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Research Article

Implementation of TPACK-based integrated innovative learning design in linear algebra course

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Abstract

The purpose of this study was to describe the results of implementing an integrated innovative learning design based on Technological, Pedagogical, and Content Knowledges (TPACK) in Linear Algebra courses. This research is an explorative, descriptive research of which analysis is carried out through implementation on students of the Mathematics Education study program at Faculty of Teacher Training and Education University of Mataram who take Linear Algebra course. The study involved 58 students spread across two classes, namely class D, with as many as 31 students, and class E, with as many as 27 students. The research instrument used was a linear algebra problem-solving test. The results showed that the resulting integrated innovative learning design has not been effectively implemented in linear algebra lectures. From the category of ability levels, the characteristics of each can be described, namely subjects in the Very Poor category. Participants understanding is still mechanical, merely applying the methods they remember, and the results are also less precise. Subjects in the Less category can use memorized methods correctly but could not develop other methods or cases. Subjects in the Fair category can try to solve problems with other rules/methods even though neither result is correct. Subjects in the Good category can solve problems with other rules but need more confidence in determining the correct answer. Meanwhile, subjects in the Very Good category can solve problems with complete confidence in determining the correct answer without a doubt. Based on these results, it is hoped that an TPACK-based integrated innovative learning design can be developed even better in the future.

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Introduction

According to the Organization for Economic Cooperation and Development's (OECD) Program for International Some problems in linear algebra lectures were identified through observations during linear algebra lectures and previous studies. Students usually do not encounter difficulties when given calculation or procedural problems, even if the problem is complex, such as the Gram-Schimdt process. However, most students have difficulty solving conceptual problems, even if the problem is not complex, such as proving a simple theorem.

Previous research in college on LA courses has been conducted by Lapp et al. (2010), which results showed that students find it more difficult to make connections between concepts, such as eigenvalues and eigenvectors, from other

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conceptual parts, such as bases and dimensions. Previous research by Arjudin et al. (2019) showed that students' ability to solve linear algebra problems still tends to be low. The lack of problem-solving partly relates to students' incomplete mathematical connection ability. Incomplete connections occur when the connected components are in the form of incorrect concepts/ideas, the connection path can be wrong/inappropriate, or the connection results can be incorrect. It indicates that there are problems in Linear Algebra courses that need to be researched to get a solution so that they can improve students' problem-solving skill, especially in Linear Algebra courses.

Several research have conducted related to problem-solving. For instance, a research conducted by Socas and Hernandez (2013) suggested that problem-solving is considered as an integral part of mathematics and is explained in terms of problem-solving, building relationships between concepts, operations, and processes implicit in mathematical activities. Meanwhile, Carlson and Bloom (2005) produced a multidimensional problem-solving framework with four stages: orientation, planning, execution, and review.

Improving students' thinking skills will certainly be difficult to achieve without being integrated into an innovative learning design. One of the higher-order thinking processes can be formed in a meaningful learning process. Knapp et al. (1995) suggested that the advantages of meaning-oriented learning that have been identified are: (a) expanding the range of mathematical content learned to give the students a sense of the breadth of mathematics and its applications; (b) emphasizing connections between mathematical ideas; (c) exploring mathematics embedded in rich "real life" situations; (d) encouraging students to find multiple solutions and focusing students' attention on the connections between the solution processes used, and (e) creating multiple representations of ideas (e.g., pictures and physical objects).

In the learning system, there are several terms that are components of the learning structure, including learning models, learning approaches, learning strategies, learning methods, and learning techniques. Developing a learning design cannot be separated from these components.

A learning model is a conceptual pattern that describes a systematic procedure drawn from start to finish, typically presented by the teacher in organizing learning experiences to achieve learning objectives (Djalal, 2017). In line with Djalal, Affandi (2011) identified learning models as systematic procedures or patterns used as guidelines for achieving learning objectives in which there are strategies, techniques, methods, materials, media, and learning assessment tools. In addition, Nordyke (2011) stated that learning models are systematic pedagogical practices that improve student learning and are designed to plan teaching and curriculum development. Furthermore, Nurdyansyah and Fahyuni (2016) pointed out that a learning model is a plan or pattern that can be used to form a curriculum (long-term learning plan), design learning materials, and guide learning in other classes.

Learning models are procedures designed with simple to complex strategies to help students acquire information, ideas, skills, values, thinking and express themselves (Joyce & Weil, 2009). The attributes of learning models are a coherent theoretical framework, an orientation towards what students should learn, and specific teaching procedures and structures (Arends, 2012). Learning models are designed based on learning theory (Allphin, 2011). Learning models are characterized by (1) Designed based on educational theory and learning theory from certain experts, (2) has a specific educational mission or purpose, (3) can be used as a guide for improving teaching and learning activities in the classroom, (4) has a sequence of learning steps (syntax), (5) has an impact as a result of the application of the learning model, and (6) makes teaching preparation (instructional design) with the guidelines of the selected learning model (Nurdyansyah & Fahyuni, 2016).

Based on the definitions that have been described, it can be concluded that learning models are learning procedures designed with systematic strategies based on learning theory. Educators design the learning model as a guide for learning in the classroom and can also be used to form or develop a learning curriculum. The learning model is a learning procedure from start to finish, so the learning model is a wrapper or frame for applying a learning approach and strategy (Djalal, 2017). Learning models describe an overall approach or plan for teaching (Arends, 2012).

An approach is defined as a way of beginning something (Subanji, 2013: 4). In this case, the approach can be interpreted as a way to start learning. In a broader sense, approach refers to a set of assumptions about how to learn. An approach is a starting point in looking at something, a philosophy or belief that is not always easy to prove. So, the approach is axiomatic, which means that the truth of the theories used is undisputed.

The learning approach is the foundation for starting and carrying out learning in a field of study/subject and gives direction and style to the learning. Approaches are often interpreted as similar to strategies, where the approach is our starting point or point of view towards the learning process. The benefit of the learning approach is that it serves as a general guideline for the learning steps that will be used.

Thus, the learning approach refers to a set of assumptions about how to learn and is a starting point in looking at learning. The learning approach is more directed to the philosophical foundation of learning.

According to Musfiqon and Nurdyansyah (2015), approach is a basic concept that accommodates, inspires, strengthens, and underlies thoughts about how learning methods are applied based on specific theories. Therefore, many views stated that approach is the same as method, even though both are different. Several methods can in one single approach. For example, in undertaking scientific approach, observation, discussion, expository, and other methods can be applied.

There are various classifications of learning approaches. According to Killen (in Sanjaya, 2009), learning approaches can be classified into teacher-centered and student-centered approaches. Approaches in learning mathematics include the constructivist approach, contextual approach, realistic mathematics approach, open-ended approach, and problem-solving approach (Sutarto & Syarifuddin, 2013: 57). In learning mathematics, in addition to those mentioned, other approaches can also be used such as the inductive-deductive approach, spiral approach, and scientific approach.

According to the Big Indonesian Dictionary (*KBBI*) (2019), a strategy is a careful plan of activities to achieve specific goals. At the same time, the definition of learning is more about efforts to teach the learner, so the learning process is the linking of new knowledge to the cognitive structure the learner already has. These links will form a new and more stable cognitive structure, which can be seen as a learning outcome (Degeng, 2013). Therefore, a learning strategy is a careful or systematic plan for teaching students so that they can form new, more stable cognitive structures.

Likened to a soccer game, of course it is not only the quality of each player that determines the outcome of a match. A strategy is always designed individually as well as a team or group in a soccer match. The goal is clearly to win the match. Strategy is needed to develop the ability to think, improvise, and creativity of soccer players, and players can determine the best alternatives in solving problems in every match (Olahragapedia.com, 2020).

According to Shadiq (2009), learning strategies are chosen to deliver subject matter in a particular teaching environment, including the scope and sequence of activities that can provide learning experiences to students. This opinion is based on the constructivist view that learning strategies emphasize content presentation on meaningful use following the sequence from the whole to the parts. Therefore, learning is more directed to serve the questions or views of the learner, with learning activities based more on primary data and manipulative materials emphasizing critical thinking skills, such as analysing, comparing, generalizing, predicting, and hypothesizing. That is why constructivist learning emphasizes the process.

Within each learning model, several strategies can be used. Strategies determine the approach that teachers can take to achieve learning objectives. Strategies can be classified into 5, namely: 1) direct instruction, 2) indirect instruction, 3) experiential learning, 4) independent study, and 5) interactive learning.

Learning strategies are patterns of action that teachers/lecturers use in various teaching events to achieve instructional goals (Djalal, 2017). Learning strategies are steps that students take to improve their learning (Shi, 2017). Strategy can be interpreted as a general pattern of teacher and student activities in realizing teaching and learning activities to achieve the goals outlined (Aji & Budiyono, 2018). Learning strategies are orientations that teachers give to students to improve learning (Enríquez et al., 2018). From several definitions that have been described, learning strategies are stages or learning procedures. Learning stages or procedures are found in the syntax of the learning model.

Implementing a learning strategy involves five steps (TLL, 2002). First, variables: analyzing the key components of learning, including examining students' backgrounds, abilities, prior knowledge, determining learning objectives, and identifying pedagogical strengths. Second, constraints: identifying resource limitations that may impact the teacher's ability to optimally organize and conduct learning. Third, decisions: making critical decisions about how learning will be organized. Fourth, assessment: collect feedback on student learning and the strengths and weaknesses of the learning. Last, refinements: use feedback to improve learning.

The components described above were developed to form an integrated innovative learning design based on TPACK (Technological, Pedagogical, and Content Knowledge) in the Linear Algebra course. The learning design is said to be innovative because it contains a student-centered learning process and is oriented towards Higher Order Thinking Skills (HOTS). Meanwhile, it is said to be integrated because this design combines components in the learning structure, such as strategies, models, approaches, methods, and learning techniques. The TPACK is used as a reference or base for its development so that the developed learning design also contains and combines elements of technology, pedagogy, and material content.

Problem of Research

Based on the description above, the formulation of the problem in this study is as follows:

The students have difficulty solving conceptual problems even though they are not complex problems like the proving simple theorems in linear algebra courses. In addition, based on the results of previous research, it is known that students also have difficulty making connections between concepts and have linear algebra problem-solving skills that tend to be low. Therefore, it is an indication of a problem that needs to be solved through this research so that it can improve students' thinking skills in problem-solving in linear algebra courses.

Method

Research Method

This type of research is exploratory, descriptive research. The approach used is a qualitative approach since it is in accordance with the characteristics of research. Creswell (2012) stated that research is carried out in the field in a natural environment, not in a situation that is conditioned in advance. Researchers meet face-to-face with respondents/subjects of research in collecting research data.

Participants

The research was conducted at the Faculty of Teacher Training and Education University of Mataram, Indonesia. The research subjects were the Department of Mathematics Education students who took Linear Algebra course. Linear Algebra was chosen because it is a staple course in the mathematics education study program. Linear algebra is one of the primary materials in the National Olympiad of Mathematics and Natural Sciences (ON-MIPA) Higher Education in Mathematics. This Linear Algebra course in the Department of Mathematics Education at University of Mataram is offered in semester III.

The study involved 58 students spread across two classes, namely class D, with as many as 31 students and class E, with 27 students. Regarding gender distribution, the class consisted of 10 male and 48 female students. Students in the Faculty of Teacher Training and Education of the University of Mataram, including in the Mathematics Education study program, are dominated by women compared to men.

Data Collection

The data collection techniques used was linear algebra problem-solving test which can be seen as follows.

Tes Pemecahan Masalah Aljabar Linier

Alokasi Waktu: 90 menit

Petunjuk :

1. Naskah terdiri dari 5 butir soal uraian, dengan bobot skor yang sama.
2. Kerjakan soal tanpa membuka buku (close book), dengan alokasi waktu 90 menit.
3. Selamat mengerjakan, semoga sukses.

Soal:

1. a. Jelaskan cara menyelesaikan SPL dengan Metode Eliminasi Gauss Jourdan.
   b. Gunakan Metode Eliminasi Gauss Jourdan (Cara OBE) untuk menentukan himpunan pnyelesaian dari SPL berikut
   $$\begin{cases} x + 2y - 3z = -2 \\ 3x - y + 5z = 1 \\ 4x + y + 2z = -1 \end{cases}$$
2. a. Jelaskan cara menghitung determinan matriks dengan cara ekspansi kofaktor sepanjang suatu baris/kolom.
   b. Gunakan cara ekspansi kofaktor untuk menghitung determinan matriks
   $$M = \begin{pmatrix} 1 & 0 & 1 & 1 \\ 2 & 1 & 3 & 1 \\ 0 & 2 & 1 & 0 \\ 0 & 1 & 1 & 3 \end{pmatrix}$$
3. a. Jelaskan cara menghitung determinan matriks dengan Cara OBE.
   b. Gunakan Cara OBE untuk menghitung determinan matriks
   $$M = \begin{pmatrix} 1 & 0 & 1 & 1 \\ 2 & 1 & 3 & 1 \\ 0 & 2 & 1 & 0 \\ 0 & 1 & 1 & 3 \end{pmatrix}$$
4. a. Jelaskan cara menghitung invers matriks dengan Cara Adjoint.
   b. Gunakan Cara Adjoint untuk menghitung A^{-1} dari matriks $A = \begin{pmatrix} 0 & -2 & 2 \\ 1 & 2 & 1 \\ 1 & 0 & -3 \end{pmatrix}$
5. a. Jelaskan cara menghitung invers matriks dengan Cara OBE.
   b. Gunakan Cara OBE untuk menghitung A^{-1} dari matriks $A = \begin{pmatrix} 0 & -2 & 2 \\ 1 & 2 & 1 \\ 1 & 0 & -3 \end{pmatrix}$.

Figure 1. Algebra problem solving test instrument

The data obtained in this study were analyzed quantitatively using descriptive statistics and qualitatively by describing and providing an overview of the effectiveness of implementing the developed learning design.

Result and Discussion

After the research subjects were given linear algebra problem-solving tasks, problem-solving score data were obtained, as in Table 1 below.

Table 1. Problem-solving score data

No.	NIM	Score	No.	NIM	Score
1	E1R020096	60	31	E1R021128	48
2	E1R021097	36	32	E1R021129	59
3	E1R021098	48	33	E1R021130	66
4	E1R021099	30	34	E1R021131	63
5	E1R021100	32	35	E1R021132	13
6	E1R021101	56	36	E1R021134	14
7	E1R021102	96	37	E1R021135	85
8	E1R021103	81	38	E1R021136	16
9	E1R021104	45	39	E1R021137	44
10	E1R021105	36	40	E1R021138	4
11	E1R021106	74	41	E1R021139	60
12	E1R021107	80	42	E1R021140	71
13	E1R021108	24	43	E1R021141	10
14	E1R021109	50	44	E1R021142	47
15	E1R021110	58	45	E1R021143	20
16	E1R021111	78	46	E1R021144	69
17	E1R021112	100	47	E1R021145	85
18	E1R021113	51	48	E1R021146	89
19	E1R021114	34	49	E1R021147	44
20	E1R021115	52	50	E1R021152	63
21	E1R021118	90	51	E1R021153	32
22	E1R021119	67	52	E1R021154	29
23	E1R021120	21	53	E1R021155	32
24	E1R021121	28	54	E1R021156	77
25	E1R021122	71	55	E1R021157	24
26	E1R021123	46	56	E1R021158	55
27	E1R021124	95	57	E1R021159	30
28	E1R021125	28	58	E1R016057	90
29	E1R021126	32			
30	E1R021127	24			

The data classified the research subjects into five categories according to the score range: Very Good, Good, Fair, Poor, and Very Poor. The percentage obtained for these categories is the category of Very Good (17.2%), Good (13.8%), Fair (12.1%), Poor (13.8%), and Very Poor (43.1 Based on the percentages, 43.1% indicates a Fair category, which means more than 50% fall under poor and very poor category. Based on this data, students of the Department of Mathematics Education at Faculty of Teacher Training and Education, University of Mataram, have not effectively applied the TPACK-based innovative learning design developed.

The characteristics of each category were descriptively explored; subjects in the Very Good category were able to explain and implement the ways/steps to solve problems appropriately. In addition, when the problems must be solved with two methods, both can be solved correctly. An excerpt of the answer for subject S-17, which is categorized as very good, is presented in Figure 2 below.

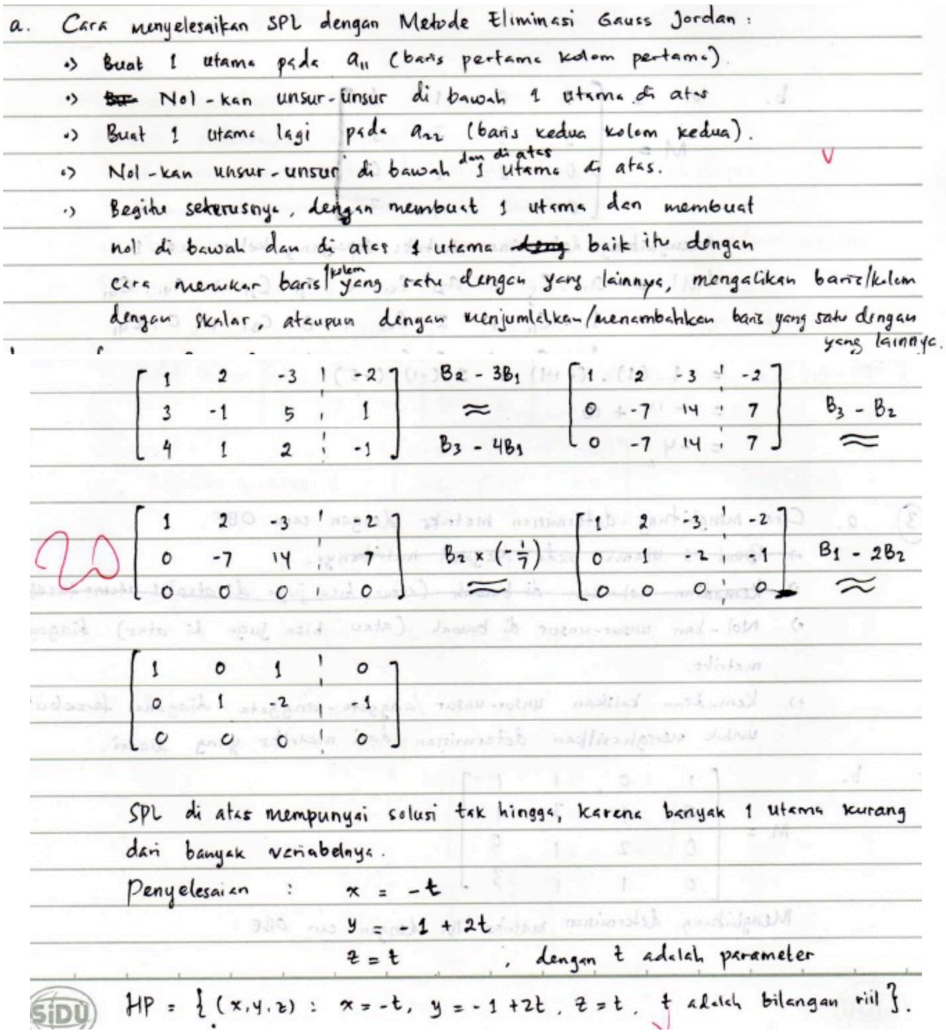

Figure 2. Excerpt of S-17's answer

The Good category subject was able to explain the method/steps to solve the problem well and was able to implement it in solving the problem case, but there were still shortcomings. Likewise, problems that two methods must solve can only be solved correctly using one of them. Figure 3 below presents an excerpt of subject S-16's answer, categorized as Good.

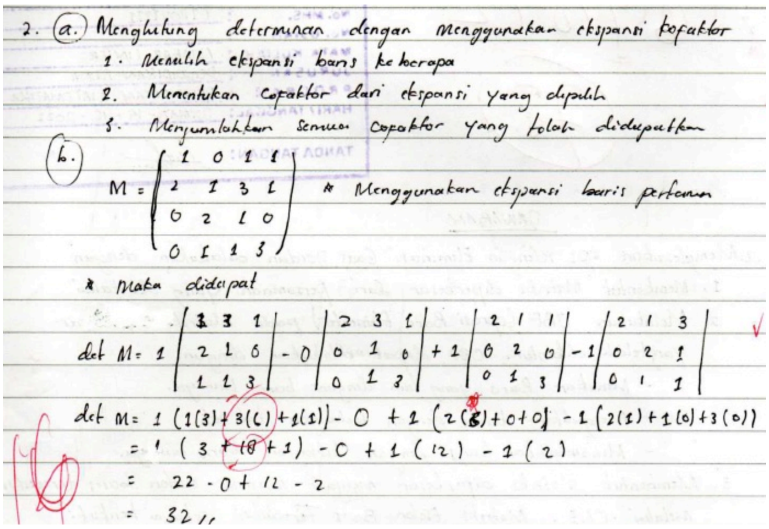

Figure 3. Excerpt of S-16's answer

Subjects in the Fair category could explain the ways/steps to solve the problem but were incomplete, and the solution implementation to the problem case was also less than perfect. An excerpt of the answer for subject S-40, which is categorized as Fair, is presented in Figure 4 below.

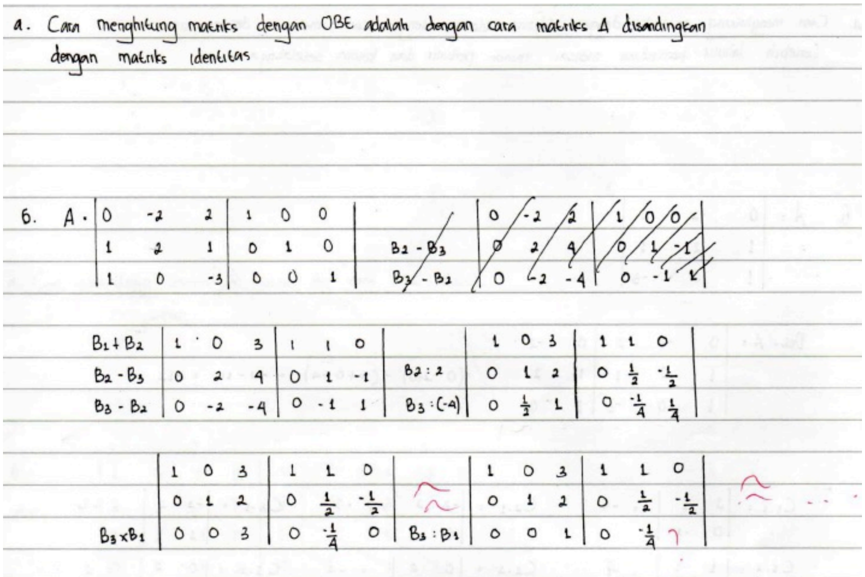
a. Cara menghitung matriks dengan OBE adalah dengan cara matriks A disandingkan dengan matriks identitas

Figure 4. Excerpt of S-40's answer

Subjects in the Poor category was not able to explain the ways/steps to solve the problem well and implement it in solving the problem case, but they have also not been precise. Figure 5 below presents an excerpt of the answer to subject S-18, categorized as Poor.

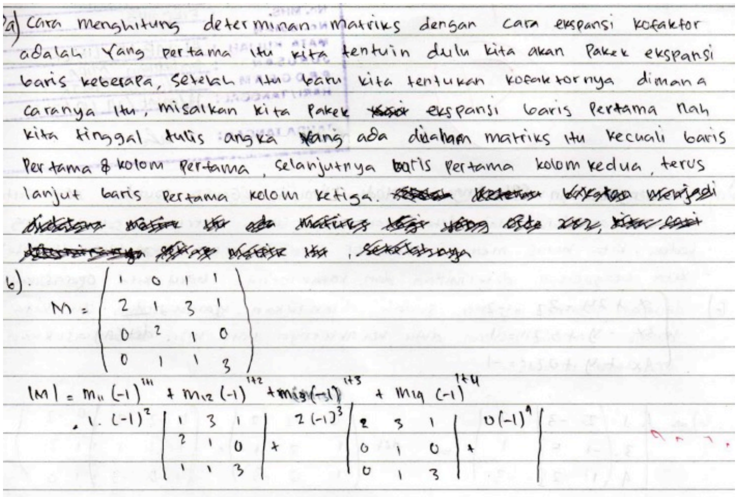
a) Cara menghitung determinan matriks dengan cara ekspansi kofaktor adalah yang pertama itu kita tentuin dulu kita akan pakek ekspansi baris keberapa, setelah itu baru kita tentukan kofaktornya dimana caranya itu, misalkan kita pakek ekspansi baris pertama nah kita tinggal tulis angka yang ada dalam matriks itu kecuali baris pertama & kolom pertama, selanjutnya baris pertama kolom kedua, terus lanjut baris pertama kolom ketiga.

Figure 5. Excerpt of answer S-18

Subjects in the very poor category could not explain the ways/steps to solve the problem, and implementing it in solving the case also did not hit substantially. The excerpt of the answer of subject S-18 who is categorized as Very Poor is presented in Figure 6 below.

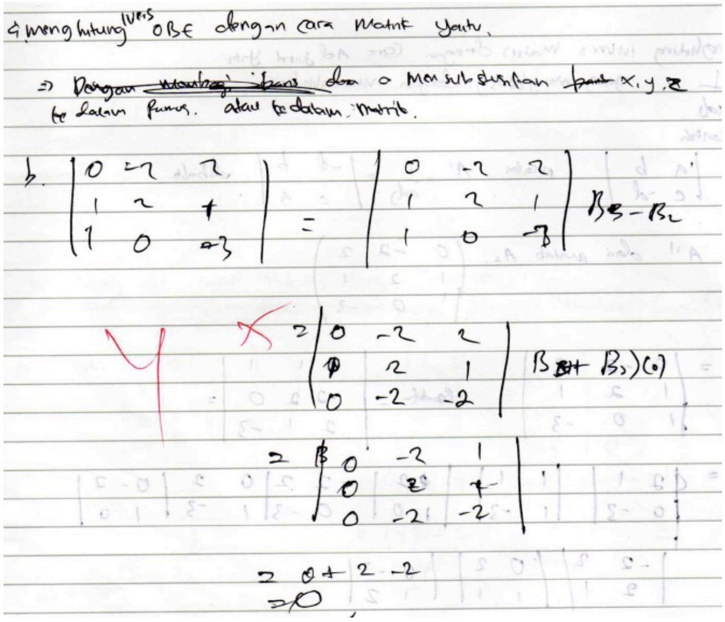

Figure 6. Excerpt of S-05's answer

From Figure 6 above, it can be argued that S-05's explanation in part shows that S-05 did not understand how to determine the inverse matrix with Elementary Row Operations or OBE, so the implementation in part b is also completely wrong.

Furthermore, the discussion was presented in terms of the understanding framework. There are four levels of understanding of mathematical rules, namely: (a) mechanical, i.e., applying memorized methods only; (b) inductive, i.e., exploration of simple cases progressing to complex cases; (c) rational, i.e., proving the rule with something else, (d) intuitive, i.e., self-belief in the truth without doubt (Meel, 2003). Meanwhile, Lehman (1977) equates understanding with three knowledge types: applications, meanings, and logical relationships.

Subjects at the Very Poor category could be classified at the level of mechanical understanding because they apply only the methods they remember, and the results are also less accurate. For example, the participants were asked to use the Gauss-Jourdan elimination method in solving System of linear equations (SPL). However, only the elimination and substitution methods were applied, which made it challenging to handle SPL with infinite solutions, so the results were wrong.

Furthermore, for subjects at a Poor category, the level of understanding can be classified as mechanical and inductive. A memorized method has been done correctly but has not been able to explore other methods or cases. For example, the participants can calculate the inverse by adjoint but cannot develop another method, namely the OBE method.

Subjects at the Fair category have between the inductive and rational level of understanding. They were able to try to solve problems with other rules/ways even though neither of them could get the right results. In this case, for example, calculating the determinant correctly using OBE and being able to develop another way with cofactor expansion, but the results are not yet correct.

Whereas subjects are at Good category, their level of understanding is between the rational and intuitive levels, since they could solve problems with other rules but not yet fully confident in identifying the correct answer. For example, the matrix inverse problem can be solved by the adjoint or the OBE method, but it is still not perfect due to calculation errors/accuracy.

Subjects who are in the Very Good category; their level of understanding is at the intuitive level, which means they can solve problems with complete confidence in the truth without doubt. This can be seen from all the explanations of methods/steps and implementation in various cases of problem-solving ranging from SPL with infinite solutions, calculating determinants with cofactor expansion and OBE methods, to determining the inverse matrix, which can be solved correctly with the OBE method and the adjoint matrix method.

Conclusion

From the research results, it can be concluded that the TPACK-based innovative learning design developed has not been effectively applied to Department of Mathematics Education students as more than 50% are still under the Fair category. For subjects in the Very Poor category, their understanding is still mechanical, meaning they could only apply the memorized method, and the results are less precise. Subjects in the Poor category can use memorized methods correctly but have not been able to develop other methods or cases. Subjects in the Fair category can try to solve problems with other rules/methods even though neither of the results was correct. Subjects in the Good category can solve problems with other rules but did not have confidence in the truth. Meanwhile, subjects in the Very Good category could solve the problems with complete confidence in the truth without doubt.

Recommendations

The things that can be suggested:

- For course lecturers, its hope that they can expand the development of integrated innovative learning designs based on TPACK in other courses in higher education
- For teachers in schools, it is hoped that they can also develop TPACK-based innovative learning designs for mathematics learning in schools.

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