MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2022, 18(12), em2196
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/12697

Enhancing creativity in genetics using three teaching strategies-based TPACK model

Erni Angraini [1,2], Siti Zubaidah [1*], Hendra Susanto [1], Noritah Omar [3]

[1] Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Malang, INDONESIA
[2] Department of Biology Education, Faculty of Teacher Training and Education, Universitas Muhammadiyah Palembang, Palembang, INDONESIA
[3] Universiti Putra Malaysia, Selangor, MALAYSIA

Received 09 June 2022 ▪ Accepted 25 November 2022

Abstract

Several studies show that the creativity of science students in Indonesia is still low and needs to be empowered and improved. One of the subjects considered difficult by students is genetics because it is abstract and complex. Therefore, educators try technological, pedagogical, and content knowledge (TPACK) model with different strategies. This study aims to analyze and describe the effect of active learning based on the TPACK model with three teaching strategies, namely problem-based learning (PBL), reading, questioning, and answering (RQA), and PBL-RQA, on student creativity in the genetics course at three classes. The research design used was a pre-test-post-test three treatment design. Several teaching strategies used in active learning based on the TPACK model in the genetics course are PBL, RQA, and a combination of PBL-RQA. The research was conducted for one semester. Data was collected through pre- and post-test in the form of description questions distributed through Google Forms. The results showed that the three active learning classes based on the TPACK model have the potential to increase student creativity. The three classes did not differ significantly in increasing student creativity. The three classes have their respective advantages, so educators can choose between the three strategies used by considering the characteristics of students. The three TPACK-based active learning can be used as recommendations in designing the learning process. Educators can also choose the three TPACK-based active learning to empower and increase student creativity.

Keywords: active learning, creativity, genetics, PBL, TPACK model

INTRODUCTION

Creativity is one of the 21st century skills that everyone needs in the digital age, because everyone is exposed to changes that occur extensively. Creativity is a person's ability to generate new, unique, and valuable ideas that are used as solutions to problems. Creativity is a person's ability to be more sensitive to problems and various weaknesses that occur, identify difficulties, make hypotheses, and find a solution (Greenstein, 2012). Creativity is also defined as a person's ability to use imagination and self-expression to create new, unique, valuable, and value-added ideas (Ferrari et al., 2009; Nikolopoulou, 2018; Olatoye et al., 2010; Papaleontiou-Louca et al., 2014; Pllana, 2019; Ray Gehani, 2011).

Creativity is important in supporting teaching and learning as well as increasing the understanding of both educators and students (Kaplan, 2019). Universities are good places to develop creativity because these institutions offer avenues for the exchange of ideas and dialogue between the academic community (Mintu-Wimsatt et al., 2007). Creativity can be introduced and stimulated in teaching activities and a supportive educational climate for students (Maksić & Spasenović, 2018). Creativity is not just an opportunity in education but a necessity for the present and future educational conditions (Ferrari et al., 2009).

Creativity is a very important skill for the application of scientific methods, especially for science students.

✉ erni@um-palembang.ac.id ✉ siti.zubaidah.fmipa@um.ac.id **(*Correspondence)** ✉ hendrabio@um.ac.id
✉ nomar@upm.edu.my

Contribution to the literature

- One of the science student courses is genetics. Genetics courses are considered difficult for students because they are abstract and complex.
- TPACK model is an educator's framework that connects three important aspects, namely, technology, pedagogy, and content knowledge.
- Three teaching strategies based on the TPACK model, namely PBL, RQA, and PBL-RQA in the genetics course, can increase student creativity.

However, students often have low creativity (Reche & Perfectii, 2020). The low creativity of science students is caused by ineffective learning methods that have an impact on student creativity (Sandika & Fitrihidajati, 2018). In addition, the low creativity of students is also caused by the lack of students desire to generate new ideas and no practical experience during learning both at the undergraduate and postgraduate levels (Muralidhar, 2013). One of the important lessons is learning in genetics courses.

Genetics is a biology course that tends to be difficult from a student's perspective. The results of distributing questionnaires using Google Forms to 94 students of the Department of Biology, Universitas Negeri Malang, who have taken the genetics course, show that genetics is a difficult subject because the material is complex, abstract, and contains many terms. The results of the following studies also show things that are not much different. Genetics is considered difficult for students because the material is abstract, too many terms are difficult to understand, and the material is very complex (Fauzi & Fariantika, 2018; Fauzi & Ramadani, 2017; Johnson & Jackson, 2015; Murray-Nseula, 2011). The complexity inherent in genetics related to genes, DNA, chromosomes, cell division, and inheritance makes it difficult for students to understand (Cimer, 2012; Kibuka-Sebitosi, 2007). Genetic phenomena are said to be complex because they consist of several interrelated levels of organization (genes, proteins, cells, tissues, organs, etc.) that contain a myriad of heterogeneous elements (Duncan & Tseng, 2010).

Genetic problems have been revealed and solutions are sought by various learning experts from various countries. For example, Choden and Kijkuakul (2020), combines problem-based learning (PBL) with scientific arguments to increase students understanding of genetics. Yilmaz et al. (2011) stated that prediction/discussion-based learning cycle and conceptual change texts are effective in helping students understand the concept of genetics. Starbek et al. (2010) stated that the use of multimedia and animation as well as illustrations, when studying genetics could increase students' knowledge and understanding of genetics content. Knippels et al. (2005) state that there are four design criteria that must be met by teaching and learning strategies to address the abstract and complex nature of genetics in biology education, as described below:

1. Sequencing the content of genetic knowledge, starting at the level of organisms that are familiar to students for example their families and generally gradually descends to the cellular as well as molecular level.
2. Explicitly linking meiosis and inheritance.
3. Distinguishing somatic and germ cell lines in the context of the life cycle.
4. Students must actively explore the relationship between organizational levels in biology and educators as facilitators in learning activities.

Lecturers of the genetics course at Universitas Negeri Malang also tried to solve problems with PBL teaching strategy in some classes and reading, questioning, and answering (RQA) in some other classes. PBL is a teaching strategy in which students work together to find solutions to complex problems (Ferreira & Trudel, 2012). While RQA requires students to understand the content of the reading, then make questions that represent the content of the reading and then answer them (Hariyadi et al., 2017). In this study, the lecturer tried to combine PBL and RQA. PBL-RQA is a PBL strategy that is integrated into RQA so that PBL can cover the shortcomings of RQA. The PBL and RQA stages have the same goal, namely, to develop learning so that students can be responsible for organizing and controlling their own learning through the activities contained in the stages (Bahri et al., 2019).

PBL, RQA, and PBL-RQA are teaching strategies in active learning. Active learning is one of learning that involves students being more active and carrying out more meaningful learning activities (Lombardi et al., 2021). Active learning is student-centered learning that engages their thinking through the use of various activities in the classroom that require students to reflect and discuss their ideas (Michael, 2006). Active learning as a one-time or continuous student exercise introduced in the classroom to encourage thinking and participation in an effort to involve them in the learning process (Mitchell et al., 2017). Active learning has been shown to improve student learning and reduce failure rates compared to traditional lectures with lectures (Freeman et al., 2014). Active learning provides opportunities for students to synthesize, analyze, evaluate, and communicate various information obtained in the classroom. Students also spend time thinking, reading, writing, discussing, and solving problems in order to better understand the material presented by the educator (Kitchens et al., 2018; Millis, 2012).

During the pandemic, the presence of technology is inevitable so that in addition to teaching strategies, lecturers need to utilize technology in learning (Sothayapetch & Lavonen, 2022). Educators are not only required to understand relevant content knowledge, but they also need to know how to convey this content to their students; at the same time, they need to adapt and update their technological knowledge to keep up with the times (Alrwaished et al., 2017). In terms of teaching, technology complements pedagogy and content that is applied together, known as technological, pedagogical, and content knowledge (TPACK model) (Atun & Usta, 2019; Irdalisa et al., 2020). The TPACK model is a framework that brings together content knowledge, pedagogy, and technology to make classroom learning more effective (Brown & Neal, 2011; Joy, 2015; Koehler et al., 2013; Novo et al., 2016; Rosenberg & Koehler, 2015; Tanak, 2018).

Therefore, this study aims to analyze and describe the effect of active learning based on the TPACK model with three different teaching strategies, namely PBL, RQA, and PBL-RQA on student creativity in the genetics course. The hypothesis of this research is that active learning based on the TPACK model with three different teaching strategies, namely PBL, RQA, and PBL-RQA can increase student creativity. Good creative abilities are expected to form students who are reliable in solving problems that occur in the community and can compete in this digital era.

METHODS

Research Design

This study employed a mixed method research (quantitative and qualitative). The research design used was a pre-test-post-test three treatment design (adapted from Cohen et al., 2018) (**Table 1**). The research was conducted for one semester in 2021. Learning in three classes of genetics was carried out asynchronously and synchronously. What distinguishes the three classes is the strategy, namely PBL, RQA, and PBL-RQA. The class that is considered the control class is RQA because this strategy has always been applied in the genetics course in the past. However, because the research was carried out during the pandemic, all processes must be supported by technology, so that the control class is also supported by technology.

Table 1. Research design

Pre-test	Treatment	Post-test
O_1	X_1: TPACK-based PBL	O_2
O_3	X_2: TPACK-based RQA	O_4
O_5	X_3: TPACK-based PBL-RQA	O_6

The PBL strategy consists of five stages, namely: student orientation to problems, organizing students to learn, guiding group investigations, developing, and submitting work, analyzing, and evaluating the problem solving process (Arends, 2012). The RQA strategy consists of several stages, namely reading the literature that has been given, compiling questions, answering questions, sharing, and reviewing (Bahri & Corebima, 2015). The PBL-RQA strategy is carried out by inserting and combining the stages of PBL and RQA so that they complement each other. PBL-RQA has six stages, namely: problem orientation and reading literature, making questions as problems and answers as solutions, organizing students to study, conducting investigations and group discussions, developing, and submitting work, analyzing, and evaluating the problem solving process (Bahri et. al., 2019). In detail, the learning process of the three classes is presented in **Table 2**.

Respondent

This study has received ethical approval from the participating universities and students. Respondents of this study were fourth semester students of the biology

Table 2. Active learning process in three classes based on TPACK model

No	Class	Technological (T)	Pedagogical (P)	Content knowledge (CK)
1	TPACK-based PBL	Discussion using: **Asynchronous:** WhatsApp groups Assignment collection: SIPEJAR (LMS at Universitas Negeri Malang/ Google Classroom Exams & giving creativity questions through Google Forms Video: YouTube *Virtual laboratory* from Harvard University MEGA software for phylogenetic tree generation **Synchronous:** *Zoom Meeting* & *Google Meet*	**Teaching strategy PBL** with following stages: **Asynchronous** (4 days): *first*, student orientation on the problem; *second*, organize students to study; *third*, guide group investigation; **Synchronous** (2 days): *fourth*, students develop and present their work through group presentations; & *fifth*, analyze and evaluate the problem solving process	**Genetics 2:** Genetic CK includes (each week 1 material): (1) get to know the scope of genetics; (2) regulation of gene expression in prokaryotic organisms; (3) regulation of gene expression in eukaryotic organisms; (4) genetic control of immune response; (5) genetic control of cell division; (6) genetics of sex expression, one gene one enzyme hypothesis, gene work interaction; (7) definition, enzymes, & specifics of recombination; (8) transformation & transduction in bacteria, conjugation in bacteria, & recombination in bacterial phages; (9) genetic material in population genetic engineering as a form of application of genetics in modern biotechnology

Table 2 (Continued). Active learning process in three classes based on TPACK model

No	Class	Technological (T)	Pedagogical (P)	Content knowledge (CK)
2	TPACK-based RQA	Same with TPACK-based PBL	**Teaching strategy RQA** with the following stages: **Asynchronous** (4 days): *first,* students read & make summaries; *second,* students make questions; *third*, students answer questions that have been made; **Synchronous** (2 days): *fourth*, students have discussions; & *fifth*, do a review	Same with TPACK-based PBL
3	TPACK-based PBL-RQA	Same with TPACK-based PBL	**Teaching strategy PBL-RQA** with the following stages: **Asynchronous** (4 days): *first*, student orientation on problems and directing students to read literature and summarize; *second,* students make questions about reading material as problems and then answer the questions as temporary solutions; *third*, organize students to study; *fourth*, guiding the investigation and group discussion; **Synchronous** (2 days): *fifth*, develop and submit work through group presentations; & *sixth,* analyze & evaluate the problem solving process	Same with TPACK-based PBL

study program, Universitas Negeri Malang, Indonesia, who programmed the genetics course. All respondents had been asked for consent to participate in the study through informed consent, and all students agreed.

A total of three classes that programmed the genetics course were tested for equivalence by using the value of students prior knowledge of genetics. The class equivalence test aims to find out, which classes can be used in research that has equal abilities. Based on the results of the normality test, all classes showed normally distributed data with a significance value of 0.93, 0.99, and 0.09 (significance value>0.05), and then the ANCOVA test was continued. The results of the ANCOVA test showed that the significance level of the initial knowledge of genetics was 0.17>0.05, which means that there was no difference in the initial knowledge of genetics in all classes. All classes are equal.

The learning process of each class uses TPACK-based active learning with different strategies, namely PBL, RQA, and PBL-RQA. The details of the three classes are PBL class with 23 students consisting of three boys and 20 girls, RQA class with 26 students consisting of five boys and 21 girls, and PBL-RQA class with 20 students consisting of four men and 16 women. Each class is divided into nine groups with two-three people.

Data Collection and Research Instruments

Student creativity data was collected through giving a pre-test at the beginning of the semester and a post-test at the end of the semester. The test is in the form of open-ended questions distributed via Google Forms. Creativity indicators consist of curiosity, fluency, originality, elaboration, flexibility (Greenstein, 2012), and metaphorical thinking (Treffinger et al., 2002). The creativity test consists of five discourses on genetic problems in everyday life. Each discourse consists of six questions with each indicator one question. In total there are 30 questions. The following is an example of a question used in this study, with the topic of genetic engineering (**Table 3**).

These questions are first analyzed for validity and reliability. Test the validity of the questions processed with the Pearson product moment correlation. The results of the validity of the questions on the creativity test showed that from the 30 questions, there was one

Table 3. Discourse and questions on creativity test

Discourse number one	
Case of COVID-19 pandemic is a very serious concern for all people in the world. Various symptoms suffered by humans who are infected with this virus, but many humans also have no symptoms at all or what are commonly called asymptomatic people, reason why some people infected with coronavirus have no symptoms at all, while others are seriously ill is one of the biggest puzzle of this pandemic. A study published in scientific journal Nature of more than 2,200 patients treated in intensive care facilities identified a specific gene that may be reason. Too little production of interferon can cause virus to multiply rapidly, leading to more severe symptoms. Two other recent studies published in journal Science also implicate role of interferon in case of COVID-19, through genetic mutations & autoimmune disorders that affect its production (https://news.detik.com/).	
Indicator	**Question**
Curiosity	1. Based on the above phenomenon, formulate 4 questions related to gene mutations!

Table 3 (Continued). Discourse and questions on creativity test

Indicator	Question
Fluency	2. Give some alternatives or ways to prevent the problem of gene mutations and the purpose of these methods!
Originality	3. Design a product of logical ideas to address the problem of genetic mutations and autoimmune disorders!
Elaboration	4. Based on the above phenomenon, give a detailed explanation and facts about the problem of gene mutations! (explanation can be more than 1)
Flexibility	5. Predict some possibilities that will occur in everyday life if there is a gene mutation!
MT	6. Write some analogies or illustrations about the phenomenon of gene mutation cases in this COVID-19 phenomenon based on what you observe every day!
Discourse number two	
The exchange of genetic material in bacteria is also referred to as genetic recombination. Recombination of genetic material in bacteria is divided into three, namely transformation, transduction, and conjugation. Transformation is the transfer of genetic material (DNA) from one bacterium to another in which the donor bacteria are lysed bacteria. Transduction is the transfer of genetic material from one bacterial cell to another by using a viral vector. Conjugation is the transfer of genetic material from one bacterium to another by forming cytoplasmic bridges.	
Curiosity	1. Based on the concept above, formulate 4 questions related to genetic recombination in bacteria!
Fluency	2. Give some ways of bacterial genetic recombination and the purpose of these methods!
Originality	3. Design logical bacterial genetic recombination ideas!
Elaboration	4. Based on the above discourse, give a detailed explanation and facts about bacterial transformation! (explanation can be more than 1)
Flexibility	5. Predict some possibilities that will happen in everyday life if there is no transformation of bacteria!
MT	6. Write some analogies or illustrations about the mechanism of bacterial genetic recombination based on what you observe every day!
Discourse number three	
The island of Java has various ethnic groups, including Bedouin & Tenggerese. If two tribes are isolated from landscapes such as mountains, rivers, valleys, hills, & there is no population movement, so that marriages occur only between these tribes.	
Curiosity	1. Based on the above phenomenon, formulate 4 questions related to the genetic material in the population!
Fluency	2. Give some alternatives or ways for the exchange of genetic material in the population and the purpose of these methods!
Originality	3. Design logical ideas to overcome the phenomenon!
Elaboration	4. Based on the above phenomenon, give a detailed explanation and facts about the genetic material in the population! (explanation can be more than 1)
Flexibility	5. Predict some possibilities that will occur in everyday life if this phenomenon occurs!
MT	6. Write some analogies or illustrations about this phenomenon based on what you observe every day!
Discourse number four	
Mrs. Bunga owns a cattle farm and wants her cows to be disease resistant and have good quality meat. Currently, the cows owned by Mrs. Bunga do not have the expected quality, for example beef cattle of good quality but less resistant to disease, cattle that are not diseased but have poor quality meat. Mrs. Bunga is confused about how to get these superior cows.	
Curiosity	1. Based on the above phenomenon, formulate 4 questions related to genetic engineering!
Fluency	2. Give some alternatives or ways to make Mother Bunga's cow superior and the purpose of that method!
Originality	3. Design a product of logical ideas to solve the problem!
Elaboration	4. Based on the above phenomenon, give a detailed explanation and facts about genetic engineering in animals! (explanation can be more than 1)
Flexibility	5. Predict some possibilities that will occur in everyday life if this phenomenon occurs!
MT	6. Write some analogies or illustrations about this phenomenon based on what you observe every day!
Discourse number five	
The emergence of commercialized genetically modified crops has provided economic benefits to farmers and communities in various countries. However, genetically modified plants are a source of controversy in society. There are people who are pro and contra against these genetically modified plants. Various examples of controversial crops are GM soybean, GM corn, GM cotton, GM tomato, and so on. Many plants are engineered so that they have superior properties possessed by animals, bacteria, and fungi. An example of genetic engineering is a luminous ornamental plant. The light of these ornamental plants comes from the gene of the Bioluminescence fungus. Genetic engineering does not only occur in plants but also in animals.	
Curiosity	1. Based on the above phenomenon, formulate four questions related to genetic engineering that occurs in plants to produce superior traits such as animals, bacteria, and fungi!
Fluency	2. Give some alternatives or ways to do genetic engineering on animals, plants, & fungi & purpose of the methods!
Originality	3. Design a product from logical ideas to produce plants that have superior traits like animals through genetic engineering!
Elaboration	4. Based on the above phenomenon, give a detailed explanation and facts about genetic engineering in plants! There can be more than one explanation.
Flexibility	5. Predict some possibilities that will occur in everyday life if there is genetic engineering of plants so that plants have superior traits that exist in animals!
MT	6. Write some analogies or illustrations about phenomenon of genetic engineering on what you observe every day!

Note. MT: Metaphorical thinking

Table 4. Summary of Pearson validity test results

Question no	r_{count}	r_{table} 5% (69)	Sig.	Criteria
1	0.137	0.233523	0.262	Invalid
2	0.435	0.233523	0.000	Valid
3	0.437	0.233523	0.000	Valid
4	0.453	0.233523	0.000	Valid
5	0.573	0.233523	0.000	Valid
6	0.540	0.233523	0.000	Valid
7	0.345	0.233523	0.004	Valid
8	0.447	0.233523	0.000	Valid
9	0.419	0.233523	0.000	Valid
10	0.581	0.233523	0.000	Valid
11	0.617	0.233523	0.000	Valid
12	0.437	0.233523	0.000	Valid
13	0.385	0.233523	0.001	Valid
14	0.459	0.233523	0.000	Valid
15	0.584	0.233523	0.000	Valid
16	0.632	0.233523	0.000	Valid
17	0.579	0.233523	0.000	Valid
18	0.508	0.233523	0.000	Valid
19	0.527	0.233523	0.000	Valid
20	0.504	0.233523	0.000	Valid
21	0.531	0.233523	0.000	Valid
22	0.464	0.233523	0.000	Valid
23	0.538	0.233523	0.000	Valid
24	0.496	0.233523	0.000	Valid
25	0.453	0.233523	0.000	Valid
26	0.665	0.233523	0.000	Valid
27	0.552	0.233523	0.000	Valid
28	0.617	0.233523	0.000	Valid
29	0.535	0.233523	0.000	Valid
30	0.592	0.233523	0.000	Valid

invalid question, namely discourse number one, on question number one (**Table 4**). The invalid questions were not used in the test both the pre- and post-test. The reliability of the questions was processed using Cronbach's alpha. Based on Cronbach's alpha value of 0.89, the reliability criteria of 29 questions are categorized as very high. The results of the validity and reliability of creativity questions indicate that the questions can be used as instruments in measuring student creativity.

The data from the pre- and post-test were assessed by assessing creativity (**Table 5**). The results of the creativity pre-test normality test obtained the results of Sig. 0.59, and the post-test of creativity obtained the results of Sig. 0.34, meaning that the data is normally distributed. The results of the homogeneity test of the pre- and post-test of creativity obtained a significance of $p>0.05$, namely 0.11 and 0.13, meaning that the data is homogeneous.

Data Analysis

The statistical analysis used for pre- and post-test data was ANCOVA. The research hypotheses were tested using ANCOVA at a significance level of 5%. If the result is significant, it will be tested further using least significant difference. The data must be normally

Table 5. Creativity test assessment

Creativity indicator	Score	Descriptor
Curiosity	4	The answer displays 3 relevant questions about a phenomenon.
	3	The answer displays 2 relevant questions about a phenomenon.
	2	The answer displays 1 relevant question about a phenomenon.
	1	The answer does not show the relevant question.
Fluency	4	The answer raises some relevant ideas to solve the problem & its purpose.
	3	The answer raises some relevant ideas to solve the problem without setting the goal.
	2	The answer raises 1 relevant idea to solve the problem with or without a goal.
	1	Answer does not generate relevant ideas to solve the problem.
Originality	4	Answers generate ideas that are innovative, relatively new, unique, or unusual & relevant to the given problem.
	3	The answer raises 1 idea that is innovative, relatively new, unique, or unusual & relevant to the given problem.
	2	The answer raises an idea that is not innovative, the idea is already in the discourse.
	1	Answer does not generate ideas.
Elaboration	4	The answers show some ideas that explain in detail by adding some existing facts.
	3	The answer displays 1 idea that explains it in detail by adding some existing facts.
	2	The answer displays 1 idea that explains in detail by adding one existing fact.
	1	Answers do not provide explanations & do not add facts.
Flexibility	4	The answer displays 3 kinds of ideas that are logical & relevant to the problem given from different points of view.
	3	The answer presents 2 kinds of ideas that are logical & relevant to the problem given from different points of view.
	2	The answer displays 1 kind of logical & relevant idea to the problem given from various different points of view.
	1	The answer does not present logical & relevant ideas to problem given from different points of view.
Metaphorical thinking	4	The answer displays some precise & logical analogies or illustrations.
	3	The answer displays 1 analogy or illustration that is correct and logical.
	2	The answer displays 1 analogy or illustration that is less or inaccurate.
	1	Answers do not provide analogies or illustrations.

Note. Source: Modification of Greenstein (2012)

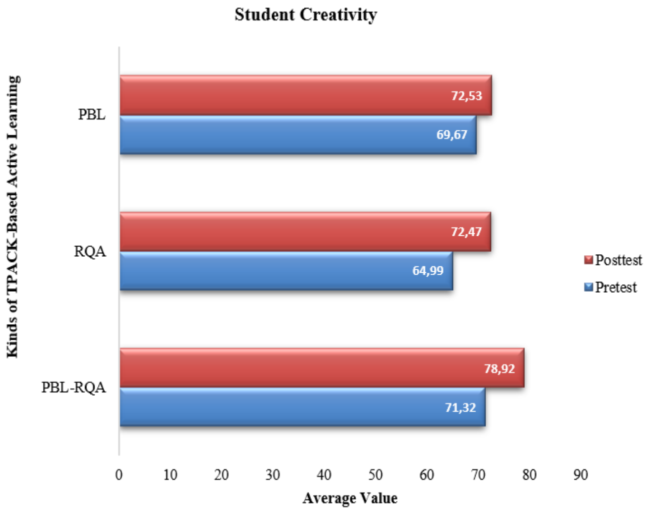

Figure 1. Average value of student creativity in TPACK-based active learning in genetics course (Source: Authors' own elaboration)

distributed and homogeneous before being analyzed using ANCOVA. The normality test was carried out with the one-sample Kolmogorov-Smirnov test on the pre- and post-test scores. The homogeneity test of data variance was carried out using Levene's test of equality of error variance. A homogeneity test was carried out on the pre- and post-test scores. All data testing was carried out using the SPSS version 25.0 program for windows. The data is also explained qualitatively from the results of student answers.

RESULTS

TPACK-based active learning with various teaching strategies, namely PBL, RQA, and PBL-RQA, showed that the three classes experienced an increase in student creativity (**Figure 1**).

Student creativity in various strategies has a significance value of 0.17. These results indicate that there is no difference in student creativity in the application of several strategies because all classes have increased (**Table 6**). So, the three classes with three different strategies both showed an increase in student creativity. The increase in creativity in the three classes with various strategies showed no significant difference in increasing student creativity (**Table 7**).

Table 7. Corrected average value of student creativity in the three TPACK-based active learning classes

No	Class	Corrected average	LSD notation
1	TPACK-based PBL	71.547	a
2	TPACK-based RQA	75.547	a
3	TPACK-based PBL-RQA	76.676	a

The results showed that the creativity of students in all classes increased, but between classes did not differ in increasing creativity. The results of the analysis of student answers also show the development of student creativity. Student creativity can be seen from several indicators, namely curiosity, fluency, originality, elaboration, flexibility (Greenstein, 2012), and metaphorical thinking (Treffinger et al., 2002). The following are examples of student answers to various questions based on creativity indicators. Student answers, as follows:

Question number 1 (curiosity): DF students formulate the following questions:

1. What is the impact of genetic engineering on plants that have superior traits that exist in animals, bacteria, and fungi?
2. What are the mechanisms for obtaining these superior seeds?
3. Are there differences that occur in plants that have superior traits that exist in animals, bacteria, and fungi?
4. Will transgenic plants cause the balance of the ecosystem to be disturbed?

The answers of DF students have presented four relevant questions about a phenomenon based on the discourse on genetic engineering.

Question number 2 (fluency): ZR students provide several alternatives or ways to do genetic engineering:

> Alternatives or ways to carry out genetic engineering to produce superior organisms include: first, obtained through collection and selection of wild-types which are then cultivated. The second is selective breeding, which is crosses carried out on plants or animals with the desired traits. In addition, it can be by mutagenesis and cell fusion. Another alternative to obtain superior organisms is by breeding through modern

Table 6. Results of ANCOVA analysis: Effect of TPACK-based active learning on student creativity

Source	Type III sum of squares	df	Mean square	F	Sig.	Partial eta squared
Corrected model	3,709.684[a]	3	1,236.561	14.877	.000	.407
Intercept	539.867	1	539.867	6.495	.013	.091
Pretest	3,124.740	1	3,124.740	37.593	.000	.366
Class	302.633	2	151.317	1.820	.170	.053
Error	5,402.770	65	83.120			
Total	390,682.957	69				
Corrected total	9,112.455	68				

Note. [a]R squared=.407 (adjusted R squared=.380)

> biotechnology that produces genetically engineered products.

ZR students answers gave rise to several relevant ideas for solving the problem and its objectives regarding genetic engineering.

Question number 3 (originality): AR students design a product from logical ideas to produce plants that have superior traits that exist in animals through genetic engineering:

> I have an idea that is to create rice that contains insulin and rice that contains protein, so that Asian consumers whose staple food is rice, don't worry about diabetes and protein deficiency. The trick is to insert insulin into the bacteria, which is then injected into rice through recombinant technology.

AR students answers bring up ideas that are innovative, relatively new, unique, or unusual and relevant.

Question number 4 (elaboration): YZ students provide explanations and facts about genetic engineering in plants:

> Agricultural crops resulting from genetic engineering are classified based on the structure and strategies used in reconstructing transgenic crops, classified into four generations. In the first generation or single trait classification, plants containing GMO elements are commonly used. In the second generation of GMOs, plants are usually the result of crosses between the commercial first generation. In the third generation, plants are referred to as near-intragenic, where transgenic elements are not used in other transgenic plants, and the fourth generation is plants classified as intragenic and cisgenic. Bt rice is resistant to stem borer, papaya is resistant to papaya ringspot virus, Bt corn and Bt cotton is resistant to Lepidoptera pests, herbicide tolerant soybeans, tomato Flavr Savr with delayed fruit ripening, Golden rice containing beta carotene in the endosperm, and bananas producing vaccines are examples of success. From the application of genetic engineering technology.

YZ students answers show some ideas that are explained in detail by adding some existing facts about genetic engineering in plants.

Question number 5 (flexibility): With the question of predicting some possibilities that will occur in everyday life if there is genetic engineering of plants that have superior traits that exist in animals? AN students provide several possibilities that occur, as follows:

> Some possibilities that will occur in everyday life if there is genetic engineering of plants that have superior traits that exist in animals, namely high production power, high nutritional quality, high resistance to disease and environmental stress, low need for fertilizers, and other chemicals.

AN students answers presented three kinds of logical and relevant ideas to the problem of genetic engineering.

Question number 6 (metaphorical thinking): AJ students write some analogies or illustrations about the phenomenon of genetic engineering:

> Analogies or illustrations about the genetic engineering phenomenon based on things I observe every day, for example, from bad selfies edited in photoshop to good and interesting photos; the addition of a feature to an existing product so that the product undergoes an update that is superior but does not eliminate the original nature of the product.

AJ students answers provide some precise and logical analogies or illustrations. Metaphorical thinking can optimize conceptual understanding of the given problems, especially genetic problems found in everyday life.

DISCUSSION

TPACK-based active learning with various teaching strategies, namely PBL, RQA, and PBL-RQA can increase student creativity. This is in accordance with the previous work by Samašonok and Leškienė (2015). They revealed that teaching strategies and methods that stimulate imagination are recommended to build favorable environments and conditions to develop creativity and encourage students to apply problem solving. Strategies that support the teaching and learning process are usually based on design-based learning, problem solving, creative thinking, research-based learning, PBL, and project-based learning. These various teaching strategies aim to create innovation in creative learning, create process thinking, especially creativity in thinking about something new and different (Seechaliao, 2017).

The TPACK model supports the three teaching strategies of PBL, RQA, and PBL-RQA which are applied in active learning in the genetics course. According to Doering et al. (2009), that active learning requires a framework in the form of a TPACK model in online learning. The application of TPACK model in learning can assist educators in conveying learning concepts to students, motivate students to learn, provide opportunities for students to be more active in experimenting according to concepts, evaluate, provide feedback on the results of student assignments, and assist students in communicating various solutions

(Stoilescu, 2015). Specific strategies on three aspects of knowledge, namely technology, pedagogy, and content are also needed by educators in learning genetics (Aivelo & Uitto, 2018). TPACK model is needed by educators to integrate technology in learning effectively (Koehler et al., 2013; Mishra & Koehler, 2008).

Various platforms and learning management system (LMS) are used in the active learning process based on this TPACK model. The platforms and LMS used are Google Meet, Zoom Meeting, WhatsApp Group, and SIPEJAR (LMS at Universitas Negeri Malang). In addition, to broaden students' knowledge, they are provided with knowledge about applications and how to use virtual laboratories from Harvard University. Students are given various videos from YouTube on each learning material to clarify their imagination and increase their creativity regarding genetics learning which is usually abstract. Students are also given knowledge about how to make phylogenetic trees by accessing gene banks through National Center for Biotechnology Information and using MEGA software. Active learning is not only used in an offline environment but also in an online environment (Banayo & Barleta, 2022; Brown, 2014; Hatta et al., 2020; Kuo & Kuo, 2015). The e-learning system in an online learning environment is used to develop creative thinking of students in higher education (Songkram, 2015). Online learning can help students develop creativity by using asynchronous online discussions, textbooks, and materials developed by educators (Corfman, 2017).

Online activities are widely used as learning media to support TPACK model during the pandemic. The right use of online learning can support creativity (Northcott et al., 2007). The technology used by students in learning aims to build their ability to practice creative thinking, work creatively with others, and innovate (NEA, 2012). Educators who teach online using appropriate technology for asynchronous online discussion can help students to develop their creative skills (Corfman, 2017). Creativity can also be achieved in an online environment through the use of various forms of technology (Riegel & Kozen, 2016).

In addition to technology, there is an element of pedagogy in TPACK model. Empowering students creativity requires developing a pedagogy that is different and better than the traditional lecture and information transfer models of the past. Online learning must evolve from a passive lecture method to a more engaged, dynamic process to maximize student learning (Joy, 2015). Active learning with appropriate pedagogical and content knowledge can create creativity in an effort to improve the quality of learning (Kutaka-Kennedy, 2015).

The teaching strategy in active learning based on TPACK model in this study was carried out with several strategies, namely PBL, RQA, and PBL-RQA. Creativity can actually be increased with these three strategies. This result is due to the various strategies applied in the learning process that have the same goals with their respective advantages. PBL has the advantage that students are invited to think more creatively in solving problems in everyday life. RQA has the advantage that students are expected to have a sense of curiosity through the stages of reading and to ask questions so as to bring up their new ideas. PBL-RQA is a combination of both PBL and RQA teaching strategies which has the advantage that students have more knowledge, ideas, and the development of creativity in solving problems through problem orientation, reading, and asking questions.

PBL resulted in greater student involvement in classroom activities. Students are guided and directed to be actively involved in building new knowledge through identifying and solving unstructured daily life problems (Choden & Kijkuakul, 2020). In PBL, students tackle real problems under the supervision of an educator (Fonseca & Gómez, 2019). The application of PBL affects students conceptual development for the better, positive changes in problem solving skills, and keeping their misconceptions at the lowest level (Akinoglu & Tandogan, 2007). PBL must be designed properly so that it gets maximum results in empowering and improving the skills needed by students in the world of work (Lapek, 2018). Classes with the RQA strategy are able to increase student involvement in the learning process through discussion forums both individually and in groups (Bahri & Corebima, 2015). Reading and asking questions that are carried out at the stage of the RQA strategy, it can improve students higher order thinking skills (Hariyadi et al., 2017). In the PBL-RQA strategy, where students are faced with various unstructured problems that come from everyday life. Through various stages such as problem orientation, reading, and asking students to make the problem more structured and clearer (Bahri et al., 2019).

The three teaching strategies of PBL, RQA, and PBL-RQA need to be well designed by educators so that their various advantages have an impact on the development and improvement of various 21st century skills, one of which is creativity. Different teaching strategies are needed to empower students creativity (Joy, 2015). Creative instructional design should be incorporated into the teaching of educators to develop the knowledge and skills needed to shape student development, particularly the development of creativity (Kaplan, 2019). Creativity can be presented in virtual classrooms through the development of appropriate content and teaching strategies by educators (Joy, 2015).

Knowledge of genetic content can be seen from the various student answers to the creativity test after TPACK-based active learning is carried out. The answers were assessed using the rubric of creativity which refers to a modification of Greenstein (2012). The results show that students creativity has increased. This phenomenon is indicated by the answers of students who have met the five indicators of creativity according to Greenstein (2012), namely curiosity, fluency, originality, elaboration, flexibility, and one indicator according to Treffinger et al. (2002), namely metaphorical thinking.

Based on student answers for the curiosity indicator, DF students have presented four relevant questions about a phenomenon based on the given discourse. Students already have a curiosity about genetic engineering phenomena that occur in everyday life, so from this curiosity, new ideas emerge from students. According to Greenstein (2012), curiosity means investigating, asking questions, seeking deeper meaning. Curiosity is a strong motivator for learning and behavior and is closely related to the emergence of one's creativity (Gross et al., 2020). The second indicator is fluency. ZR students on questions with fluency indicators provide answers by bringing up several relevant ideas to solve problems and their objectives regarding genetic engineering.

According to Greenstein (2012), fluency is a person's ability to produce a number of ideas. According to Treffinger et al. (2002), fluency refers to the quantity or ability of a person to generate ideas in large numbers. A person's ability to respond to open-ended questions or refer to a person's thought process.

Based on AR students answers to questions with indicators of originality, they have brought up ideas that are innovative, relatively new, unique, or unusual and relevant. These unusual ideas will bring up and increase student creativity, especially in the genetics course. According to Treffinger et al. (2002), originality refers to the ability to generate new and unusual ideas. According to Greenstein (2012), originality is ideas that are new, fresh, unique, or unusual generated by someone. Originality is needed to generate creativity in the fields of science and art (Scheffer et al., 2017).

Another indicator is elaboration. YZ students provide answers to questions with elaboration indicators. YZ has presented some ideas in detail by adding some facts about the genetic engineering of plants. Elaboration refers to the ability to add detail, beautify, and expand ideas (Shively, 2011). Elaboration involves making ideas richer, more interesting, and more complete (Treffinger et al., 2002). In the questions with flexibility indicators, AN students presented three kinds of ideas that were logical and relevant to problems regarding genetic engineering that occur in everyday life. The logical and relevant ideas are presented from different points of view. This is in accordance with the statement of Greenstein (2012), that flexibility is an idea that shows various possibilities. Flexibility is the ability to see topics from different perspectives (Shively, 2011). Flexibility refers to the ability to change the direction of one's thinking or change the point of view of one's thinking. Flexibility involves being open to reviewing ideas or experiences (Treffinger et al., 2002).

Metaphorical thinking indicators require students to display some appropriate and logical analogies or illustrations. The answers of AJ students on the indicators of metaphorical thinking have shown an analogy about the genetic engineering phenomenon associated with daily activities. According to Treffinger et al. (2002), that metaphorical thinking can optimize conceptual understanding of the problems found in everyday life. Metaphorical thinking refers to the ability to use comparisons or analogies to make new connections. Navaneedhan and Kamalanabhan (2016) stated that metaphorical thinking helps students to generate and refine ideas. Metaphorical thinking will build self-regulation planning, monitoring, and evaluation of their own thinking which allows them to form the right attitude and acquire knowledge.

The results of this study indicate that the TPACK-based PBL, RQA, and PBL-RQA teaching strategies do not differ in increasing student creativity in the genetics course. Therefore, these three strategies can be used in genetics or other courses. But all three also have their own limitations.

A limitation of the PBL class is that students need a lot of time to find solutions to the problems given. The RQA class has limitations, namely that a small number of students have similar questions and answers. This may be caused by the reference as the same reading material from the lecturer. The PBL-RQA class has limitations caused by the relatively long stages, so students need a relatively longer time than PBL and RQA. Limitations also occur in technological aspects such as: digital devices such as laptops or cellphones that do not support and unstable signals.

Limitation

In this study, no conventional strategy was used for the control class. Usually before the pandemic, genetics courses were taught with the RQA strategy. However, because this research was carried out during the COVID-19 pandemic, research must use various technologies, both asynchronously and synchronously. The strategy used to become RQA based on the TPACK model, is the same as that carried out in the other two class treatments, so that it becomes a limitation in the study which causes all classes to be treatment (without a control class).

CONCLUSION

Student creativity in genetics can be enhanced by various teaching strategies such as PBL, RQA, and PBL-RQA. The teaching strategy is implemented in active learning based on the TPACK model. However, each teaching strategy has different limitations in its implementation. Therefore, if they are going to implement the three teaching strategies, educators are expected to be able to prepare them well to overcome these limitations. The solution to overcoming the limitations of these teaching strategies can be an opportunity for further research.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: This study was supported by Universitas Negeri Malang PNBP, which has provided funding support through the 2021 funding Doctoral Dissertation Research with Contract Number: 5.3.530/UN32.14.1/LT/2021.

Acknowledgements: The authors would like to thank to late Prof. Dr. Mohamad Amin for the assistance in this research.

Ethical statement: Authors stated that Universitas Negeri Malang does not yet have a specific protocol for this type of research. Research permission was obtained from Universitas Negeri Malang with letter number 5.3.1900/UN32.14/LT/2021. Authors further stated that the informed consents were obtained from the participants. Data was treated as confidential information used exclusively for research purposes and it is not possible to identify participants from the data.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Aivelo, T., & Uitto, A. (2018). Teachers' approaches to genetics teaching mirror their choice of content and avoidance of sensitive issues. *BioRxiv*, 350710. https://doi.org/10.1101/350710

Akinoglu, O., & Tandogan, R. O. (2007). The effects of problem-based active learning in science education on students' academic achievement, attitude, and concept learning. *EURASIA Journal of Mathematics, Science and Technology Education, 3*(1), 71-81. https://doi.org/10.12973/ejmste/75375

Alrwaished, N., Alkandari, A., & Alhashem, F. (2017). Exploring in- and pre-service science and mathematics teachers' technology, pedagogy, and content knowledge (TPACK): What next? *EURASIA Journal of Mathematics, Science and Technology Education, 13*(9), 6113-6131. https://doi.org/10.12973/eurasia.2017.01053a

Arends, R. I. (2012). *Learning to teach*. McGraw-Hill.

Atun, H., & Usta, E. (2019). The effects of programming education planned with TPACK framework on learning outcomes. *Participatory Educational Research, 6*(2), 26-36. https://doi.org/10.17275/per.19.10.6.2

Bahri, A., & Corebima, A. D. (2015). The contribution of learning motivation and metacognitive skill on cognitive learning outcome of students within different learning strategies. *Journal of Baltic Science Education, 14*(4), 487-500. https://doi.org/10.33225/jbse/15.14.487

Bahri, A., Suryani Idris, I., Nurman, R., & Ristiana, E. (2019). PBLRQA strategy potential in enhancing metacognitive skills of students with different academic achievement. *Journal of Physics: Conference Series, 1317*, 012199. https://doi.org/10.1088/1742-6596/1317/1/012199

Banayo, A., & Barleta, C. J. (2022). Online education as an active learning environment in the new normal. *International Journal of Educational Management and Development Studies, 2*(4), 72-96. https://doi.org/10.53378/352078

Brown, A. L. (2014). Implementing active learning in an online teacher education course. *American Journal of Distance Education, 28*(3), 170-182. https://doi.org/10.1080/08923647.2014.924695

Brown, C. A., & Neal, R. E. (2011). *Using 21st century thinking skills applied to the TPACK instructional model* [Paper presentation]. Annual Meeting of the AECT International Convention.

Choden, T., & Kijkuakul, S. (2020). Blending problem based learning with scientific argumentation to enhance students understanding of basic genetics. *International Journal of Instruction, 13*(1), 445-462. https://doi.org/10.29333/iji.2020.13129a

Cimer, A. (2012). What makes biology learning difficult and effective: Students views. *Educational Research and Reviews, 7*(3), 61-71.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education*. Routledge. https://doi.org/10.4324/9781315456539

Corfman, T. D. (2017). *Creativity in asynchronous online discussions* [Doctoral dissertation, Walden University].

Doering, A., Veletsianos, G., Scharber, C., & Miller, C. (2009). Using the technological, pedagogical, and content knowledge framework to design online learning environments and professional development. *Journal of Educational Computing Research, 41*(3), 319-346. https://doi.org/10.2190/EC.41.3.d

Duncan, R. G., & Tseng, K. A. (2011). Designing project-based instruction to foster generative and mechanistic understandings in genetics. *Science Education, 95*(1), 21-56. https://doi.org/10.1002/sce.20407

Fauzi, A., & Fariantika, A. (2018). Courses perceived difficult by undergraduate students majoring in biology. *Biosfer, 11*(2), 78-89. https://doi.org/10.21009/biosferjpb.v11n2.78-89

Fauzi, A., & Ramadani, S. D. (2017). Learning the genetics concepts through project activities using drosophila melanogaster: A qualitative Descriptive study. *Journal of Biological Education Indonesia, 3*(3), 238-247. https://doi.org/10.22219/jpbi.v3i3.4897

Ferrari, A., Cachia, R., & Punie, Y. (2009). Innovation and creativity in education and training in the EU member states: Fostering creative learning and supporting innovative teaching. *JRC*. https://publications.jrc.ec.europa.eu/repository/handle/JRC62370

Ferreira, M., & Trudel, A. (2012). The impact of problem based learning (PBL) on student attitudes toward science, problem-solving skills, and sense of community in the classroom. *Journal of Classroom Interaction, 47*(1), 23-30.

Fonseca, V. M. F., & Gómez, J. (2017). Applying active methodologies for teaching software engineering in computer engineering. *Revista Iberoamericana de Tecnologias Del Aprendizaje* [*Iberoamerican Journal of Learning Technologies*], *12*(3), 147-155. https://doi.org/10.1109/RITA.2017.2738178

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *PNAS, 111*(23), 8410-8415. https://doi.org/10.1073/pnas.1319030111

Greenstein, L. (2012). *Assessing 21st century skills: A guide to evaluating mastery and authentic learning*. SAGE.

Gross, M. E., Zedelius, C. M., & Schooler, J. W. (2020). Cultivating an understanding of curiosity as a seed for creativity. *Current Opinion in Behavioral Sciences, 35*, 77-82. https://doi.org/10.1016/j.cobeha.2020.07.015

Hariyadi, S., Corebima, A. D., Zubaidah, S., & Ibrohim, I. (2017). The comparison of the question types in the RQA (reading, questioning, and answering) learning model and conventional learning model. *International Journal of Humanities Social Sciences and Education, 4*(7), 10-18. https://doi.org/10.20431/2349-0381.0407002

Hatta, P., Aristyagama, Y. H., Yuana, R. A., & Yulisetiani, S. (2020). Active learning strategies in synchronous online learning for elementary school students. *Indonesian Journal of Informatics Education, 4*(2), 86-93. https://doi.org/10.20961/ijie.v4i2.46019

Irdalisa, Paidi, & Djukri. (2020). Implementation of technology-based guided inquiry to improve TPACK among prospective biology teachers. *International Journal of Instruction, 13*(2), 33-44. https://doi.org/10.29333/iji.2020.1323a

Johnson, J., & Jackson, F. (2015). Use of multiple intelligence modalities to convey genetic and genomic concepts in African American College biology students. *Natural Science, 07*(06), 299-308. https://doi.org/10.4236/ns.2015.76033

Joy, K.-K. (2015). A proposed model to increase creativity, collaboration, and accountability in the online classroom. *International Journal of Information and Education Technology, 5*(11), 873-876. https://doi.org/10.7763/ijiet.2015.v5.630

Kaplan, D. E. (2019). Creativity in education: Teaching for creativity development. *Psychology, 10*(02), 140-147. https://doi.org/10.4236/psych.2019.102012

Kibuka-Sebitosi, E. (2007). Understanding genetics and inheritance in rural schools. *Journal of Biological Education, 41*(2), 56-61. https://doi.org/10.1080/00219266.2007.9656063

Kitchens, B., Means, T., & Tan, Y. (2018). Captivate: Building blocks for implementing active learning. *Journal of Education for Business, 93*(2), 58-73. https://doi.org/10.1080/08832323.2017.1417232

Knippels, M. C. P. J., Waarlo, A. J., & Boersma, K. T. (2005). Design criteria for learning and teaching genetics. *Journal of Biological Education, 39*(3), 108-112. https://doi.org/10.1080/00219266.2005.9655976

Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)? *Journal of Education, 193*(3), 13-19. https://doi.org/10.1177/002205741319300303

Kuo, Y. C., & Kuo, Y. T. (2015). Active learning in online learning environments for adult learners. In *Proceedings of the Annual Convention of the Association of Educational Communications and Technology* (pp. 242-248).

Kutaka-Kennedy, J. (2015). A proposed model to increase creativity, collaboration, and accountability in the online classroom. *International Journal of Information and Education Technology, 5*(11), 873-876. https://doi.org/10.7763/IJIET.2015.V5.630

Lapek, J. (2018). Promoting 21st century skills in problem-based learning environments. *CTETE-Research Monograph Series, 1*(1), 66-85. https://doi.org/10.21061/ctete-rms.v1.c.4

Lombardi, D., Shipley, T. F., Bailey, J. M., Bretones, P. S., Prather, E. E., Ballen, C. J., Knight, J. K., Smith, M. K., Stowe, R. L., Cooper, M. M., Prince, M., Atit, K., Uttal, D. H., LaDue, N. D., McNeal, P. M., Ryker, K., St. John, K., van der Hoeven Kraft, K. J., & Docktor, J. L. (2021). The curious construct of active learning. *Psychological Science in the Public Interest, 22*(1), 8-43. https://doi.org/10.1177/1529100620973974

Maksić, S. B., & Spasenović, V. Z. (2018). Educational science students implicit theories of creativity. *Creativity Research Journal, 30*(3), 287-294. https://doi.org/10.1080/10400419.2018.1488200

Michael, J. (2006). Where's the evidence that active learning works? *American Journal of Physiology-Advances in Physiology Education, 30*(4), 159-167. https://doi.org/10.1152/advan.00053.2006

Millis, B. J. (2012). Active learning strategies in face-to-face courses. *IDEA Paper, 53*, 1-8.

Mintu-Wimsatt, A., Sadler, T., & Ingram, K. (2007). Creativity in online courses: Perceptions of MBA students. *MERLOT Journal of Online Learning and Teaching, 3*(4), 324-330.

Mishra, P., & Koehler, M. J. (2008). *Introducing technological pedagogical content knowledge* [Paper presentation]. Annual Meeting of the American Educational Research Association.

Mitchell, A., Petter, S., & Harris, A. L. (2017). Learning by doing: Twenty successful active learning exercises for information systems courses. *Journal of Information Technology Education: Innovations in Practice, 16*(1), 21-46. https://doi.org/10.28945/3643

Muralidhar, K. (2013). Biology education, creativity, & career. *International Journal of Applied and Natural Sciences, 2*(2), 53-64.

Murray-Nseula, M. (2011). Incorporating case studies into an undergraduate genetics course. *Journal of the Scholarship of Teaching and Learning, 11*(3), 75-85.

Navaneedhan, C. G., & Kamalanabhan, T. J. (2016). Is metaphorical thinking related to development of cognitive structures among learners? *World Scientific News, 52*, 1-13.

NEA. (2012). Preparing 21st century students for a global society: An educator's guide to" the four Cs. *National Education Association*. https://dl.icdst.org/pdfs/files3/0d3e72e9b873e0ef2ed780bf53a347b4.pdf

Nikolopoulou, K. (2018). Creativity and ICT: Theoretical approaches and perspectives in school education. In T. A. Mikropoulos (Ed.), *Research on e-learning and ICT in education* (pp. 87-100). Springer. https://doi.org/10.1007/978-3-319-95059-4_5

Northcott, B., Miliszewska, I., & Dakich, E. (2007). ICT for (I)nspiring (C)reative (T)hinking. In *Proceedings Ascilite Singapore 2007* (pp. 761-768).

Novo, A., Bastos, G., & Vasconcelos, A. I. (2016). Effects of a virtual learning environment on librarians' information literacy and digital literacy competences. In *Proceedings of the European Conference on Information Literacy* (pp. 655-664). https://doi.org/10.1007/978-3-319-52162-6_64

Olatoye, R., Akintunde, S., & Ogunsanya, E. (2010). Relationship between creativity and academic achievement of business administration students in Southwestern Polytechnics, Nigeria. *African Research Review, 4*(3), 134-149. https://doi.org/10.4314/afrrev.v4i3.60164

Papaleontiou-Louca, E., Varnava-Marouchou, D., Mihai, S., & Konis, E. (2014). Teaching for creativity in universities. *Journal of Education and Human Development, 3*(4), 131-154. https://doi.org/10.15640/jehd.v3n4a13

Pllana, D. (2019). Creativity in modern education. *World Journal of Education, 9*(2), 136-140. https://doi.org/10.5430/wje.v9n2p136

Ray Gehani, R. (2011). Individual creativity and the influence of mindful leaders on enterprise innovation. *Journal of Technology Management and Innovation, 6*(3), 82-92. https://doi.org/10.4067/s0718-27242011000300006

Reche, I., & Perfectti, F. (2020). Promoting individual and collective creativity in science students. *Trends in Ecology and Evolution, 35*(9), 745-748. https://doi.org/10.1016/j.tree.2020.06.002

Riegel, C., & Kozen, A. (2016). Attaining 21st century skills in a virtual classroom. *Educational Planning, 23*(3), 41-55.

Rosenberg, J. M., & Koehler, M. J. (2015). Context and technological pedagogical content knowledge (TPACK): A systematic review. *Journal of Research on Technology in Education, 47*(3), 186-210. https://doi.org/10.1080/15391523.2015.1052663

Samašonok, K., & Leškienė, B. (2015). Creativity development: Theoretical and practical aspects. *Journal of Creativity and Business, 1*, 19-34.

Sandika, B., & Fitrihidajati, H. (2018). Improving creative thinking skills and scientific attitude through inquiry-based learning in basic biology lecture toward student of biology education. *Journal of Biological Education Indonesia, 4*(1), 23-28. https://doi.org/10.22219/jpbi.v4i1.5326

Scheffer, M., Baas, M., & Bjordam, T. K. (2017). Teaching originality? Common habits behind creative production in science and arts. *Ecology and Society, 22*(2), 29. https://doi.org/10.5751/ES-09258-220229

Seechaliao, T. (2017). Instructional strategies to support creativity and innovation in education. *Journal of Education and Learning, 6*(4), 201-208. https://doi.org/10.5539/jel.v6n4p201

Shively, C. H. (2011). Grow creativity! *International Society for Technology in Education, 38*(7), 10-15.

Songkram, N. (2015). E-learning system in virtual learning environment to develop creative thinking for learners in higher education. *Procedia-Social and Behavioral Sciences, 174*, 674-679. https://doi.org/10.1016/j.sbspro.2015.01.600

Sothayapetch, P., & Lavonen, J. (2022). Technological pedagogical content knowledge of primary school science teachers during the COVID-19 in Thailand and Finland. *EURASIA Journal of Mathematics, Science and Technology Education, 18*(7), em2124. https://doi.org/10.29333/ejmste/12118

Starbek, P., Starčič Erjavec, M., & Peklaj, C. (2010). Teaching genetics with multimedia results in better acquisition of knowledge and improvement in comprehension. *Journal of Computer Assisted*

Learning, 26(3), 214-224. https://doi.org/10.1111/j.1365-2729.2009.00344.x

Stoilescu, D. (2015). A critical examination of the technological pedagogical content knowledge framework: Secondary school mathematics teachers integrating technology. *Journal of Educational Computing Research, 52*(4), 514-547. https://doi.org/10.1177/0735633115572285

Tanak, A. (2018). Designing TPACK-based course for preparing student teachers to teach science with technological pedagogical content knowledge. *Kasetsart Journal of Social Sciences, 41*(1), 1-7. https://doi.org/10.1016/j.kjss.2018.07.012

Treffinger, D. J., Young, G. C., Selby, E. C., & Shepardson, C. (2002). Assessing creativity: A guide for educators. *The National Research Center on the Gifted and Talented*. https://eric.ed.gov/?id=ED505548

Yilmaz, D., Tekkaya, C., & Sungur, S. (2011). The comparative effects of prediction/discussion-based learning cycle, conceptual change text, and traditional instructions on student understanding of genetics. *International Journal of Science Education, 33*(5), 607-628. https://doi.org/10.1080/09500691003657758

https://www.ejmste.com