Research-based learning (RBL) based on digital learning environment (DLE) in the context of TPACK proficiency among prospective mathematics teachers viewed from creative thinking ability: A quasi-experimental study

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Abstract: *This article presents an experimental study conducted to examine the impact of a research-based learning (RBL) approach based on a digital learning environment (DLE) on the Technological Pedagogical Content Knowledge (TPACK) proficiency and creative thinking abilities of prospective mathematics teachers. The study aims to prepare these teachers for the Society 5.0 era and support the government's educational initiatives. The researchers integrated a DLE consisting of an integrated website with a Learning Management System (LMS) Moodle, which included e-modules, quizzes, and other resources. The study also emphasizes the importance of character development and the need for teachers to possess strong TPACK knowledge and creative thinking skills. The TPACK framework, which encompasses pedagogical content knowledge, technological pedagogical knowledge, technological content knowledge, and technological pedagogical content knowledge, is considered crucial for effective technology integration in teaching. The researchers conducted a quasi-experimental study using a 3 x 3 factorial design to investigate the influence of different instructional models on TPACK capabilities among students at different stages of creative thinking skills. The study collected data through documentation, observation, interviews, and tests. The data were analyzed using analysis of variance (ANOVA) and post-hoc multiple comparisons. The findings of the study contribute to the advancement of education and align with the goals of the Merdeka Belajar-Kampus Merdeka (MBKM) initiative, emphasizing innovation, collaboration, and sustainable practices in education.*

Key Words*:* Research-Based Learning (RBL); Digital Learning Environment (DLE); TPACK Proficiency; Prospective Mathematics Teachers; Creative Thinking Ability

Introduction

Education serves as a benchmark for national progress, and the advancement of education requires support from all stakeholders, including educators, students, parents, schools, communities, and the government. As the agents of learning, teachers must continually enhance their competencies to keep up with the evolving times. In addition to possessing Pedagogical Content Knowledge (PCK), teachers now need to master technological knowledge encompassed by Technological Pedagogical Content Knowledge (TPACK) (Agyei & Keengwe, 2014; Suriyah, Zainudin, & Yektiana, 2021; Meng et al., 2020). Moreover, there is a prevalent tendency among student teachers to rely solely on inductive concepts during teaching practice, which poses a significant challenge for teacher education institutions.

Furthermore, many prospective teachers have yet to utilize technology during field practice fully, and students raise concerns regarding their inadequate performance in routine problem-solving tasks.

Higher education institutions are urged to revamp their curricula, especially in teacher education programs, to prepare for the era of Society 5.0. In this era, educators are expected to possess strong technological, pedagogical, and content knowledge (TPACK) and the ability to think creatively. Creative thinking involves the process of formulating problems and expressing their solutions accurately, fluently, and flexibly (Benton et al., 2017; Sukestiyarno, 2015; Suriyah et al., 2020). Furthermore, students should be equipped with soft skills and life skills, one of which is the strengthening of character, fostering a flexible mindset that stimulates creativity, perseverance, resilience, and upholding the value of honesty (Thohir, Jumadi, & Warsono, 2022; Grant, 1981; Gündoğdu, 2019).

Creative thinking is a fundamental skill that learners should possess, thus making it an essential thinking pattern to be included in the educational curriculum (Agyei & Keengwe, 2014; Suriyah, Zainudin, & Yektiana, 2021; Meng et al., 2020). Thinking creatively is necessary for generating (formulating), solving, and completing models or problem-solving plans. A series of creative thinking activities in mathematics aim to equip learners in facing various problems (Benton et al., 2017; Sukestiyarno, 2015; Suriyah et al., 2020; Thohir, Jumadi, & Warsono, 2022). Therefore, prospective mathematics teachers must possess this ability. The categorization of creative thinking in this study, according to Gotoh (2004), reveals a progression of mathematical thinking skills in problem-solving, consisting of three levels as presented in Table 1, namely empirical (informal) activities, algorithmic (formal) activities, and constructive (creative) activities.

Table 1. Levels of Mathematical Thinking by Gotoh

Stage 1: Empirical (informal) activity
During this stage, problem-solving involves the application of mathematical rules and procedures in a technical or practical manner, often without a conscious understanding or awareness of the underlying principles.
Stage 2: Algorithmic (formal) activity
During this stage, explicit utilization of mathematical techniques is employed to execute mathematical operations, calculations, manipulations, and problem-solving tasks.
Stage 3: Constructive (creative) activity
During this stage, non-algorithmic decision-making strategies are utilized to tackle non-routine problems that require the exploration and creation of novel rules or approaches.

Therefore, through this research, in line with supporting the government's MBKM (Merdeka Belajar-Kampus Merdeka) initiative to achieve eight Key Performance Indicators (KPI) and in anticipation of the Society 5.0 era, the research team conducted an experimental study on research-based learning after implementing Digital Learning Environment (DLE) practices, focusing on the TPACK proficiency of prospective mathematics teachers in relation to their creative thinking abilities. The DLE utilized in this study consisted of an integrated website with a Learning Management System (LMS) Moodle, which encompassed e-modules, quizzes, and other resources. In this context, the researchers contributed to the government's program by conducting research on prospective mathematics teachers, aiming to prepare them to become competent and professional mathematics educators.

The utilization of DLE enhances student engagement and exhibits a significant influence Gotoh (2004). The content arrangement, project tasks, online guidelines, and collaboration through Digital Learning Materials improve mathematics learning in vocational education in the Netherlands (Barana, Marchisio, & Sacchet, 2021). Awareness of utilizing technology in the learning environment impacts creative thinking abilities (Zwart et al., 2017). The implementation of e-learning can enhance creative thinking skills (Safik et al., 2021). However, there is a limited number of studies that examine the impact of technology implementation on character development. E-jawi, a character-based digital platform rooted in Javanese culture, has been previously developed (Safitri, 2018), and the use of digital storytelling in Social Studies lessons significantly influences students' character development (Rahim & Hamzah, 2016). Additionally, the application of character-based e-learning using Edmodo in Physics instruction influences learning outcomes (Saripudin, Komalasari, & Anggraini, 2021).

Researchers continue to produce findings that contribute to the progress of education (Saripudin, Komalasari, & Anggraini, 2021; Suriyah et al., 2021a, 2021b; Puspananda & Suriyah, 2017a; Suriyah, Kusmayadi, & Usodo, 2017; Utami & Suriyah, 2017; Suriyah et al., 2018; Safitri et al., 2017; Puspananda & Suriyah, 2017b). In this study, the researchers have designed a DLE to be used by prospective mathematics teacher candidates during their field practice, aiming to enhance their creative thinking abilities, strong TPACK proficiency, and character development. Previous research has also been conducted on TPACK (Suriyah, Zainudin, & Yektiana, 2021; Meng et al., 2020). TPACK is crucial in preparing professional and globally-minded teachers. The TPACK framework guides researchers and educators in addressing the challenges faced by teachers when integrating technology into their instruction. TPACK consists of three essential components: content, pedagogy, and technology, which are interconnected and influence one another (Suriyah et al., 2021a; Chai, Koh, & Tsai, 2017; Maeng et al., 2013; S.N. Kushner Benson et al., 2015; Angelie & Valanides, 2015; Wei et al., 2019; Khan Samia, 2011).

Technology Pedagogy and Content Knowledge (TPACK) represents the connection and interaction between content, pedagogy, and technology within a curriculum and instructional design (Agyei & Keengwe, 2014; Suriyah, Zainudin, & Yektiana, 2021; Meng et al, 2020; S.N. Kushner Benson et al., 2015; Angelie & Valanides, 2015; Wei et al., 2019). TPACK encompasses the knowledge and understanding that underlie teachers' actions with technology (Khan Samia, 2011; Voogt et al., 2016). The following is the framework of TPACK:

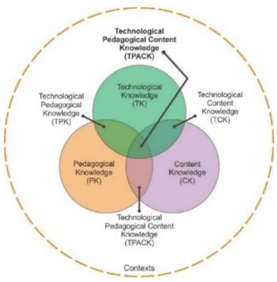

Figure 1. TPACK Framework

The TPACK framework developed by Koehler consists of three pillars, which are integrated to form four knowledge bases: (1) Pedagogical Content Knowledge (PCK), which refers to knowledge of appropriate teaching methods for specific content, (2) Technological Pedagogical Knowledge (TPK), which involves understanding how to use technology in teaching practices, (3) Technological Content Knowledge (TCK), which focuses on aligning technology with content learning, and (4) Technological Pedagogical Content Knowledge (TPACK), which represents the integration of technology, content, and pedagogy (Jaipal-Jamani et al., 2018; Hauk et al., 2014). TPACK is highly relevant for prospective mathematics teachers, as it provides them with the necessary knowledge and skills to effectively integrate technology into their teaching practices. However, in contemporary education, character development is also essential for fostering creative thinking (Suriyah et al., 2020; Saripudin, Komalasari, & Anggraini, 2021; Suriyah et al., 2021a).

The utilization of technological advancements involves the development of a Digital Learning Environment (DLE), which serves as a prerequisite and means to achieve innovative educational outcomes in order to meet the demands of the digital economy and learner needs (Jason, 2011; Principles, 2000). Through the DLE, self-directed and collaborative learning can occur without spatial limitations (Noskova, Kulikova, & Yakovleva, 2020), enabling learners to interpret information (Al-Qallaf & Al-Mutairi, 2016) critically. This study experiments with a learning environment that promotes creative thinking abilities through Research-Based Learning (RBL) with the integration of a DLE.

In order to develop both TPACK and creative thinking abilities, it is important to implement learning activities that enhance students' capacity to solve problems creatively and, in the process, foster their TPACK. One approach to achieve this is through a learning approach that accommodates students' learning goals in higher education. According to Mukaromah's research (2020), higher education should provide several benefits, including: 1) integrating students into the values, practices, and ethics of their chosen discipline, 2) ensuring that the course content encompasses the latest research findings, 3) enhancing students' understanding of how their chosen discipline contributes positively to society, 4) developing and improving generic skills such as critical and analytical thinking, information retrieval, and problem-solving, as well as skills in conducting and evaluating research that is beneficial for students' personal and professional lives, and 5) providing opportunities to enhance learning methods that have been associated with positive student learning outcomes.

According to Mukaromah (2020), one instructional model that aligns with these benefits is Research-Based Learning. Poonpan and Suwanmankha (2005) and Dafik (2015:6) explain that Research Based Learning is a learning system that incorporates authentic learning (learning through real-life examples), problem-solving, cooperative learning, contextual learning (hands-on and minds-on), and inquiry-based approaches, all rooted in the constructivist philosophy. In terms of language, the term Research Based Learning refers to a learning approach based on research or inquiry. Research-Based Learning is a model developed within the constructivist paradigm. It emphasizes activities such as analysis, synthesis, and evaluation to enhance students' and instructors' abilities in assimilating and applying knowledge (Widyawati, 2010). According to Mukaromah (2020), the primary goal of implementing Research Based Learning is to promote higher-order thinking skills and encourage students to become creators. This theory aligns well with the understanding that the process of creative thinking is inherent in the higher-order thinking level known as "creating."

Reflecting on the six stages of higher-order thinking skills discussed earlier, systematic planning is required for their implementation, and the involvement of various related elements becomes crucial. These elements include the faculty members, the classroom setting, and the research group. These three elements are viewed as an interconnected triple helix relationship that cannot be separated, as depicted in Figure 2.

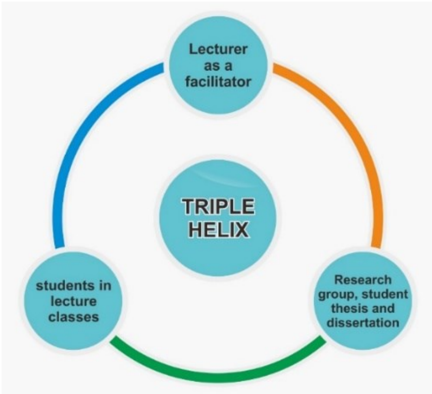

Figure 2. Triple Helix Relationship (Dafik, 2015)

In general, the Triple Helix relationship is the foundation for implementing Research Based Learning (RBL) in education. RBL is a learning model that focuses on research problems within research groups as the main topic of discussion in the classroom. In this approach, a lecturer does not merely present outdated or non-contextual concepts that are irrelevant to the current era or the field itself. Instead, they are expected to deliver studies and findings that align with the latest developments in the relevant research groups. The implementation of RBL is based on the constructivist philosophy, characterized by the application of contextual teaching and learning approaches, discovery learning, and project-based learning, and encompasses four aspects: (1) Problem-posing-based learning: Problems are posed based on the research conducted by the lecturer within the research group; (2) Recently prior knowledge-based learning: Learning is based on the most recent and up-to-date research findings; (3) Application of problem-solving procedures aligned with modern research methodologies; and (4) Analysis and verification of data accuracy.

Based on previous research, there has been no development of a Digital Learning Environment (DLE) within the Research Based Learning model specifically focused on the TPACK (Technology Pedagogy and Content Knowledge) capabilities in relation to the creative thinking skills of prospective mathematics teachers. In this regard, the researcher integrates the digital learning environment into the Research Based Learning model, assuming that the discoveries made by students through their research, guided and directed by educators, do not require a relatively long time that could potentially make students bored. Additionally, students will feel supported throughout their research projects, with the role of the lecturer as a facilitator within the RBL approach. Through the aforementioned modifications, it is expected that students will achieve maximum effectiveness in mathematics learning in the classroom, consequently acquiring optimal TPACK capabilities.

The objectives of this research are to determine: (1) which approach yields better TPACK capabilities, students accustomed to the RBL with DLE model, the RBL model, or direct instruction; (2) which approach yields better TPACK capabilities, students at stage 1, stage 2, or stage 3 of creative thinking skills; (3) within each instructional model, which approach yields better TPACK capabilities, students at stage 1, stage 2, or stage 3 of creative thinking skills; (4) within each stage of creative thinking skills, which approach yields better TPACK capabilities, students using the RBL with DLE model, the DLE instructional model, or direct instruction.

The urgency and feasibility of this research lie in assisting the acceleration of implementing the new paradigm of TPACK based on DLE, strengthening creative thinking skills, and meeting the needs of innovation and technology. This research supports the MBKM curriculum in achieving Key Performance Indicators (KPIs), including innovation, collaborative relationships, and sustainable practices based on collegiality and mutual learning.

Literature Review

1. Research-Based Learning (RBL)

Research Based Learning (RBL) can motivate students to be active in learning. In line with Arifin (2010), RBL enables students to; 1) have a strong understanding of basic concepts and methodologies, 2) solve problems creatively, 3) have a scientific attitude that seeks truth, to be open and honest. RBL provides opportunities for students to develop contextual concepts by discovering new things from the research process and based on student centered learning (Trisnasih, 2016) Widayati (2010).

RBL can be used as a learning reform in higher education to improve the quality of learning and graduates who are prepared for the 21st century (Lahamuddin, 2015). Jenkin et. al. in (Yahya, 2010) (Guinness, 2012), pinpoint the advantages of RBL by providing opportunities for learners to not only know the content of teaching materials, but they also have the opportunity to practice searching, constructing hypotheses, and gaining better understanding and knowledge. RBL can provide benefits for learners in the form of motivation, active learning, and skill development (Singh (2014: 22), Peter Trem (2010) and Dafik (2015).

2. Digital Learning Environment (DLE)

According to NCTM, there are at least three positive impacts of technology integration in mathematics learning, namely increasing learning outcomes and the effectiveness of mathematics instruction, influencing what and how mathematics should be learned and taught (43). One of the utilization of technological advances is to develop a digital learning environment (DLE). DLE is a prerequisite and a means to achieve creative and innovative educational outcomes in order to meet the requirements of the digital economy as well as the needs of today's students (44). Through DLE, students can engage in independent and collaborative learning anywhere and anytime without the limitations of the classroom, build online communities (45), be independent, construct their own knowledge, interpret it critically and perform project tasks (46).

3. TPACK Proficiency of Prospective Mathematics Teachers

TPACK (Technology Pedagogy and Content Knowledge) is a form of knowledge needed to use technology intelligently in classroom teaching and learning activities (Barana, Marchisio, & Sacchet, 2021; Zwart et al., 2017; Safik et al., 2021; Safitri, 2018). The TPACK framework directs researchers and educators to the necessary components for teaching with technology. TPACK has three important components; content, pedagogy, and technology that are connected, interacting, and influencing each other (Agyei & Keengwe, 2014; Suriyah, Zainudin, & Yektiana, 2021; Barana, Marchisio, & Sacchet, 2021; Rahim & Hamzah, 2016; Saripudin, Komalasari, & Anggraini, 2021; Suriyah et al., 2021a, 2021b). TPACK is described as a package of teacher knowledge in integrating technology, pedagogy, and content knowledge in a curriculum and instruction design (Barana, Marchisio, & Sacchet, 2021; Rahim & Hamzah, 2016; Saripudin, Komalasari, & Anggraini, 2021; Suriyah et al., 2021a). TPACK as the overall knowledge and insights that underlie teachers' actions with technology in their teaching practice (Safitri, 2018; Suriyah et al., 2021b; Puspananda & Suriyah, 2017a). There are three pillars of TPACK; (1) content knowledge, which is about the subject matter to be taught, (2) pedagogical knowledge, which is about the knowledge of the teaching and learning process, and (3) technological knowledge, which is about the knowledge of teachers using technology in teaching, for example using media with technology, providing computer-assisted evaluation, and even creating online and interactive learning environments (Barana, Marchisio, & Sacchet, 2021; Rahim & Hamzah, 2016; Saripudin, Komalasari, & Anggraini, 2021; Safik et al., 2021; Safitri, 2018; Suriyah et al., 2021b; Puspananda & Suriyah, 2017a).

4. Creative Thinking Ability

According to Krulik and Rudnick's (2019) Levels of Reasoning (Thinking) as shown in Figure 3, the lowest level of thinking is recall which incorporates almost automatic and reflexive thinking skills. The next level is basic thinking, which is the understanding and recognition of mathematical concepts. The boundaries of the categories are not easy to define. The basic level for one person may be the recall level for another.

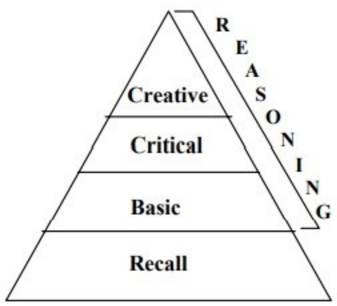

Figure 3. Levels of Reasoning

The highest level of reasoning is creative thinking. It is the original and reflective reasoning and produces complex products. It involves synthesizing, building and applying ideas and producing new products. Airasian, et.al. (2001) developed a taxonomy for learning, teaching and assessment based on the dimensions of knowledge and cognitive processes that revised Bloom's taxonomy. The cognitive processes include remembering, understanding, applying, analyzing, evaluating and creating. The highest cognitive process category of create relates to the creative process. Creating means putting elements together to form a coherent and functional whole.

Method

This research employed a quasi-experimental design, specifically a 3 x 3 factorial design, using analysis of variance (ANOVA) as the statistical technique. The design was utilized to investigate the influence of different instructional models among three groups linked to students' creative thinking skills at stages 1, 2, and 3 on the TPACK capabilities of prospective mathematics teachers. The population of this study consisted of students from PGRI campuses in Java and surrounding areas who were enrolled in the Micro Teaching Mathematics Education course. The sample was obtained using stratified cluster random sampling, which involved dividing the population into strata and randomly selecting sample members from each subpopulation. After the sample selection process, the high category was represented by Universitas PGRI Madiun, the medium category by IKIP PGRI Bojonegoro, and the low category by STKIP Taman Siswa Bima, West Nusa Tenggara.

This research used documentation, observation, interviews, and tests to collect data. The documentation method was employed to gather data from the final examination scores of the school mathematics course. The obtained data were used to test the initial ability balance. Prior to conducting the test for the initial ability balance among the three populations, the normality of data for each group and the homogeneity of variances among the three groups were assessed. The normality test was conducted using the Lilliefors method, and the results indicate that the groups originate from populations with a normal distribution. The homogeneity test employs the Bartlett test, and the results indicate that the three populations have homogeneous variances ($\chi2$ observed = 0.3833 < 5.991 = $\chi2$ critical). The test for the balance among the three groups utilized a one-way ANOVA, and the results show that the observed F-value (F observed = 0.655) is greater than the critical F-value (F critical = 3). This indicates that the three populations have the same initial ability.

Another method used was the test method to determine the stage of students' creative thinking ability. The last method employed was observation and interviews to assess students' TPACK ability. The development of test, observation, and interview instruments was carried out by constructing a blueprint and creating instruments based on the blueprint. These instruments were then validated by experts and piloted by students who previously took the

School Mathematics Micro Teaching course at IKIP PGRI Bojonegoro. After piloting, the test instrument was analyzed for discrimination power, difficulty level, and reliability.

The ANOVA assumptions were tested, including the normality test using the Lilliefors method and the homogeneity test using the Bartlett method. The normality and homogeneity assumptions of the data were met. Next, the TPACK ability data were analyzed using a two-way ANOVA with unequal cell sizes, followed by post-hoc multiple comparisons using the Scheffe method.

Results and Discussion

The results of the TPACK ability test were analyzed using a two-way ANOVA with unequal cell sizes. After conducting the two-way ANOVA analysis with unequal cell sizes, the results are summarized in Table 2.

Table 2. Summary of Two-Way ANOVA Analysis with Unequal Cell Sizes

	Sum of Squares	***Degrees of Freedom***	***Mean Square***	F_{obs}	$F_{critical}$	**Decision**
Model (A)	14667,79	2	7333,90	22,52	3,00	H_{0A} is rejected
Creative Thinking (B)	7998,09	2	3999,05	12,28	3,00	H_{0B} is rejected
Interactions (AB)	3137,56	4	784,39	2,41	2,37	H_{0AB} is rejected
Error	83363,91	256	325,64			
Total	109167,36	264				

Since H_{0A}, H_{0B}, H_{0AB} are rejected, it is necessary to perform post-hoc multiple comparisons between rows and columns using Scheffe's method to determine significant differences in mean TPACK competence.

Table 3. Means and Total Means of TPACK Competence in Learning Models and Stages of Creative Thinking Ability

Learning Model	**Creative Thinking Ability**			**Marginal Mean**
	Stage 3	***Stage 2***	***Stage 1***	
Direct Method	67,70	52,73	43,43	54,36
RBL	69,00	64,00	56,33	63,27
RBL *with* DLE	76,17	71,32	72,17	72,85
Marginal Mean	70,83	63,37	56,58	

Furthermore, since H_{0A} is rejected, a post-hoc Scheffe's method is employed for further analysis of the two-way analysis of variance. The results of the post-hoc multiple comparisons between rows using the Scheffe's method are as follows: $F1_{.-2.}$ = 12.48, $F_{1.-3.}$ = 46.46, $F_{2.-3.}$ = 10.72. The obtained F_{tab} value is 6. Therefore, $F_{1.-2.}$ = 12.48 > F_{tab}, $F_{1.-3.}$ = 46.46 > F_{tab}, and $F_{2.-3.}$ = 10.72 > F_{tab}. Subsequently, since H_{0B} is rejected, a post-hoc Scheffe's method is conducted for further analysis of the two-way analysis of variance. The results of the post-hoc multiple comparisons between columns using the Scheffe's method are as follows: $F_{.1-.2}$ = 7.73, $F_{.1-.3}$ =

23.53, $F_{.2-.3}$ = 6.46. The obtained F_{tab} value is 6. Therefore, $F_{.1-.2}$ = 7.73 > F_{tab}, $F_{.1-.3}$ = 23.53 > F_{tab}, and $F_{.2-.3}$ = 6.46 > F_{tab}.

Table 2 presented earlier shows that H_{0AB} is rejected, indicating an interaction between the applied learning models and the examined variable, which is the creative thinking ability consisting of stages 1, 2, and 3. Subsequently, post-hoc multiple comparisons are conducted between cells and within the same column, yielding the following results:

Table 4. Results of Post-Hoc Multiple Comparisons between Cells and within the Same Row

H_0	F_{obs}	F_{table}	Decision
$\mu_{11} = \mu_{12}$	1,09	15,52	H_0 is accepted
$\mu_{11} = \mu_{13}$	0,59	15,52	H_0 is accepted
$\mu_{12} = \mu_{13}$	0,03	15,52	H_0 is accepted
$\mu_{21} = \mu_{22}$	1,15	15,52	H_0 is accepted
$\mu_{21} = \mu_{23}$	5,91	15,52	H_0 is accepted
$\mu_{22} = \mu_{23}$	2,71	15,52	H_0 is accepted
$\mu_{31} = \mu_{32}$	10,23	15,52	H_0 is accepted
$\mu_{32} = \mu_{33}$	4,02	15,52	H_0 is accepted
$\mu_{32} = \mu_{33}$	4,02	15,52	H_0 is accepted

Table 5. Results of Post-Hoc Multiple Comparisons between Cells and within the Same Column

H_0	F_{obs}	F_{table}	Decision
$\mu_{11} = \mu_{21}$	1,89	15,52	H_0 is accepted
$\mu_{11} = \mu_{31}$	2,79	15,52	H_0 is accepted
$\mu_{12} = \mu_{22}$	3,33	15,52	H_0 is accepted
$\mu_{12} = \mu_{32}$	19,40	15,52	H_0 is rejected
$\mu_{13} = \mu_{33}$	32,78	15,52	H_0 is rejected
$\mu_{13} = \mu_{23}$	9,24	15,52	H_0 is accepted
$\mu_{21} = \mu_{31}$	0,07	15,52	H_0 is accepted
$\mu_{22} = \mu_{32}$	7,06	15,52	H_0 is accepted
$\mu_{23} = \mu_{33}$	6,61	15,52	H_0 is accepted

Based on the results of the post-hoc multiple comparisons between rows and considering the marginal means in Table 3, the TPACK competence of students can be concluded as follows: students who received the RBL with DLE treatment performed better than those with the RBL treatment and direct instruction treatment, and students in the RBL treatment group exhibited better TPACK competence compared to those in the direct instruction treatment group. The effectiveness of the RBL with DLE model in the learning process aligns with the viewpoint of Chambers and Thiekotter (2013: 109) that learners are more likely to remember concepts and knowledge they discover (in contrast to traditional instructional models). Moreover, it allows learners to surpass the provided information.

Based on the results of the post-hoc multiple comparisons between columns and considering the mean values of TPACK competence, it can be concluded that: TPACK competence is better in the group of students with stage 3 creative thinking ability compared to the groups with stage 2 and stage 1 creative thinking abilities. Additionally, TPACK competence is better in the group of students with stage 2 creative thinking ability compared to the group with stage 1 creative thinking ability. Students with stage 3 creative thinking ability are highly active in discussions and asking questions when encountering difficulties, resulting in a better mastery of the material being studied and discussed. This finding aligns with Suriyah (2022), who states that students at this stage exhibit superior constructive response patterns, view difficulties as opportunities, and possess the high motivation and self-directed learning abilities. According to Sholihah, Suyitno, & Dwijanto (2020), Wahyudi et al. (2019), and Nuha, Waluya, & Junaedi (2018), creative thinking ability significantly influences learning outcomes, and educators should develop students' creative thinking abilities. According to Gotoh's theory, stage 3 represents the highest level, where students must choose a strategy and coordinate various explanations in their tasks. They must decide the desired level of detail and how to present the sequence of actions or logical conditions of the action system. Students need to evaluate the characteristics of the final product in comparison to a set of goals, explain conclusions regarding the success or difficulties encountered during the development process, and provide suggestions for improving planning and construction processes. This level of creative thinking ability generally reflects thinking strategies not only in mathematics.

Based on Tables 3 and 4 above, the following conclusions can be drawn: in the RBL with DLE model, the TPACK competence is equally good across each stage of creative thinking. In the RBL model, the TPACK competence of students with different stages of creative thinking is also equally good. In the direct instructional model, the mathematics learning achievement of students with stage 3 creative thinking ability is equally good compared to students with stage 2 creative thinking ability. The TPACK competence of students with stage 2 creative thinking ability is equally good compared to students with stage 1 creative thinking ability. However, students with stage 3 creative thinking ability exhibit better TPACK competence than students with stage 2 creative thinking ability.

Based on Table 5 and considering the average mathematics learning achievement in Table 3, the following conclusions can be drawn: (1) For students with stage 3 creative thinking ability, the TPACK competence of students taught with the RBL with DLE, RBL, and direct instructional models is equally good; (2) For students with stage 2 creative thinking ability, the TPACK competence of students taught with the RBL with DLE model is equally good as those taught with the RBL model, and the TPACK competence of students taught with the RBL model is equally good as those taught with the direct instructional model. However, students taught with the RBL with DLE model exhibit better TPACK competence than those taught with the direct instructional model; (3) For students with stage 1 creative thinking ability, the TPACK competence of students taught with the RBL with DLE model is equally good as those taught with the RBL model, and the TPACK competence of students taught with the RBL model is equally good as those taught with the direct instructional model. However, students taught with the RBL with DLE model exhibit better TPACK competence than those taught with the direct instructional model.

The effectiveness of the RBL with DLE model is in line with the research conducted by Sholihah, Suyitno, & Dwijanto (2020), Wahyudi, et al. (2019), Nuha, Waluya, & Junaedi (2018), which suggests that with the appropriate model, approach, techniques, and student-centered learning strategies, the TPACK competence of students can be enhanced. Based on design research conducted by Prahmana & Kusumah (2016), Research-Based Learning encourages mathematics education students to produce high-quality articles published in several international seminars, national, and international journals.

According to the research conducted by Pratama (2017), to address the imbalance among the three pillars of higher education, namely education, research, and community service, where many institutions prioritize education over the other two aspects, leading to low quality and quantity of university research, Research-Based Learning (RBL) plays a crucial role. One alternative approach to integrating research into teaching is the use of scientific journals as instructional materials. Scientific journals contain research findings that have been evaluated by experts, making them a representation of research integration in teaching. According to this research, scientific journals offer several advantages compared to textbooks in terms of publication time, concept novelty, review process, and writing inspiration. In the upcoming research, scientific journals will be used as one of instructional materials in the teaching process.

According to the research conducted by Nursofah, Komala, and Rusdi (2018), there is an interaction between Research Based Learning and Creative Thinking Skills. The conclusion of the study is that research-based learning requires high motivation, and educators should be able to provide motivation and enthusiasm to students so that research activities align with the learning objectives. Based on the research by Salimi (2017), Research-Based Learning can train and explore students' abilities through the stages of research. This model is highly suitable for implementation in higher education teaching.

Conclusion

Based on the research findings and data analysis conducted, the following conclusions can be drawn: (1) In the group of students treated with the RBL with DLE model, their TPACK abilities were better than those treated with the RBL model and direct instruction. In the group of students treated with the RBL model, their TPACK abilities were better than those treated with direct instruction; (2) The TPACK abilities of students with stage 3 creative thinking skills were better than those with stage 2 and stage 1 creative thinking skills. Additionally, students with stage 2 creative thinking skills had better TPACK abilities than those with stage 1 creative thinking skills; (3) In the RBL with DLE model, the TPACK abilities of students with stage 1, 2, and 3 creative thinking skills were equally good. In the RBL model, the TPACK abilities of students with stage 1, 2, and 3 creative thinking skills were equally good. In direct instruction, the TPACK abilities of students with stage 3 creative thinking skills were equally good as those with stage 2 creative thinking skills, and the TPACK abilities of students with stage 2 creative thinking skills were equally good as those with stage 3 creative thinking skills. However, students with stage 3 creative thinking skills had better TPACK abilities than those with stage 1 creative thinking skills; and (4) Among students with stage 3 creative thinking skills, the TPACK abilities of those treated with the RBL with DLE, DLE, and direct instruction models were equally good. Among students with stage 2 creative thinking skills, the TPACK abilities of those treated with the RBL with DLE model were equally good as those treated with the RBL model, and the TPACK abilities of those treated with the RBL model were equally good as those treated with direct instruction. However, students treated with the RBL with DLE model had better TPACK abilities than those treated with direct instruction. Among students with stage 1 creative thinking skills, the TPACK abilities of those treated with the RBL with DLE model were equally good as those treated with the RBL model, and the TPACK abilities of those treated with the RBL model were equally good as those treated with direct instruction. However, students treated with the RBL with DLE model had better TPACK abilities than those treated with direct instruction.

Despite the valuable findings obtained from this research, there are some limitations that should be acknowledged. Firstly, the study focused on a specific sample of students from a particular educational institution, which limits the generalizability of the results to a broader population. Secondly, the research was conducted within a specific timeframe, which may not capture long-term effects and changes in TPACK abilities and creative thinking skills. Thirdly, the research relied on self-reported data, which may be subject to response bias or inaccuracies in participants' perceptions. Lastly, the study did not explore other potential factors that could influence TPACK abilities, such as prior experience or exposure to technology.

Future research in this area could consider the following suggestions to address the limitations mentioned above. Firstly, conducting similar studies in different educational settings and with a larger and more diverse sample of participants would enhance the generalizability of the findings. Secondly, longitudinal studies could be conducted to investigate the long-term effects of RBL and DLE models on TPACK abilities and creative thinking skills. This would provide insights into the sustainability and durability of the observed improvements. Additionally, incorporating objective measures, observational data, and self-reports would provide a more comprehensive and accurate assessment of participants' TPACK abilities. Lastly, exploring other factors that may influence TPACK development, such as the role of prior technological experiences or the impact of specific instructional strategies, would contribute to a deeper understanding of the complex interplay between teaching approaches and student outcomes.

By addressing these limitations and pursuing the suggested avenues for future research, a more robust and nuanced understanding of the relationship between RBL, DLE, TPACK, and creative thinking skills can be achieved, ultimately informing educational practices and enhancing the quality of teaching and learning in higher education.

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