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Implementation of Fuzzy Tsukamoto Method in Analyze Science Teacher's Technological Pedagogical Content Knowledge

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Abstract. Improving the quality of teachers is the toughest challenge as well as a strategic effort that must be done to improve the quality of education in Indonesia, especially Aceh. The qualifications of a teacher are determined by the ability of technological pedagogical content knowledge (TPACK). The ability of teachers' TPACK is an important factor that determines the success of improving the quality of education in an area. The purpose of this study was to determine the level of TPACK ability of science teachers in Lhokseumawe City using the fuzzy t.,sukamoto method in evaluating teacher learning. Based on the results of the study, it can be supposed that the Fuzzy Tsukamoto method can be used to determine the level of TPACK ability of science teachers in Lhokseumawe City. Using a random sample of 10 (ten) data records that 5 (five) records have a degree of very good, 4 (four) records have a degree of good and 1 (one) record has a degree of very bad. Teachers in Lhokseumawe City have a very good level of TPACK.
Keywords: TPACK, Science Teachers, Fuzy Tsukamoto

Introduction

The current development of the industrial revolution 4.0 has an impact on the very rapid development of science and technology. All areas of life are directed at the use of digital technology. One of them is in the field of education, entering the industrial revolution, the world of education is required to construct learning that involves technology. (Pérez & Montoya, 2022) explained that education 4.0 is a term used by education experts to describe how to implement technology into learning.

In the era of education 4.0, the education system must face several challenges related to digitalization. Refer to (Haderer & Ciolacu, 2022) the main feature of this era is the use of digital platforms to increase the efficiency of the teaching and learning experience of teachers, students, and administration. Besides that, (Valtonen *et al.*, 2020) added that teachers are required to have the ability to integrate technology into the learning process, such as using computer applications, the web and other ICT learning. There are many benefits of using technology in learning, as described by (Nasution *et al.*, 2020) yaitu, 1) for students to increase attention, concentration, motivation, and independence, 2) for teachers can reduce the use of time for delivering material, make student learning experiences more enjoyable, design material more interesting, and encourage teachers to increase knowledge and abilities about computers. The same is also explained by (Jogezai *et al.*, 2021; Ahmed & Opoku, 2022) Technology has the potential to revolutionize the traditional teaching process, enhance pedagogical abilities through synchronous and asynchronous methods, remove educational barriers such as space and time and improve quality, student engagement, income, and quality of service.

The teacher is one of the determining factors for success in the learning process. The teacher's ability to integrate technology into classroom learning is an integral part of the teacher's pedagogical and professional ability indicators known as *technological pedagogical content knowledge* (TPACK). Refer to (Aqib et al., 2018) Effective learning in this era can be seen from 3 factors namely : technology, content, and pedagogy covered in TPACK. In addition, teacher TPACK competence is one of the most important elements in professional development (Castéra et al., 2020). This competency is based on a combination of technological knowledge, with broad pedagogical expertise and in-depth knowledge of the content/teaching materials (Rossi, 2018). Refer to (Rochintaniawati *et al.*, 2019) TPCK development begins with the use of simple technology that is easy to use for both teachers and students and gradually develops to become increasingly advanced. Thus, the development of teacher TPCK is needed to create a quality learning process so that it can produce quality students in order to improve the quality of education and achieve national education goals (Balcin dan Ergun, 2017).

The tough challenge facing the world of education today is the ability of teachers to design competency development plans based on the TPCK. So far teacher evaluation has only focused on teaching abilities without teacher TPACK evaluations. This is proven based on data obtained from Ministry of Education and Culture of the Republic of Indonesia/ Kemdikbud (2022), It is known that the quality of teacher learning in district/city high schools in Aceh still needs to be improved, because teachers still use repetitive methods in carrying out learning and just to complete assignments. So far, teacher performance assessment in the learning process has only been carried out through teacher learning evaluation activities which are routinely carried out at the end of each teaching semester which aims to obtain information regarding the merits of the learning activities that have been implemented in class. Evaluation of teacher learning should be used as material for reflection for teachers in developing and implementing the TPACK component (Pulungtana & Dwikurnaningsih, 2020). However, it does not show a reflective process of teacher learning outcomes. Therefore, it is necessary to make efforts to find out the ability of TPCK science teachers so that they can continue to be improved so that student learning becomes better in the future (Cacho, 2014).

This study aims to analyze the TPACK ability level of science teachers at public high schools in Lhokseumawe using the Fuzzy Tsukamoto method. Refer to (Nugraha et al., 2019) Fuzzy Tsukamoto method can describe the relationship between input and output which is very accurate and has high precision. This method is used to determine the level of competency and TPACK evaluation of science teachers based on data and facts obtained in the field so that the TPACK abilities of teachers, especially in the city of Lhokseumawe, can be continuously improved.

Methods

The type of research used is descriptive with a quantitative approach which aims to determine the TPACK ability level of science teachers at Public High Schools in the city of Lhokseumawe. The number of samples in this study were 10 teachers (3 boys and 7 girls) with an age range of 27-40 years who were selected by purposive sampling. The selection of the sample was based on the length of experience teaching science and those who were considered to be representative of science teachers who were spread across public high schools in Lhokseumawe City. Data obtained through surveys and observation of teacher learning based on the TPACK component consisting of 34 questions (Schmidt et al., 2009) processed with the Fuzzy Tsukamoto method (Nugraha et al., 2019).

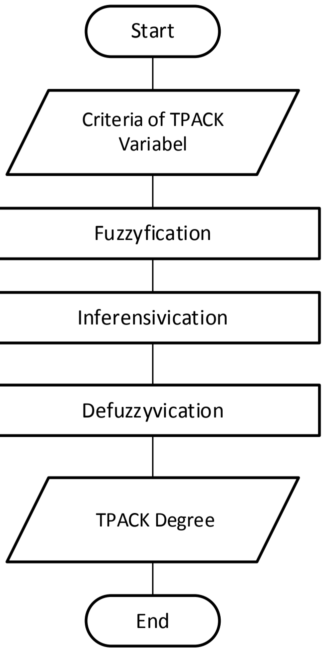


Figure 1. Tsukamoto Fuzzy Process Flowchat

Results and Discussion

Before calculating the fuzzy inference system, the most important thing to do is retrieval of data to be processed through the Tsukamoto fuzzy algorithm. Data were collected through questionnaires distributed to teachers who were the target sample of the research to measure techological content knowledge (TCK), technological pedagogical knowledge (TPK) and pedagogical content knowledge (PCK) scores. The distribution of the data obtained can be seen in the following Table 1.

Tabel 1. Table TCK, TPK and PCK score

No.	Initialization	TCK	TPK	PCK
1.	G1	85	90	90
2.	G2	90	85	90
3.	G3	85	85	85
4.	G4	75	85	85
5.	G5	100	100	100
6.	G6	80	80	80

7.	G7	90	90	90
8.	G8	80	70	75
9.	G9	80	85	90
10.	G10	70	75	70

The first stage carried out in the Tsukamoto fuzzy method is fuzzification where the user inputs scores for each input variable which consists of TCK, TPK and PCK for each member of the set that has been determined. After that, a fuzzyfication calculation is performed on each variable to determine the bad, good, and very good membership values. The range of values for each input variable can be seen in the following Table 2.

Tabel 2. Range of Member Values of Fuzzy Set of Input Variables

Input Variabels	Set Members	Domain/Range Score
K1 – TCK	Bad	0 – 40
	Well	30 – 80
	Very good	70 – 100
K2 – TPK	Bad	0 – 40
	Well	30 – 80
	Very good	70 – 100
K3 – PCK	Bad	0 – 40
	Well	30 – 80
	Very good	70 – 100

Each input variable has a score obtained from research data collection will be identified as TCK/K1, TPK/K2 and PCK/K3. Each score for these variables will be measured the degree of membership in each fuzzy set using the formula (1), (2), (3), (4), (5), (6), (7), (8) and (9).

1. TCK/K1
   a) Bad membership degree

$$\mu Bad\ (x) = \begin{cases} 1\ ; x\ \leq 30 \\ \frac{40-x}{40-30}\ ; 30\ \leq x\ \leq 40 \\ 0\ ; x\ \geq 40 \end{cases} \qquad (1)$$

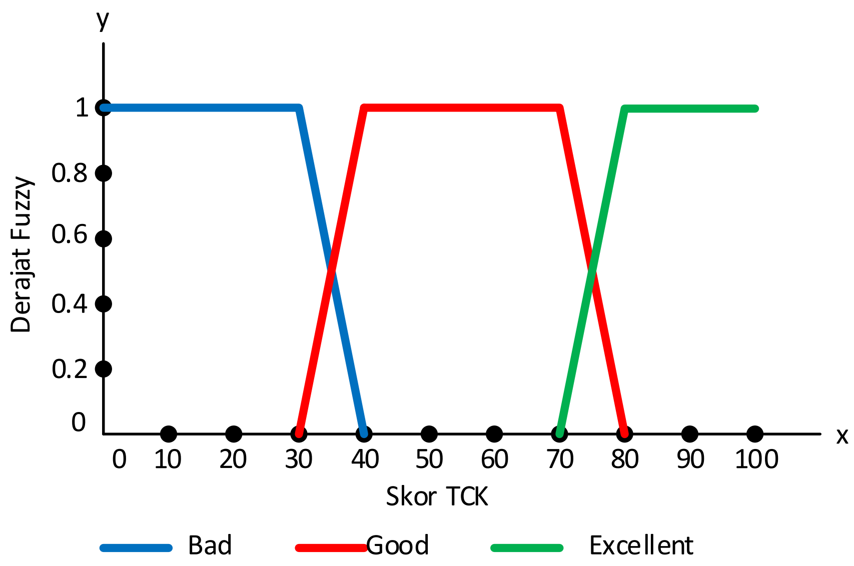
   b) Good membership degree

$$\mu Good\ (x) = \begin{cases} 1\ ; 40\ \leq x\ \leq 70 \\ \frac{40-x}{40-30}\ ; 30\ \leq x\ \leq 40 \\ \frac{80-x}{80-70}\ ; 70\ \leq x\ \leq 80 \\ 0\ ; 30\ \geq x\ \geq 80 \end{cases} \qquad (2)$$

c) Excellent membership degree

$$\mu Excellent\ (x) = \begin{cases} 1\ ; x\ \geq 80 \\ \frac{x-70}{80-70}\ ; 70\ \leq x\ \leq 80 \\ 0\ ; x\ \leq 70 \end{cases} \qquad (3)$$

The output of the fuzzy set membership function with 3 linguistic values, namely bad, good and very good, the calculation is visualized using a shoulder curve as shown in Figures 2, 3 and 4.



Figur 2. Shoulder curve and trapezoid of TCK

2. TPK/K2
   a) Bad membership degree

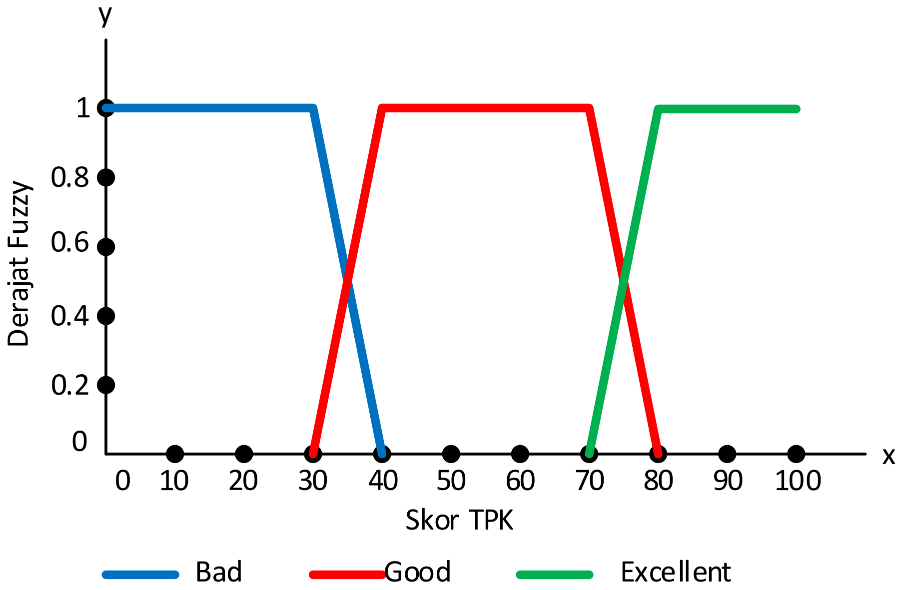
$$\mu Bad\ (x) = \begin{cases} 1\ ; x\ \leq 30 \\ \frac{40-x}{40-30}\ ; 30\ \leq x\ \leq 40 \\ 0\ ; x\ \geq 40 \end{cases} \qquad (4)$$

   b) Good membership degree

$$\mu Good\ (x) = \begin{cases} 1\ ; 40\ \leq x\ \leq 70 \\ \frac{40-x}{40-30}\ ; 30\ \leq x\ \leq 40 \\ \frac{80-x}{80-70} ; 70\ \leq x\ \leq 80 \\ 0\ ; 30\ \geq x\ \geq 80 \end{cases} \quad (5)$$

c) Excellent membership degree

$$\mu Degree\ (x) = \begin{cases} 1\ ; x\ \geq 80 \\ \frac{x-70}{80-70}\ ; 70\ \leq x\ \leq 80 \\ 0\ ; x\ \leq 70 \end{cases} \quad (6)$$



Figur 3. Shoulder curve and trapezoid of TPK

3. PCK/K3
   a) Bad membership degree

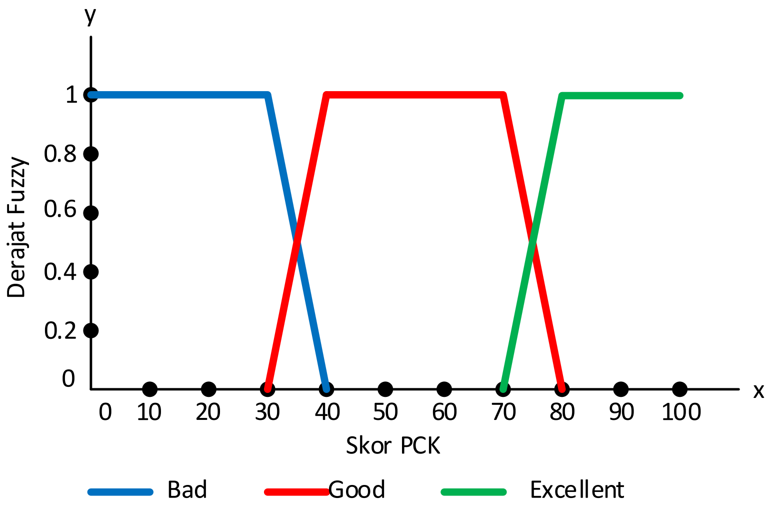
$$\mu Bad\ (x) = \begin{cases} 1\ ; x\ \leq 30 \\ \frac{40-x}{40-30}\ ; 30\ \leq x\ \leq 40 \\ 0\ ; x\ \geq 40 \end{cases} \quad (7)$$

   b) Good membership degree

$$\mu Good\ (x) = \begin{cases} 1\ ; 40\ \leq x\ \leq 70 \\ \frac{40-x}{40-30}\ ; 30\ \leq x\ \leq 40 \\ \frac{80-x}{80-70} ; 70\ \leq x\ \leq 80 \\ 0\ ; 30\ \geq x\ \geq 80 \end{cases} \quad (8)$$

c) Excellent membership degree

$$\mu Excellent\ (x) = \begin{cases} 1\ ; x\ \geq 80 \\ \frac{x-70}{80-70}\ ; 70\ \leq x\ \leq 80 \\ 0\ ; x\ \leq 70 \end{cases} \quad (9)$$



Figur 4. Shoulder curve and trapezoid of PCK

Based on the shoulder curve in Figure 4, it can be seen that the degree of membership of the PCK fuzzy set for the bad predicate is at a score of 0 to 40 as shown by the blue line, then the good predicate is at a score of 30 to 80 as shown by the red line and for the very good predicate at the score above 70 as shown by the green line.

Fuzzy performance output is needed for the purpose of classifying each record or test data that has calculated the degree of membership (Nugraha et al., 2019). The performance output is also the output reference for the variable to be studied, namely TPACK. The range of decision values can be seen in Table 3.

Table 3. Range of Member Values of Fuzzy Set of Decision Variables

Decision	Domain/Range
Grievous	0 – 30
Bad	20 – 40
Sufficient	40 – 60
Good	60 – 80
Excellent	80 – 100

The output of the fuzzy set membership function for the output value uses 5 linguistic values, namely very bad, bad, fair, good and very good. Calculations using formulas (10), (11), (12), (13) dan (14) and visualized using the shoulder curve in Figure 5.

$$\mu Grievous\ (z) = \begin{cases} 1\,; z \ \leq 20 \\ \frac{30-z}{30-20}\,; 20 \ \leq z \ \leq 30 \\ 0\,; z \ \geq 30 \end{cases} \tag{10}$$

$$\mu Bad\ (z) = \begin{cases} 1\,; 30 \ \leq z \ \leq 40 \\ \frac{z-20}{30-20}\,; 20 \ \leq z \ \leq 30 \\ 0\,; 20 \ \geq z \ \geq 40 \end{cases} \tag{11}$$

$$\mu Sufficient\ (z) = \begin{cases} 1\,; 50 \ \leq z \ \leq 60 \\ \frac{z-40}{50-40}\,; 40 \ \leq z \ \leq 50 \\ 0\,; 40 \ \geq z \ \geq 60 \end{cases} \tag{12}$$

$$\mu Good\ (z) = \begin{cases} 1\,; 70 \ \leq z \ \leq 80 \\ \frac{z-60}{70-60}\,; 60 \ \leq z \ \leq 70 \\ 0\,; 60 \ \geq z \ \geq 80 \end{cases} \tag{13}$$

$$\mu Excellent\ (z) = \begin{cases} 1\,; 90 \ \leq z \ \geq 100 \\ \frac{z-80}{90-80}\,; 80 \ < z \ > 90 \\ 0\,; 80 \ < z \end{cases} \tag{14}$$

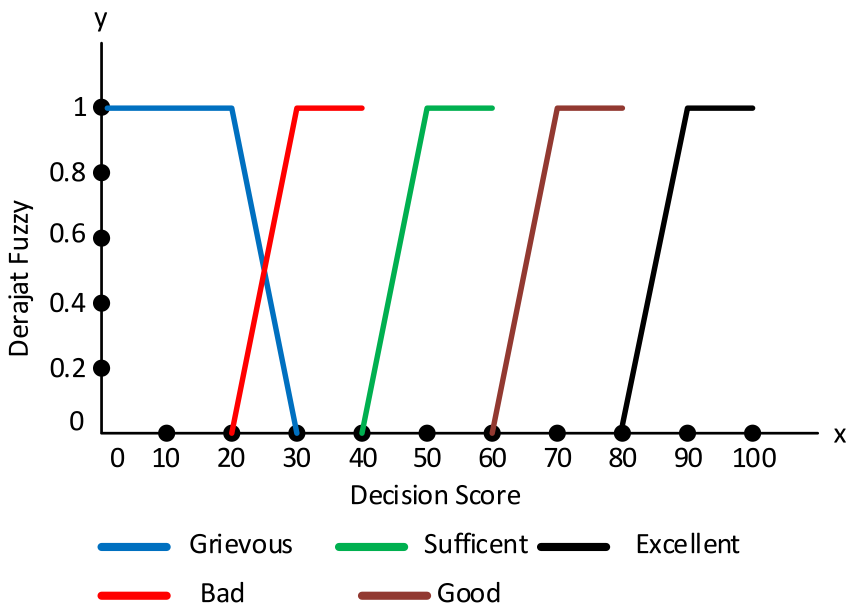


Figure 5. Shoulder curves and decision trapezoids

The inference stage can be done by referring to the rule base table that has been obtained. Then, it is repeated on each rule so that each rule gets a value of predicate. The value of predicate is the minimum value of membership in each rule. The rule base table used in this study can be seen in the following Table 4.

Tabel 4. Rule Based of TPACK Calculation

No	K1	K2	K3	Decision
1	Excellent	Excellent	Excellent	Excellent
2	Excellent	Excellent	Good	Excellent
3	Excellent	Excellent	Grievous	Good
4	Excellent	Good	Excellent	Excellent
5	Excellent	Good	Good	Good
6	Excellent	Good	Grievous	Suffcient
7	Excellent	Grievous	Excellent	Excellent
8	Excellent	Grievous	Good	Good
9	Excellent	Bad	Bad	Bad
10	Good	Excellent	Excellent	Excellent
11	Good	Excellent	Good	Good
12	Good	Excellent	Bad	Sufficient
13	Good	Good	Excellent	Good
14	Good	Good	Good	Good
15	Good	Good	Bad	Sufficient
16	Good	Bad	Excellent	Sufficient
17	Good	Bad	Good	Sufficient
18	Good	Bad	Bad	Bad
19	Bad	Excellent	Excellent	Good
20	Bad	Excellent	Good	Good
21	Bad	Excellent	Bad	Bad
22	Bad	Good	Excellent	Cukup
23	Bad	Good	Good	Good
24	Bad	Good	Bad	Bad
25	Bad	Bad	Excellent	Sufficient
26	Bad	Bad	Good	Bad
27	Bad	Bad	Bad	Grievous

The final stage of the Tsukamoto fuzzi algorithm calculation process is called defuzzification, this stage produces an output value in the form of a crisp value (z). The method used in this process stage is the center average defuzzifier, this method can be written in the form of the following equation.

$$Z = \frac{\sum(a_p * Z_i)}{\sum a_p} \qquad (13)$$

Where : Z : Centralized average defuzification
ap : Predicate alpha value/minimum value of membership degree
Zi : Crisp value obtained from inference results

Tabel 5. Fuzzy Tsukamoto's Decision

No.	Sebutan	Range
1	Very Low	$0 \leq N < 45$
2	Low	$45 \leq N < 56$
3	Sufficient	$56 \leq N < 65$
4	Hight	$65 \leq N < 80$
5	Very Hight	$80 \leq N \leq 100$

After going through these stages, the next stage is testing and calculating the actual data. The score used is obtained from collecting research data and then inputting it into the system that has been built, the results of the calculation can be seen in Table 6.

Table 6. Research Data Calculation Results

No.	Initialization	K1	K2	K3	Fuzzy Tsukamoto Rating	Fuzzy Decision
1	G1	100	100	100	90.00	Excellent
2	G2	80	80	72	86.80	Excellent
3	G3	65	68	64	20.00	Grievous
4	G4	75	72	80	77.00	Good
5	G5	90	84	80	90.00	Excellent
6	G6	72	76	68	67.14	Good
7	G7	100	100	100	90.00	Excellent
8	G8	75	60	80	75.00	Good
9	G9	80	64	64	70.00	Good
10	G10	100	100	100	90.00	Excellent

Based on the calculation results at each step of the process, it can be concluded that the Tsukamoto Fuzzy Method can be used to calculate the degree/performance of teachers in Lhokseumawe City. Using a random sample of 10 (ten) data records, it was found that 5 (five) records had a very good degree, 4 (four) record has a Good degree and 1 (one) record has a very bad degree. Overall it can be said that teachers in Lhokseumawe City have a good TPACK level/performance. Refer to (Wang, 2022) teachers at high TPACK levels show high levels of confidence in their abilities and are beginning to recognize the role of technology in learning. This can be proven based on the results of observations made in several public high schools, science teachers are very enthusiastic about designing lesson plans that are TPACK oriented even though the facilities and infrastructure are still lacking and limited because the use of technology really helps teachers in teaching science material to students. In line with the TPACK assessment by (Baris, 2015; Mouza, 2014) which states the high results of TPACK can be influenced by the implementation of the curriculum. Since the implementation of the independent curriculum in schools, teachers in the city of Lhokseumawe have been very enthusiastic about increasing their competence in designing lessons. This is also in line with (Phillips, 2016) which states that an increase in teacher TPACK can be influenced by teachers' habits in practicing technology in learning. In others side, the high degree of teacher TPACK ability, is also due to routine teacher training activities in the MGMP teacher group, so that these teachers exchange ideas and have understanding about the use of technology or digital media in learning (Chatmaneerungcharoen, 2019). However, due to the lack of supporting infrastructure such as internet and computer connections in some schools, the TPACK oriented teacher learning design is difficult to implement properly.

Conclusion

Based on the results of the teacher's TPACK analysis using the Fuzzy method, it can be concluded that the TPACK ability of science teachers at public high schools in Lhokseumawe City is in a good category. Of the 10 data records, it was found that 5 records had a very good degree, 4 records had a good degree and 1 record had a very bad degree. High school science teachers have started to integrate technology in science learning, through the use of digital platforms recommended in the independent learning curriculum. For further research, it is hoped that teachers' TPACK abilities can continue to be improved and collaborate with teachers of other subjects.

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