Hamami & Morris, 2020)	case studies and conceptual analysis	-	Belgia, Eropa
A15	(Yan et al., 2020)	Descriptive and analytical approach	Mathematics Education Student, Soochow University	China, Asia

From table 2, it can be seen that the articles have come from representing the continents of the world, of which 40% is the European continent (A1, A4, A6, A9, A11, A14), 33% is the American continent (A2, A3, A5, A7 , A13), 13% Asia (A8, A15) and 7% the Australian Continent (A10) and the African Continent (A12). Next, answering the main question in this article will be explained as follows:

1. Epistemological and Ethical Philosophy of Mathematics

The philosophy of mathematics epistemologically emphasizes the nature and origins of mathematical knowledge obtained and understood (Luecke & Sanders, 2023) truth, meaning, certainty and how to interpret them. The philosophy of mathematics provides important points regarding the nature and methodology that play a role in (Zulhendri & Jamaris, 2021). So, with this basic idea, the role of mathematics in the socio-cultural context, the subjective – objective character of mathematical knowledge, the relationship between mathematics and other knowledge, the relationship between main principles and constructivism and the socio-cultural didactic view will be mapped (Ernest, 2018).

Intellectual development begins from a doubt that is developed critically and is assembled into a commitment to principles and ethics, all of which go through the stages of Dualism, Multiplicity and Relativity (Ernest, 2004). Learning mathematics cannot be separated from the use of mathematical symbols, mathematical formulas and using mathematical logic in solving mathematical problems (Vrhovski, 2022). There are 6 epistemological aspects of mathematical objects, namely form, quality, structure, formula, nature and applicability (Haule & Johnson, 2023), and there are 5 stages in acquiring mathematical knowledge, namely perception, exposition, execution, assimilation and rationalization (Haule & Johnson, 2023). Next, the scope of mathematical epistemology is (Sadewo et al., 2022) shown in Figure 3.

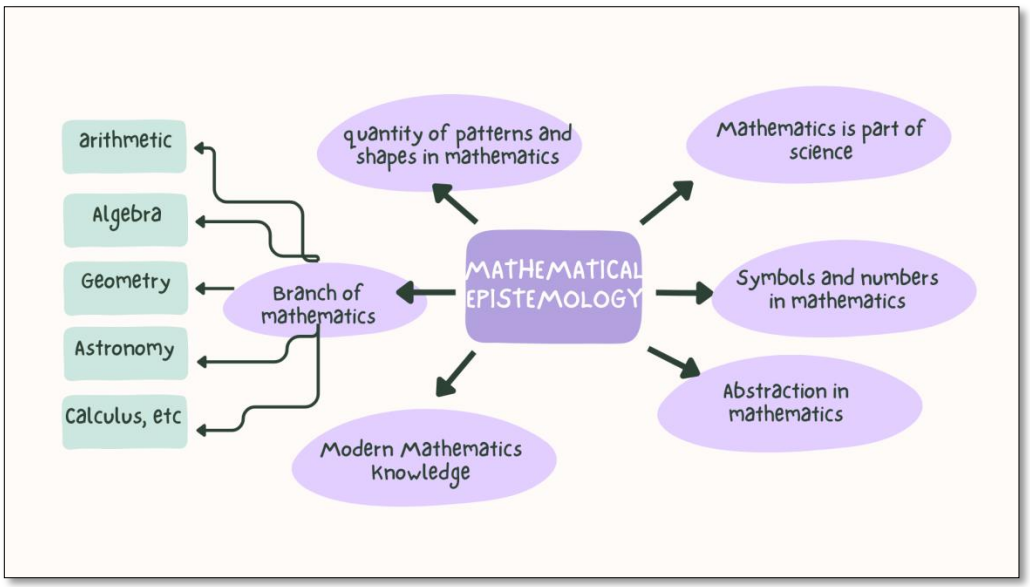


Figure 3. Coverage of Mathematical Epistemology

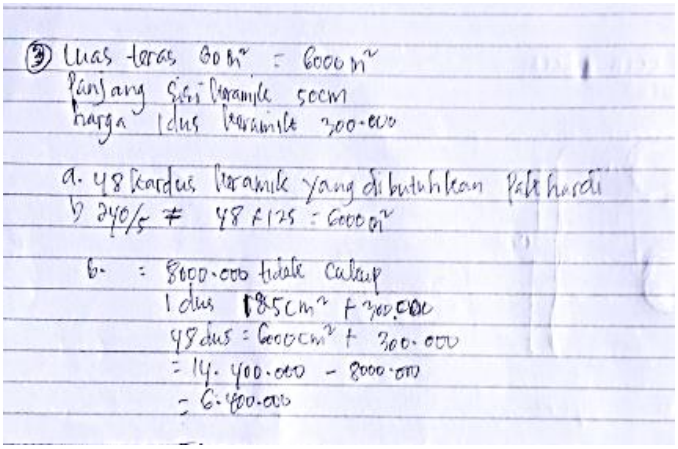
So the epistemological aim of the philosophy of mathematics is to provide an understanding of the mathematical knowledge that is obtained and justified. With an epistemological basis, there is no confusion and uncertainty regarding the concepts of mathematics.

The application of epistemology in mathematics learning involves how students think and learn, as well as interact with agreed values and norms which constitute the ethics that are formed in mathematics learning (Hußmann et al., 2019). The philosophy of mathematics ethically considers and analyzes the ethical implications of mathematical practices (Dubbs, 2020).

The implication of the ethical value of mathematics is based on the impact of broad developments in mathematics in society, such as developments in technology and statistics (Sadewo et al., 2022). One application of ethical values in solving mathematical problems is the selection of appropriate axioms and theorems (Zalukhu et al., 2023) without being forced to use axioms or theorems that are not appropriate to solve the problems presented, this choice must be based on the strong beliefs of a mathematician (Vrhovski, 2022). The philosophy of mathematics ethically upholds justice and responsibility so that it is able to solve social problems and social inequality by involving critical thinking on mathematical principles as the main context (Ernest, 2021). Thus, the aim of ethical philosophy of mathematics is to question the values, norms and moral principles related to the use of mathematics in everyday life.

2. The Epistemological and Ethical Relationship Between Philosophy Of Mathematics In 21st Century Learning

The application of mathematical philosophy in the practice of mathematics learning will train the mind to carry out logic to obtain the best truth by emphasizing educational values both ethically and morally (Khasawneh et al., 2023). Incorporating the philosophy of mathematics curriculum is important in learning practices (Khasawneh et al., 2023; Yan et al., 2020). Because the philosophy of mathematics will emphasize epistemological and ethical issues in resolving problems. The character of solving a given problem is by examining and developing evidence, both formal and informal, that adheres to the concept and selecting the correct empirical method (Hamami & Morris, 2020; Birhane, 2021). For example to answer this question *"Mr. Herdi plans to install ceramic tiles to cover the floor of his 60m² terrace house, and the ceramic tiles used are square with a side of 50cm. The price for 1 box is Rp. 300,000, determine: a. How many boxes of tiles are needed to cover the terrace floor, if 1 box contains 5 tiles?; b. If Mr. Herdi has R8,000,000, are these funds sufficient? If it's not enough, how much additional cost does Mr Herdi need to add?*"



English Version

Terrace area $60m^2 = 6000\ m^2$
Ceramic side length $50\ cm$
Price 1 dus ceramic 300.000

a. 48 ceramic cartridges you need, Mr. Hardy.
$\frac{240}{5} \neq 48 \times 125 = 6000m^2$

b. 8.000.000 Not enough
$1\ dus\ 185\ cm^2 + 300.000$
$48\ dus = 6000cm^2 + 300.000$
$= 14.400.000 - 8.000.000$
$= 6.400.000$

Figure 4. Wrong Answer From Question

From figure 4, The error occurred in line-1 where it should be $60m^2$ =$600.000cm^2$; baris-5 where the solution should be used either formally or informally, but students only carry out mathematical multiplication operations incorrectly and do not comply with the concept of tiling; line-8 where the student incorrectly wrote the amount of money needed where it should be 48 box x Rp.200.000 = Rp. 9.600.000 so that this error has an impact until the actual solution is obtained.

Next, for the relationship between the philosophy of mathematics and learning such as figure 5 (Sadewo et al., 2022)

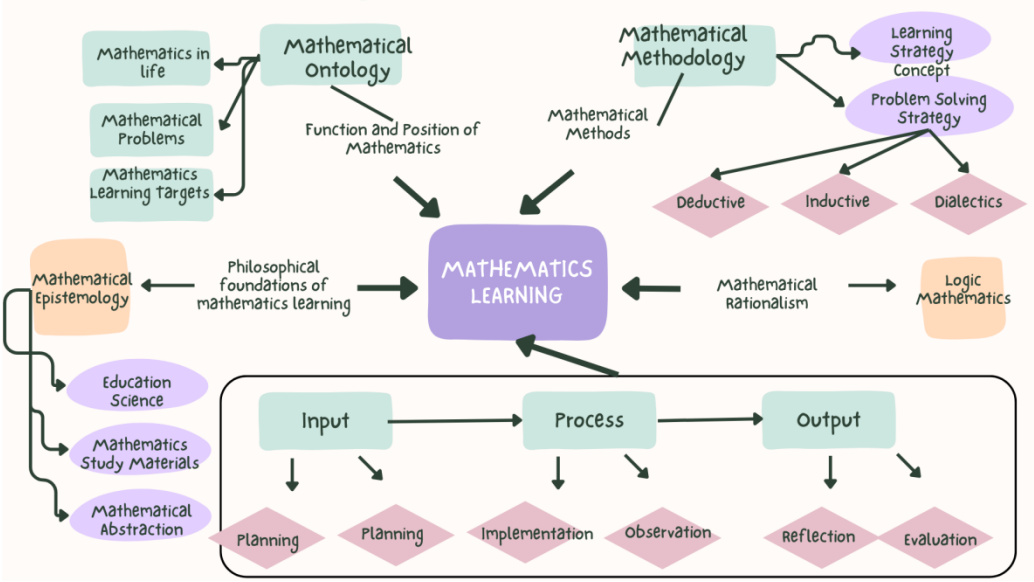


Figure 5. The Relationship Between Mathematical Philosophy and Learning

Figure 5 explains that mathematics learning is supported based on the learning process, mathematical rationalism, mathematical methods, the function and position of mathematics and not forgetting the philosophical foundations of mathematics learning. In the learning method, a plan for delivering material is prepared so that students can evaluate evidence in depth and logically which is obtained independently and in discipline (Beswick & Fraser, 2019).

The learning models that can be used in mathematics learning practice in the 21st century include:

a. Problem-based learning: the use of this model provides students with real situations that require solving problems from mathematics. Where to develop critical thinking skills and mathematical problem solving (Fitria & Zan, 2023).

b. Collaborative learning: using this model students work in groups to complete assigned projects, this model helps students to work with each other in teams and be able to communicate effectively (Luecke & Sanders, 2023).

c. Inquiry-based learning: using this model, students are encouraged to carry out direct exploration and investigation of mathematical concepts themselves, where the teacher is a facilitator in the learning process (Borodzhieva, A 2022).

d. Use of technology: the use of this technology supports the mathematics learning process such as using certain mathematics software, applications or online learning platforms. With the help of this technology, it can support students to understand complex and abstract mathematics (Beswick & Fraser, 2019).

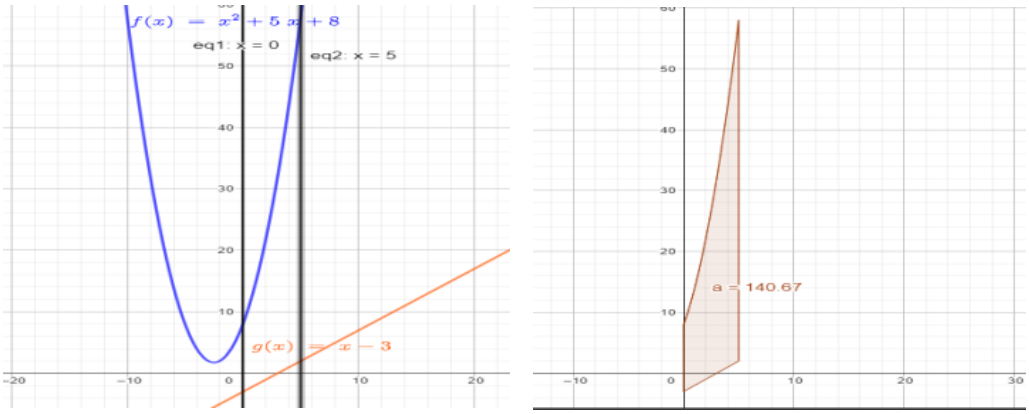


Figure 6. Use of Geogebra

As an example, the figure 6 shows the phase in calculating the area between the function $f(x) = x^2 + 5x + 8$ and the function $g(x) = x - 3$ with the limit $0 \leq x \leq 5$ with the help of geogebra software.

e. Contextual Learning: the use of this model teaches mathematics in a context that is relevant and meaningful for students, which raises problems in everyday life. By constructing, it causes mathematics to become easier to understand and between people to understand more between cultures, which causes an evolution in mathematical thinking with a higher epistemological basis (Hudson, 2019).

f. Inclusive Education: Mathematics education now focuses more on inclusivity, which means providing opportunities for all students, including those who have special needs or are gifted in mathematics (Moura, 2022).

Connecting learning methods with mathematics to social-ecological sustainability issues is one of the challenges teachers face in connecting mathematical concepts with students' very diverse personalities (Abtahi, 2022). In mathematics learning practices,

mathematics education is reflected in a mathematics teacher who teaches in class focusing on norms, values implied in proof, and does not look at the cultural background of the students (Tanswell & Rittberg, 2020). At the beginning of the meeting, the teacher establishes an initial agreement with the students, which is an example of the application of ethics. The application of ethics to learning practices is always changing (Buchanan et al., 2022) in accordance with the learning community environment in the class.

Mathematics learning in the 21st century is to prepare students to have relevant skills and character according to the demands of the 21st century so that they are able to compete in a global society. Where, mathematics learning in the 21st century emphasizes the development of skills in critical thinking and creative thinking (Wagner, 2022), able to communicate and collaborate (Hußmann et al., 2019)(Beswick & Fraser, 2019) well and able to solve problems related to mathematics in life. Apart from that, teachers use various forms of assignments to stimulate students' potential by utilizing existing resources such as the use of technology (Yan et al., 2020).

Apart from that, ethics cannot be expressed directly, but must be practiced for teachers to realize their ability, commitment and confidence to work together. A teacher practices ethics by negotiating based on the norms and values held by students (Tanswell & Rittberg, 2020); Chronaki et al., 2022) does not differentiate between ethnic groups (Buchanan et al., 2022), between rich and poor, between smart and stupid, and how to use technology in teaching and learning activities in the classroom. Teachers must maintain consistency between pedagogical and epistemological beliefs in their actions (Uzuriaga López, 2021). So that teachers will provide different learning practices according to the needs of students in their class (KarataŞ & Yilmaz, 2021; David, 2023; Handican et al., 2023). By applying mathematics based on mathematical philosophy, you will improve your mathematical and language skills (Chronaki et al., 2022; Luecke & Sanders, 2023). This would be a major mathematics education reform focused on absolutism (Davison & Mitchell, 2008).

Thus, the implications of this writing suggest that the mathematics teachers who teach math in the 21st century should provide student-centric mathematical learning by sharpening critical thinking, creativity, communication and the ability to collaborate so that the epistemology of Mathematics can be mastered by students. And not forgetting in practice to pay attention to the ethical values that exist without distinction between race and group where previously established rules agreed jointly. As for the shortcomings of this writing, there are fewer sources of reading in more depth.

CONCLUSION

The epistemological aim of the philosophy of mathematics is to provide an understanding that mathematical knowledge is obtained and justified. With an epistemological basis, there is no confusion and uncertainty regarding the concepts of mathematics. Then the aim of ethical philosophy of mathematics is to question the values, norms and moral principles related to the use of mathematics in everyday life. Adhere to the principles of mathematical philosophy epistemologically and ethically, which emphasizes the truth of a concept, its application in life and ethical values in learning practice. The relationship between philosophy in the practice of 21st century mathematics learning using supportive learning methods such as problem based learning, collaborative learning, inquiry based learning, contextual and the use of technology. These actions lead to students' readiness to face global needs in the 21st century, where these students will have character values including critical, creative, communicative and collaborative. It is recommended that as a teacher who practices mathematics learning in the 21st century, use appropriate learning methods so that students' character values can be formed.

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