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TPACK and Learning Strategies in Genetics: A Pedagogical Study

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Abstract
Genetics is a part of biological science that contains topics such as genetic structure, protein synthesis, cell division, and inheritance of traits. Genetics is one of the most commonly found misconceptions and difficulties in learning this material due to its complex, abstract and rapid development. To overcome these problems, it is necessary to analyse Technological Pedagogical and Content Knowledge (TPACK) and analyse various learning strategies used in teaching genetics so that it can be taken into consideration for teachers in teaching genetics in the classroom. The purpose of writing this article is to analyze TPACK, models, methods, and learning media that have been used to address the various issues described above to inspire teachers in teaching genetics. This research uses descriptive qualitative method by collecting relevant research in the form of national and international articles available on Google Scholar. From the results of the research, it was found that teachers have applied a variety of models, methods, and media in learning genetics. The success in this learning process certainly depends on the teacher's TPACK analysis skills so that the teacher not only pays attention to the content but also can adjust it to the needs of students.

Keywords: TPACK, learning strategies, genetics

1. Introduction

Genetics is a part of biological science that focuses on the study of genes. In genetics, we study how inherited traits are controlled by genetic factors or genes (Klug & Cummings, 1997). According to Etobro and Banjoko (2017), genetics is a scientific discipline that studies the mechanism of gene inheritance from parents to offspring. Offspring inherit genes from both biological parents that determine certain traits, such as physical characteristics, inherited talents, and susceptibility to genetic diseases. The science of genetics covers a wide range of topics, including gene structure and function, reproductive mechanisms, gene expression, genetic mutation and recombination, and the distribution of genes in populations. In addition, genetics also includes practical applications such as genetic engineering. In the independent curriculum, genetics material is taught in phase F in grade XII. According to the Biology Book for SMA/MA class XII published by the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia, this genetics material is discussed in chapter two with the title 'Genetics and Inheritance of Traits' which contains topics such as genetic structure, protein synthesis, cell division, and inheritance of traits.

In biology, misconceptions are often found in concepts, and genetics is no exception (Tekkaya, 2002). Genetics is one of the most commonly found misconceptions and difficulties in learning it, this is because genetics material is often faced with substances that are too complex and abstract in nature. This material includes concepts related to genes, DNA, chromosomes, cell division, and inheritance, which are often seen as difficult by students (Murray-Nseula, 2011; Cimer, 2012; Fauzi & Ramadani, 2017). Research conducted by Fauzi & Fariantika (2018) found that genetics material is often considered a complex domain of knowledge and full of difficult terminology. In addition, the perception of genetics material as abstract and esoteric (Corebima, 2009; Tsui & Treagust, 2010) further adds to the difficulty in understanding concepts by students. Nusantari (2011) and Tekkaya (2002) highlighted that the microscopic objects and processes involved in genetics are often considered far from the context of students' daily lives, making it difficult to be fully absorbed. Another factor that poses a challenge in teaching genetics is the low motivation of learners, which leads to reduced interest and participation in the learning process. In addition, rapid advances in the field of molecular genetics are not in line with the information contained in textbooks, which still focus on classical genetics. This results in the emergence of misconceptions in genetics material (Nusantari, 2011). These misconceptions held by students will eventually become a serious problem. The results of research conducted by Nadelson (2009), Cokadar (2012), and Primandiri & Santoso (2015) show that this inaccurate or incomplete understanding can hinder correct and thorough understanding. Misconceptions on this material have affected all levels of education, from elementary school to college. The difficulties experienced by learners in understanding science subjects, particularly genetics, have posed significant challenges in preparing them for learning at more advanced levels (Bahar, 2003).

Despite the difficulty in understanding this material, it is also important to recognise that genetics material has a very significant relevance in various fields of life, such as health, industry and agriculture. Machova & Ehler (2023) state that genetics has become part of our daily lives in terms of healthcare, agriculture and technology. Similarly, Snustad & Simmons (2012) stated that genetics is closely related to DNA and plays a crucial role in various aspects of human life, such as in agriculture, health, and medicine. However, there are still challenges in the field of education related to teaching genetics, namely learning that is still carried out conventionally, especially through the lecture method (Radjabessy, 2019) without considering a more interactive learning approach. The complexity of this material demands a more holistic and innovative learning approach for students to better understand genetics concepts. On the other hand, studies rarely provide more specific national recommendations on how to target these issues at different levels of the education system. This situation makes the necessary changes in education policy more difficult to implement and achieve (Machova & Ehler, 2023).

To overcome various problems in teaching genetics, it is necessary for teachers to master Technological Pedagogical and Content Knowledge (TPACK). The knowledge a teacher requires to successfully use (digital) technology for teaching topic content is conceptualized in seven areas by the TPACK framework. The three fundamental domains are content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). The application of TPACK in learning plays an important role in creating interactions that allow students to investigate their own learning and knowledge, thus supporting the creation of interactions between educators and students (Dayanti & Hamid, 2021). The purpose of writing this article is to analyze TPACK, models, methods, and learning media that have been used to address the various issues described above to inspire teachers in teaching genetics.

2. Methods

This research uses a qualitative descriptive method. According to Sugiyono (2016), qualitative methods are used to research on natural object conditions, with researchers acting as the main instrument. Descriptive research focuses on assessing the status of human groups, objects, situations, system thinking, and events in the present, with the aim of providing a systematic, factual, and accurate description (Nazir, 2014). The data collection technique in this research is by studying relevant literature from articles, textbooks, interviews with teachers, and analyzing lesson plans used by teachers in the learning process. Literature searches in the form of national and international articles were conducted through the Google Scholar database with the topic of learning strategies on genetics material including approaches, models, methods and media with a range of years 2020-2024 with journal indexes ranging from Sinta 1-6 and Q1-Q3. From this search, 11 articles were obtained which will be analyzed and used to support the author's ideas and become the basis of this article. The purpose of this descriptive qualitative research is to provide an overview of TPACK analysis as well as various learning strategies used to teach biology on genetics.

3. Result and Discussion

3.1. TPACK analysis

TPACK is a unique construction in a learning environment that needs to be supported by its development. A thorough understanding of TPACK will be helpful in developing context-appropriate tactics to carry out high-quality instruction.

Table 1. Cores genetics material

Questions	Big Idea 1 Genetic Substance	Big Idea 2 Protein Synthesis	Big Idea 3 Cell Reproduction	Big Idea 4 Inheritance of Traits	Big Idea 5 Mutations
What should students learn about this concept?	Students are expected to know the structure, function, interrelated location between genes, DNA and chromosomes.	Students are expected to know that DNA has a role in the formation of proteins which ultimately become a form of gene expression.	The difference between meiosis and mitosis, especially in what cells, the number of chromosomes produced and their stages, the purpose of mitotic and meiotic division, and learning and interpreting the relationship between meiosis and	Study the application of Mendel's Laws I & II, monohybrid, dihybrid and pseudo-crossing types.	Mutations in genes and chromosomes. Syndromes caused by autosomal and gonosomal mutations.

			inheritance of traits.		
Why is the concept important for students to master?	Because this concept is a basic concept for students to learn further concepts related to genetics, such as mutation, evolution, and genetic engineering.	Because this material can also be authentic learning that emphasises real problems (there is an essential AA that cannot be synthesised by the body).	This concept is key in understanding the concepts of segregation in trait inheritance and mutation.	Knowing the chances of a cross can serve as a preventive basis for inherited genetic problems.	As a practical value education in life, especially prevention and handling in terms of harmful natural mutations. Knowing the benefits or advantages that can be obtained from artificial mutations.
Related to this concept, what concepts do you think are not yet recognised?	Molecular DNA structure, gene expression leading to enzyme formation, hormones and proteins in depth.	Detailed processes of initiation, elongation and termination in both transcription and translation.	Concepts about fusion of vesicles that form cell plates (in plants). Detailed concepts about G1, G2, and S phase.	Inheritance of traits with more than two different traits. Use of more complex statistics (genetic linkage).	Treatment mutagen (mutagen-induced revertant) and gene complementation .
What difficulties might you experience in teaching this concept?	Because this material is abstract, so teachers must prepare alternative media that can represent visual, audio and kinetic media.	Delivery of abstract material. Determinatio n of codons, codogenes and the interpretation of DNA strands into proteins is one of the most difficult process that can be said to be difficult.	Maintain student focus to be able to be thorough in distinguishing the position of homologous or tetrad chromosomes, sister chromatids, especially in meiosis, 1 and 2 in anaphase.	Fully understand the patterns of inheritance of traits even if it is not written what type of pseudo-cross. Determine the probability of a cross.	Improve students' visual literacy in interpreting images of genes and chromosomes.
What student conditions (prior knowledge/way of thinking/interest) do you consider in teaching this concept?	How well and how deeply they know genes, DNA and chromosomes. Both conceptual and contextual understanding .	Understand the characteristics of DNA and RNA, understand terms in enzyme material, recognise types of	Structure of chromosomes and cell organelles.	Good numeracy skills.	Knowledge of alleles, chromosomes, failure to separate. Knowledge of the stages of meiosis division (prophase, anaphase, crossing over).

		chemical bonds.			
What other factors did you consider in teaching this concept?	The teacher's ability to analogise the relationship between these concepts.	Students' interest and motivation must be considered and strengthened (giving rational suggestion).	Students' initial abilities related to terms on chromosomes and the state of learning facilities.	Emphasising the usefulness of the concept in survival will be able to increase students' seriousness and desire to learn it even though it is complicated.	The teacher's ability to relate to real life. The extent of students' understanding of cell division material that involves crossing over.
What is the sequence/flow you have chosen to teach the concept?	Explain starting from what they know (could be genes or DNA first). Then in order of largest or smallest. This can be helped with a representative analogy.	Explain the general concept of protein synthesis, general and essential stages of transcription and translation. Explain the detailed stages of each stage with differences in pro and eukaryotic cells.	Through conventional methods and discussions, students are invited to understand the division of the properties of amitotic, mitotic and meiotic cell division. Then using an animated video, students watched the stages of the division process followed by an interactive video so that there was a stimulus.	Students know Mendel's Laws I and II and their application and then the teacher goes into practice in doing ordinary crosses and pseudo crosses with various terms and conditions.	Students in groups can make a presentation with different themes (point mutation and aberration mutation). Each group can also explain 3 effects of each mutation.
How do you know whether students have understood or not?	Ask questions about the relationship between genes, DNA and chromosomes.	Working on worksheet or open a question and answer forum.	Q&A and essay test and resume on this concept in different possible products.	Working on essay questions can determine the integrity of students' knowledge of the material.	Using oral or written tests.
How do you utilise existing technology to teach the concept?	Audio visual media, AR, presentation app, YouTube, articles articles sourced from the website, provide	Audio and visual media or interactive videos (AR, presentation app, visual images, YouTube, articles	Audio visual media, laptop, projector as media to teach this concept.	Use technology such as laptops/computers, projectors as support in learning.	Audio visual media, smart tv, projector, mobile phones.

	explanations with the help of 3D models.	sourced from websites).			
How would you get around the lack of technology in your school to achieve your goals?	Maximising visual media aided by contextualised analogies.	Students can do role playing with flipped classroom.	Maximising the tuils board, pictures and cell division models as a way to get around the limited media at school.	Utilise the availability of whiteboards and textbooks.	Utilising picture media and teaching material modules.

Based on the results of the Cores (Content Representation) analysis on the Table 1, there are five big ideas that students must learn in genetics material. The first big idea is the substance of genetics which studies the structure, function, interrelated location of genes, DNA and chromosomes, protein synthesis, cell reproduction, inheritance of traits and mutations. The second big idea is protein synthesis where students are expected to know the role of DNA in the formation of proteins which will later become a form of gene expression. Cell reproduction is the third big idea where in this material students will learn the difference between meiosis and mitosis. Then the fourth big idea is about the inheritance of traits related to the application of Mendel's Laws I and II, monohybrid, dihybrid crosses and various types of pseudo crosses. Finally, the fifth big idea discusses mutations in genes and chromosomes. These five concepts are important to master because they are basic concepts for understanding more complex genetics that are molecular in nature, relate to real problems in life, make students understand various prevention and treatment in natural mutations and know the benefits of artificial mutations.

Various difficulties that will be faced by students during learning are abstract material, not close to students' daily lives, difficulty focusing due to complex material and many difficult terms. To overcome these difficulties, students need good prior knowledge in knowing genes, DNA and chromosomes, DNA and RNA characteristics, chromosome structure and cell organelles and numeracy skills to be able to understand the material so that students can continue at a more difficult level. In teaching genetics, teachers need to consider factors such as the teacher's ability to analogise the interrelationship of various concepts, student interest and motivation, students' initial abilities, more emphasis on usefulness and conditions in real life and of course learning strategies including approaches, models, methods and media that will determine the teacher's success in teaching genetics material.

In the assessment process, there are several ways that teachers can do to determine the level of student understanding after the learning process is complete such as asking students to convey the results of the study in the form of presentations, giving assignments using LKPD, or conducting direct questions and answers. Various technologies can be used to make the genetics learning process more interesting, for example by using audiovisual media, augmented reality (AR), presentation applications, interactive videos and 3D media. If the use of technology cannot be done optimally due to limited facilities and infrastructure at school, teachers can work around it by using contextual visual media, doing role play with a flipped classroom, maximising the blackboard by drawing and making teaching modules.

3.2. Curriculum and material analysis

Genetics material is taught in phase F in grade XII SMA/MA with the learning outcome 'students have the ability to apply the concept of inheritance of traits'. In the SMA/MA Biology Book issued by the Ministry of Education, Culture, Research and Technology in 2022, this material is in chapter two entitled 'Genetics and Inheritance of Traits'. This material covers four dimensions of knowledge, namely factual, conceptual, procedural, and metacognitive. According to Barmawi et al. (2024), factual knowledge refers to the understanding and appreciation of facts or factual information related to a field of knowledge. Meanwhile, conceptual knowledge is knowledge about how the basic elements are connected to each other and work together in a larger structure. Procedural knowledge includes knowledge of steps or procedures in carrying out activities, such as skill processes, algorithms, techniques, and steps collectively referred to as procedures or proper sequences (Anderson & Krathwohl, 2010). The last dimension is metacognitive knowledge which according to Ormrod (2009) includes the following: contemplating general concepts about thinking, learning and knowledge; understanding the limits of learning and memory abilities; planning learning tasks that can be realistically fulfilled within a certain period of time; knowing and using effective learning strategies; and remembering material. An explanation of each dimension of knowledge on genetics material is described in Table 2 below.

Table 2. Dimensions of knowledge in genetics

Dimension	Description
Factual	Includes knowledge of terminology such as DNA, RNA, genes, chromosomes and mutations.
Conceptual	Includes knowledge of principles, categories, classes, parts or arrangements such as principles of genetics, DNA & RNA models, DNA replication models, stages of protein synthesis, mitotic and meiotic division and Mendel's Law.
Procedural	Includes knowledge of how to do something, in genetics such as the procedure for observing fruit fly (*Drosophila melanogaster*) chromosomes and the procedure for observing mitosis in onion roots.
Metacognitive	It includes knowledge about oneself such as students finding out their weaknesses in genetics material and developing appropriate learning strategies to understand genetics material.

3.3. Model analysis

Based on the analysis of various articles that discuss learning models on genetics material, genetics learning can be applied using various models, such as problem-based learning, discovery learning, and guided inquiry. These three learning models have different targets and objectives. The problem-based learning (PBL) model is a problem-based learning model with the aim that students can learn problem-solving skills or abilities instead of solving a problem (Widodo, 2021). Based on Nainggolan's research (2023) by applying the problem-based learning model, the research results show that the application of the PBL model can improve students' concept understanding in genetics material. The purpose of the model applied is to see students' concept understanding in genetics material without seeing an increase in problem solving skills. In contrast to the previous PBL model research (Nainggolan, 2023), the discovery learning (DL) model in genetics learning conducted by Nahdiah (2021) aims to see interest and learning outcomes. The results showed that the application of the DL model on heredity material was able to increase the interest and learning outcomes of high school

students. The purpose of applying the model is not only related to understanding the material but also seeing student interest.

Another learning model, guided inquiry integrated with virtual lab, has been proven to improve students' analytical thinking skills in the classroom (Baruno, 2021). The analysis aspect in question consists of the ability to distinguish, organise, and attribute. In the study, it was found that the distinguishing aspect had the highest achievement compared to the other two aspects, namely the organising and attributing aspects. This shows that the guided inquiry learning model can strengthen students' ability to distinguish information, which is the first and crucial step in the analysis process. Meanwhile, Baruno's research (2021) looks more at the effect of implementing guided inquiry integrated with virtual labs on improving analytical thinking skills and does not focus on concept understanding alone. The use of learning models in genetics material can be adjusted based on learning objectives and aspects to be reviewed, both cognitive and affective aspects. The use of the model can also be integrated with certain technologies to see the effect of using technology on improving the aspects being studied.

3.4. Method analysis

From the articles analysed, there are several methods used in the genetics learning process, namely role play, discussion and experimentation. The role play model used by Sinaga et al. (2016) showed that the method can improve students' learning outcomes where motor, viewing, oral, and writing activities in this method can activate discussions, enliven the atmosphere and encourage students to practice their skills so that the impression obtained by students about the subject matter studied is stronger. According to Hamdayana (2014), the role-playing method has several advantages, including giving learners the freedom to make decisions and express themselves fully and easily found and applied in various situations and different times. In addition, teachers can also evaluate the understanding of each learner through observation during the implementation of the game, and this method provides a fun learning experience for children.

The next method is discussion and experimentation conducted by Sulistiawati (2021). According to Widodo (2021), the discussion method is one of the effective approaches in teaching students communication skills, argumentation, and interaction with individuals who have different characters. The experimental method, on the other hand, is a learning strategy that emphasises active and practical activities, where students are directed to understand and master the material through real activities, thus creating an effective and efficient learning pattern (Sulistiawati, 2021). These two methods are used in teaching genetics on the subject of genetic engineering. The results showed that the discussion and experimentation methods can improve student achievement and learning motivation. Therefore, it is necessary for teachers to be able to apply learning methods that are in accordance with the characteristics of the material so that they can support the effectiveness of learning in the classroom.

3.5. Media Analysis

Learning media serves as a tool in the teaching process that aims to clarify the material conveyed by the teacher to students (Yuliono et al., 2018). This media facilitates direct interaction between teachers and students as well as between students and learning resources, allowing students to learn independently according to their respective abilities (Feri &

Zulherman, 2021). Based on the analysis of various articles, there are various learning media used to teach genetics material, such as learning modules, genetics button media, audiovisual media, virtual laboratories, interactive learning media with articulate storyline, and mind mapping. Research conducted by Oka et al. (2020) showed that the use of learning modules can increase students' activeness in thinking, searching, processing, describing, combining, concluding, and solving problems, so that they are no longer passive and only receive information from the teacher. Modules also support independent learning because they are equipped with instructions that allow students to learn without the direct presence of the teacher.

The genetics button media used by Musdalifa (2022) in genetics learning was proven to improve students' knowledge and understanding of inheritance of traits in living things, which in turn improved their learning outcomes. Furthermore, audiovisual media developed by Kapughu et al. (2023) using the model organism *Drosophila melanogaster* presents an innovative learning that is more interesting and can be used by students independently at any time, so that the concept of inheritance patterns of traits can be conveyed well to students and students can easily understand the concept and get a meaningful learning experience. While Fahmi et al. (2024) developed a virtual laboratory that facilitates students in recognising and understanding the use of technology in learning. This research shows that virtual reality technology-based learning can encourage students to design, develop, and utilise technology, and improve their understanding of the law of inheritance of traits. Putri et al. (2022) developed an interactive learning media articulate storyline that is able to improve student learning outcomes thanks to its attractive appearance and reduce boredom when reading the material. In line with this interactive media, the use of mind mapping according to Narsan (2022) can also reduce students' boredom and allow them to pour out ideas or concepts that are in their minds freely and make the learning process fun so as to encourage students to learn independently which ultimately improves their academic achievement.

4. Conclusion

The success or failure of learning in the classroom depends on the teacher's ability to adjust the material to be taught with the learning strategy that will be carried out. Not only that, teachers also need to look at student characteristics so that the learning process that has been designed can be fully followed by students. TPACK analysis can help teachers to see the relationship between the three components of learning, namely teachers, materials and students. TPACK helps teachers formulate the big ideas that should be taught in genetics, why the material is important, the obstacles that will be faced in teaching the material and what solutions can be done to overcome these problems. Teachers also need to write down the dimensions of knowledge based on the material to be taught. Genetics material can be taught using various learning strategies such as using problem-based learning, discovery learning and guided inquiry models. The learning methods can include role playing, discussion and experimentation. Meanwhile, the media can use learning modules, genetics button media, audiovisual media, virtual laboratories, interactive learning media with articulate storyline, and mind mapping. For now, it is not yet known which learning strategy is most effective in teaching genetics and further research is needed for that. In addition, to facilitate teachers in understanding TPACK, it is necessary to conduct internal coaching by schools so that teachers can behave professionally in teaching.

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