

IMPLEMENTATION OF TPACK-BASED LEARNING DESIGN ON THE ROTATING OBJECT CONCEPT

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ABSTRACT

This research aims to develop a learning design based on pedagogy technology and content knowledge (TPACK) on mathematics subject matter and the concept of rotating objects. For elementary and middle school mathematics, it is still possible to deliver it based on students' experiences in everyday life. At the high school level, the concept of the volume of a rotating object is difficult to imagine because it requires a higher level of understanding. Therefore, it is necessary to design learning that can provide direct experience to students. The research respondents were class XII IPA students at SMAK Santo Bonaventura Madiun for the 2023-2024 academic year. This type of research is development research. The development method used is ADDIE, but it has limitations, namely that it has not been implemented in larger classes. The validation test includes validating the GeoGebra-assisted mathematics learning design by one teacher and the rotating object props by the lecturer. The effectiveness of the learning design is tested by examining the test results on the pre-test and post-test. The findings of this research are that the percentage of assessments from learning design experts is 77.5%, and the percentage of assessments from learning media experts is 76%. It was concluded that the learning tool was feasible, usable, and needed minor revisions. Meanwhile, the effectiveness test was obtained through the percentage of classical completion from 30.77% to 84.62%. This shows increased students' understanding of the volume of rotating objects after using teaching aids.

ABSTRAK


Penelitian ini bertujuan untuk mengembangkan desain pembelajaran berbasis teknologi pedagogi dan pengetahuan konten (TPACK) pada materi pelajaran matematika konsep benda putar. Untuk matematika tingkat SD dan SMP masih dimungkinkan penyampaian berdasarkan pengalaman siswa dalam kehidupan sehari-hari. Untuk tingkat SMA, konsep volume benda putar sulit dibayangkan karena memerlukan pemahaman yang lebih tinggi. Oleh karena itu, perlu dirancang pembelajaran yang dapat memberikan pengalaman langsung kepada siswa. Responden penelitian adalah siswa kelas XII IPA SMAK Santo Bonaventura Madiun tahun pelajaran 2023-2024. Jenis penelitian ini adalah penelitian pengembangan. Metode pengembangan yang digunakan adalah ADDIE tetapi memiliki keterbatasan yaitu belum diimplementasikan dalam kelas yang lebih besar. Uji validasi meliputi validasi rancangan pembelajaran matematika berbantuan GeoGebra oleh satu orang guru dan alat peraga benda putar oleh dosen. Sedangkan, uji efektivitas rancangan pembelajaran diperoleh dari hasil tes pada pretes dan postes. Temuan penelitian ini yaitu persentase penilaian dari ahli rancangan pembelajaran yaitu 77,5% dan persentase penilaian dari ahli media pembelajaran yaitu 76%. Disimpulkan bahwa perangkat pembelajaran layak, dapat digunakan, dan perlu revisi kecil. Sedangkan, uji efektivitas diperoleh melalui persentase ketuntasan klasikal dari 30,77 % menjadi 84,62%. Hal ini menunjukkan bahwa terjadi peningkatan pemahaman konsep volume benda putar siswa setelah menggunakan alat peraga.

Kata Kunci:

TPACK;
matematika;
konsep benda putar;

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**INTRODUCTION**

Mathematics still to be considered a difficult subject by some students. For elementary and middle school level mathematics, it is still possible to deliver it based on students' experiences in everyday life. For the senior high school level, the matter of the volume of rotating objects is difficult to imagine because it requires a higher understanding. Therefore, it is necessary to design learning that can provide direct experience to students¹.

¹ Al Jupri et al., "The Development of Mathematics Teacher Professional Competencies through Social Media," *Jurnal Elemen* 8, no. 1 (2022): 308–22, <https://doi.org/10.29408/jel.v8i1.4782>; Jeffrey W. Redinger, Paul B. Cornia, and Tyler J. Albert,

In the Era of Society 5.0, all societal activities are human-centered and based on technology ². As a review of literature or previous research (containing state of the art) with the aim of strengthening the importance of research, namely the results of research in 2020 during the Covid pandemic. Learning activities continue even though they are carried out online. It can be concluded that the average student mathematics learning outcomes before online learning are greater than the average student mathematics learning outcomes after online learning. Based on the influence of online learning, as many as 45% of students like mathematics, and 55% of students do not like mathematics. This research is only limited to studying the influence of online learning without studying online learning platforms and strategies ³.

This condition shows that all human activities are always in contact with technology. Besides mastering subject matter and pedagogy, teachers must also keep up with technological developments. Therefore, integration of materials, pedagogy, and technology is very necessary. Technological, Pedagogical, and Content Knowledge (TPACK) is learning that uses a combined application of an education system that prioritizes technology and certain applications (content) in learning ⁴. The application of integrated technology as a support has not yet been widely mastered. Conditions in the field show that the teaching assistance process is less intensive in developing technology-based teaching materials ⁵. Technological developments have become a means to make it easier for someone to do their work. Mishra and Koehler ⁶ show that the ability to use

“Teaching During a Pandemic,” *Journal of Graduate Medical Education* 12, no. 4 (2020): 403–5, <https://doi.org/10.4300/JGME-D-20-00241.1>.

² Laxman Luitel, “Exploring Teachers’ Experiences on the Nature of Mathematics Based on Their Curricular and Pedagogical Practices: A Phenomenological Inquiry,” *International Electronic Journal of Mathematics Education* 15, no. 3 (2020): 598–613, <https://doi.org/10.29333/iejme/9135>; Gregoria Ariyanti and Fransiskus Gatot Iman Santoso, “The Effects of Online Mathematics Learning in the Covid-19 Pandemic Period : A Case Study of Senior High School Students at Madiun City , Indonesia” 12, no. 3 (2020): 4–11; G. Ariyanti and F. G.I. Santoso, “Analysis of Mathematics Learning Outcomes on Senior High School Students in Madiun City, Indonesia in COVID-19 Pandemic,” *Journal of Physics: Conference Series* 1663, no. 1 (2020), <https://doi.org/10.1088/1742-6596/1663/1/012037>.

³ Ariyanti and Santoso, “The Effects of Online Mathematics Learning in the Covid-19 Pandemic Period : A Case Study of Senior High School Students at Madiun City , Indonesia”; Ariyanti and Santoso, “Analysis of Mathematics Learning Outcomes on Senior High School Students in Madiun City, Indonesia in COVID-19 Pandemic.”

⁴ Imamul Khaira, Evi Susilawati, and Refli Renaldi, “Implementasi Rancangan Pembelajaran Berbasis Tpack Untuk Meningkatkanhasil Belajar,” *Jurnal Teknologi Pendidikan* 14, no. 2 (2021): 111–19.

⁵ Ambar Sri Lestari, “The Application of Technology, Pedagogy, Content, Knowledge (TPACK) During The COVID-19 Pandemic,” *Evaluasi: Jurnal Manajemen Pendidikan Islam* 6, no. 1 (2022): 128, <https://doi.org/10.32478/evaluasi.v6i1.866>.

⁶ F. Fakhriyah et al., “Analysis of Technological Pedagogical Content Knowledge (Tpack) Ability Based on Science Literacy for Pre-Service Primary School Teachers in Learning Science Concepts,” *Jurnal Pendidikan IPA Indonesia* 11, no. 3 (2022): 399–411, <https://doi.org/10.15294/jpii.v11i3.37305>.

technology is an important part and element in supporting effective learning. The field of teacher education is changing, and keeping up with innovation is no longer enough. Students and teachers must be able to use various learning technologies to find the right knowledge at the right time and for the right purpose.

TPACK is a framework regarding the knowledge educators need to integrate learning effectively and efficiently. TPACK aims to develop basic knowledge in this learning. The seven domains of knowledge contained in the TPACK learning approach concept are: 1) Content Knowledge, which is the educator's mastery of the learning material they teach; 2) Pedagogical Knowledge, which is the educator's basic knowledge regarding learning processes and strategies; 3) Technological Knowledge, which is the educator's knowledge related to the use of digital technology (hardware and software); 4) Pedagogical Content Knowledge, is the application of appropriate learning strategies so that learning material is achieved well; 5) Technological Content Knowledge, is the application of educators' abilities to mastery of technology and materials in the learning process; 6) Technological Pedagogical Knowledge, is an online assessment using g-form in evaluating; 7) Technological, Pedagogical, Content Knowledge, is educators' comprehensive knowledge regarding digital technology, learning processes and strategies, as well as learning materials ⁷.

The current learning paradigm requires mastery of content, pedagogy, and technology. Teachers must utilize and apply information technology in the learning process in their classes. The latest learning challenges require teachers to have the ability to use Technological Pedagogical and Content Knowledge (TPACK) based learning. TPACK-based learning directs teachers to master knowledge about how to facilitate students learning from subject matter content through pedagogical and technological approaches.

Mathematics material is quite complicated, including the concept of integrals, which is applied to rotating objects and is part of the basic concepts of Calculus. In particular, Calculus has very important concepts of rate of change (differentiation) and cumulative growth (integration). In addition, the focus is on proficiency in symbolic methods for differentiation and integration and their application to solve various problems ⁸. TPACK tends to identify the information a teacher needs to integrate technology into learning ⁹.

⁷ Farah Indrawati, "Pengembangan Aplikasi Pembelajaran Matematika Melalui TPACK," *Prosiding Diskusi Panel Nasional Pendidikan Matematika* 7, no. 1 (2021): 349–56.

⁸ I. U. Machromah, M. E.R. Purnomo, and C. K. Sari, "Learning Calculus with Geogebra at College," *Journal of Physics: Conference Series* 1180, no. 1 (2019), <https://doi.org/10.1088/1742-6596/1180/1/012008>; Soroosh Hassanpour and G. R. Heppler, "Approximation of Infinitesimal Rotations in Calculus of Variations," *Journal of Guidance, Control, and Dynamics* 39, no. 3 (2016): 703–10, <https://doi.org/10.2514/1.G001041>.

⁹ Nalurita Absari, Priyanto Priyanto, and Muslikhin Muslikhin, "The Effectiveness of Technology, Pedagogy and Content Knowledge (TPACK) in Learning," *Jurnal Pendidikan Teknologi Dan Kejuruan* 26, no. 1 (2020): 43–51, <https://doi.org/10.21831/jptk.v26i1.24012>.

In the era of globalization, technology develops rapidly in all aspects of life, including education. Integrating information, communication and technology (ICT) in education, such as computer-based teaching. Integrating IT brings great efficiency to both teachers and students. In mathematics, different types of software can be used to understand mathematical concepts, visualize mathematical objects, and calculate data. One of the commonly used software in mathematics is GeoGebra¹⁰. GeoGebra is open-access software that can be downloaded from www.geogebra.com. Using GeoGebra is one of the best options for teaching students the application of calculus. GeoGebra has many benefits that make geometry, algebra, and statistics easier to understand. Based on related research, using math software can support math learning, especially in visual activities. The purpose of using GeoGebra in this resource is to develop students' knowledge of how rotating bodies are formed. Using GeoGebra construction is a good idea, but more complex than it seems¹¹.

In this research, we will investigate how to develop a TPACK-based learning design based on the concept of mathematics, which is the volume of rotating objects. The research respondents were class XII IPA students at SMAK Santo Bonaventura Madiun. This class was chosen because, at this class level, there is a concept about the volume of rotating objects in mathematics lessons.

Methods

The research objectives are to investigate how to develop a TPACK-based learning design for the volume of rotating objects. The model used in this development research, ADDIE, includes five steps: analysis, design, development, implementation, and evaluation. The ADDIE model relies on each stage being done in the given order but focuses on reflection and iteration. The model gives us a streamlined, focused approach that provides feedback for continuous improvement.

Data analysis, in the form of validity and effectiveness tests, was carried out to determine the feasibility of the learning design and teaching aids for mathematics learning with the concept of rotating objects. The validation test includes validating the GeoGebra-assisted mathematics learning design by one teacher and the rotating object props by the lecturer. The effectiveness of the learning design is tested by examining the test results on the pre-test and post-test on mathematics questions on the volume of rotating objects.

The TPACK-based mathematics learning design developed is that students study in groups in the classroom, students present the results of discussions in front of the class, and students carry out learning in the computer laboratory using the GeoGebra application to complete the concept of rotating objects. The final activity stage is that students study the real shape of a rotating

¹⁰ Aminah Ekawati, "Penggunaan Software Geogebra Dan Microsoft," *Jurnal Pendidikan Matematika* 2, no. 3 (2016): 148–53.

¹¹ Machromah, Purnomo, and Sari, "Learning Calculus with Geogebra at College."

object, which is obtained from a curve (with a wire formed into an arch) that is rotated with a prop that the researcher has developed.

In product development steps, the ADDIE research and development model is considered more rational and more complete. This model can be used for various forms of product development in learning activities such as models, learning strategies, learning methods, media and teaching materials.

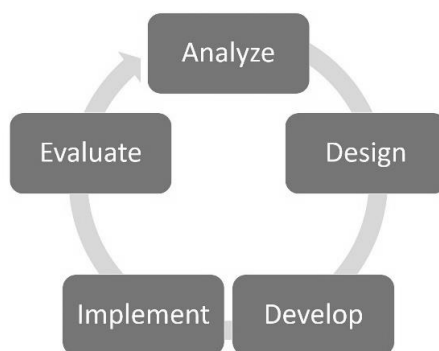


Figure 1. The ADDIE model

This research is a simple development study to find out the results of developing learning designs using GeoGebra and teaching aids in mathematics to learn about the concept of rotating objects. Data collection in this research is in the form of questionnaires and test data. The respondents were class XII IPA students at SMAK Santo Bonaventura Madiun for the 2023-2024 academic year.

Table 1. Implementation of research using the ADDIE approach

Analysis	Analyze students' needs and abilities. Identify the causes of problems in high school mathematics learning; that is, students need an idea of rotating objects formed from curves rotated around coordinate axes. Students difficulty understanding the concept of rotating object.
Design	Design a student learning format for the volume of rotating objects. Verify the desired results or achievements (learning objectives) and determine the methods or strategies to be applied.
Develop	Create material development prototypes. Develop and validate learning resources and develop required supporting materials and strategies.
Implement	Implementation of learning and observation. Preparation of the learning environment and implementation of learning by involving students.
Evaluate	Evaluate the results of activities. Assess product quality and learning process.

Based on Table 1, the Analyze, Design, and Develop steps are as follows. The solution researchers offer is the development of TPACK-based learning tools, including a Learning Plan regarding the volume of rotating objects using the GeoGebra application and rotating object aids to help students understand the concept of rotating objects and calculating their volume. In preparing the learning plan, the researcher adjusts it to the instructional objectives, observes student

characteristics, develops learning strategies, develops teaching aids, and develops evaluation criteria. Next, based on Table 1, the implementation and Evaluation steps are as follows. TPACK-based learning is implemented at Santo Bonaventura Madiun High School. Next, we evaluate the pretest and posttest results for the effectivity test.

Validation was carried out by colleagues (learning media experts) and mathematics teachers (learning planning experts). The research subjects were class XII IPA students at SMAK Santo Bonaventura Madiun. The data collected are: (1) the results of the first stage data in the form of test data from learning planner experts, (2) the results of the second stage data in the form of test results data from learning media experts, and (3) the results of the third stage data in the form of test result data try small groups. The method used to collect data is a questionnaire. The instrument used to collect data in this development research was a questionnaire sheet. Questionnaire sheets and test questions are used to collect data from reviews from material experts, learning media experts, and students. Quantitative data was analyzed by calculating the percentage of scores obtained from filling out the validation sheet. Table 2 gives the criteria for the TPACK-based mathematics learning tools developed.

Table 2. Validation criteria

Criteria	Validation level (V)
$V \leq 20\%$	Very unfit, cannot be used
$20\% < V \leq 40\%$	Not suitable, recommended not to use, needs major revision
$40\% < V \leq 60\%$	Decent, usable and needs minor revisions
$60\% < V \leq 80\%$	Feasible, usable, and needs minor revisions
$80\% < V \leq 100\%$	Very feasible, can be used without revision

RESULT AND DISCUSSION

The model used in this development research, namely ADDIE, includes five steps: analysis, design, develop, implement, and evaluate. The ADDIE model concept is applied to build basic performance in learning, namely the concept of developing a learning product design. ADDIE is an instructional design centered on individual learning, has immediate and long-term phases, is systematic, and uses a systems approach to human knowledge and learning. Effective ADDIE instructional design focuses on implementing authentic tasks, complex knowledge, and genuine problems. Thus, effective instructional design promotes high fidelity between the learning environment and the actual work setting. The ADDIE learning model is based on an effective and efficient systems approach and an interactive process between students, teachers, and the environment¹².

As implementers of the learning prepared by the research team, namely the class XII mathematics teacher at SMAK Santo Bonaventura Madiun. The

¹² Fitria Hidayat and Muhamad Nizar, "Model Addie (Analysis, Design, Development, Implementation and Evaluation) Dalam Pembelajaran Pendidikan Agama Islam," *Jurnal Inovasi Pendidikan Agama Islam (JIPAI)* 1, no. 1 (2021): 28–38, <https://doi.org/10.15575/jipai.v1i1.11042>.

TPACK-based learning design that has been developed in this research is explained as follows:

- ✓ Technological Knowledge: Teachers can design learning media and teaching materials using computer applications for mathematics, namely GeoGebra. They are also capable of accessing the Internet and displaying teaching materials in PPT form using an LCD projector.
- ✓ Pedagogical Knowledge: Teachers are able to determine appropriate approaches, models, methods, and learning strategies to deliver teaching material and create meaningful learning. In this case, the teacher uses a group learning model with methods such as question-and-answer, observation, and discussion, with the help of concrete media (visual aids).
- ✓ Content Knowledge: Teachers master the teaching material that will be delivered with the latest references and can relate it to the environment around the students. For example, a rotating object, such as a flower pot, can be observed in the resulting shape.
- ✓ TPACK: Knowledge about integrating technology, pedagogy, and material/content arranged in a learning plan, applied by the teacher through model group learning.

This research developed a learning design and mathematics learning media for the volume of rotating objects. The learning design integrates technology, namely the GeoGebra computer application, and learning media, namely rotating object props. The description of the research results summarizes the results of the development and verification of the learning plan, including the learning model. The development model used is the ADDIE model. Development includes the processes or steps taken to produce a product. The ADDIE development model stages used in this research consist of:

First, Analyze. Activities carried out at the analysis stage include (1) analysis of the learning objectives that students need to master; specifically, the learning design identifies competency standards, essential competencies, and learning outcomes; (2) analyzing student characteristics in terms of the knowledge, attitudes, and skills that students have; and (3) researchers compile material that is relevant to the objective, namely the concept of rotating objects. In this phase, researchers evaluate the analysis results independently in collaboration with mathematics teachers to improve them. *Second*, Design. The design stage focuses on three activities: selecting teaching materials according to student characteristics and the instructional goals to be achieved, learning strategies and models, and assessment and evaluation methods. At this stage, the researcher designs the learning model, lesson plans, and student worksheets. Researchers and teachers will evaluate the results obtained at this stage to improve the design results.

Third, Development. The development stage includes searching and collecting relevant information sources to enrich the material, creating group work materials and guides using the GeoGebra application, and creating teaching aids for rotating objects. The next development stage activity is validating the product design being developed and modifying it based on expert opinions. *Fourth*, Implementation. At this stage, the results of learning development are applied to determine the impact on the quality of learning, such as effectiveness and learning efficiency. This stage includes product design improvements verified by experts and implemented in small groups to receive input from students for product design improvements. And last, *fifth*, Evaluation. The final stage is conducting an evaluation, which includes formative evaluation. Formative evaluation collects data at each phase used for improvement. It is carried out at the end of the program to determine its effect on student learning outcomes and the quality of learning at large. This type of evaluation is related to the development research stage to improve the resulting development product.

Learning planning and learning media experts assess development products in terms of learning plans and the design of rotating objects through questionnaires. The results of the learning planner expert assessment are presented in Table 3.

Table 3. Learning plan validation results

No	Statement	Score
1	Suitability of the structure of the learning implementation plan	5
2	Suitability of the learning model with the learning steps	4
3	Conformity of learning objectives with learning material information	4
4	Suitability of learning materials and questions	4
5	Suitability of illustrations or pictures with learning material	3
6	Appropriateness of test questions to learning outcomes	4
7	Suitability of assessment information	3
8	Suitability of the bibliography used as a reference for learning resources	4
	Amount	31

Based on the data in the table, the percentage of assessments by learning planning experts can be calculated, that is

$$Percentage = \frac{\sum x}{\sum x_i} \times 100\% = 77.5\%$$

The results of the learning media expert assessment are presented in Table 4.

Table 4. Validation results of rotating object props

No	Statement	Score
1	Suitability to learning objectives	3
2	Clarify the concept of rotating objects	4
3	Safe to use in learning activities	4
4	The form is simple and easy to use	4

5	The display of the props is attractive	4
	Amount	19

Based on the data in the table, the percentage of assessments by learning media experts can be calculated, that is

$$\text{Percentage} = \frac{\sum x}{\sum x_i} \times 100\% = 76\%$$

The calculation results concluded that the learning tool was feasible, usable, and needed minor revisions.

Next, an effectiveness test is carried out to measure the level of success in using learning designs with GeoGebra and learning media (rotating props) to improve student learning outcomes. Differences in learning outcomes can be seen from the completeness of student learning outcomes. The completeness of the learning outcomes was obtained from the pre-test and post-test assessments, attended by 13 students from class XII Science who had carried out learning using GeoGebra and rotating object props. To determine the effectiveness of the learning design using GeoGebra and rotating object props, a pretest and posttest were given, and the results are shown in Table 5.

Table 5. The student pretest and posttest scores

Student	Pre test	Post test
1	45	60
2	60	70
3	70	80
4	60	70
5	50	60
6	70	80
7	60	70
8	65	70
9	75	80
10	60	80
11	60	75
12	60	85
13	70	80
Mean	61.92	73.85
Percentage increase	19.25%	

Based on Table 5, the 13 tested students obtained a score for the pretest of 61.92 and a score for the posttest of 73.85. From the results of the pretest and posttest assessments, through analysis, it can be concluded that there is a difference in the value of the results obtained before and after using GeoGebra

and rotating object props in learning. It can be concluded that the learning design using GeoGebra and rotating learning object props is effective.

A class is said to have completed its learning (classical completeness) if, in that class, there are $\geq 75\%$ of students who have completed their learning from the minimum completeness criteria value that has been set at school, namely 70¹³. Based on the table, it appears that the learning results obtained classical completeness of 30.77%, and the posttest results showed classical completeness of 84.62%, which means that the GeoGebra learning design and rotating object props in mathematics learning have an impact on student learning outcomes so that the learning design can be used.

Discussion

Based on the results of the research above, it can be understood that the implementation of a TPACK-based learning design as an integration of learning in the Society 5.0 Era has proven to improve learning outcomes regarding the volume of rotating objects for students in class XII IPA SMAK Santo Bonaventura Madiun. This teaches us that TPACK-based learning is a new type of knowledge teachers must master to integrate technology well in learning in the Era of Society 5.0. The results of this research are in line with the results of the study put forward by Rahmadi¹⁴, who stated that TPACK-based learning is a new type of knowledge that educators must master to be able to integrate technology well into learning. This research aims to determine the application of TPACK-based learning to the volume of rotating objects in class XII Science. It can be analyzed that student learning outcomes increase after the learning process. This is also in accordance with the theory, given that the millennial generation tends to learn material more quickly through technology. It cannot be denied that using technology wisely will have a positive impact on educational development.

TPACK is a combination of three important elements in learning: technological knowledge, which can be used to facilitate the delivery of teaching material; pedagogical knowledge, which contains the learning methods and models that will be applied; and content knowledge, which includes learning material. These three elements can be arranged in a learning plan. The efforts carried out in learning mathematics regarding the concept of rotating objects based on TPACK in this research were by applying technology in the form of mathematics learning assisted by the GeoGebra mathematics application and rotating objects teaching aids developed by researchers. Furthermore, the pedagogical component is visible through the learning model, namely group learning, where the process takes place in heterogeneously formed groups, and it is hoped that students will care about complementing each other and discussing

¹³ Al-Tabany. Trianto, *Mendesain Model Pembelajaran Inovatif Progresif Dan Kontekstual* (Jakarta: Kencana, 2017).

¹⁴ Imam Fitri Rahmadi, "Technological Pedagogical Content Knowledge (TPACK): Kerangka Pengetahuan Guru Abad 21," *Jurnal Pendidikan Kewarganegaraan* 6, no. 1 (2019): 65, <https://doi.org/10.32493/jpkn.v6i1.y2019.p65-74>.

each other in solving problems. This is related to pedagogy as an educational science. Meanwhile, related to the content, namely mathematics material, which is considered difficult, especially by high school students, namely the volume of rotating objects. The process of gaining knowledge can also be linked to students' learning experiences, which can increase students' motivation to understand mathematics material and material better. Adapting to the current technology-savvy generation can provide a pleasant learning atmosphere.

Some responses from students after participating in TPACK-based learning on the volume of rotating objects : (1) Students enjoy TPACK-based learning; (2) Students understand the concept of rotating objects; (3) Students can imagine the shapes that occur due to rotating a curve around an axis; and (4) TPACK-based learning has an impact on the learning outcomes of high school students.

The research results show that validation tests have been carried out, including validation of the GeoGebra-assisted mathematics learning design by one teacher and validation of rotating object concept teaching aids by one lecturer. The effectiveness of the TPACK-based learning design was tested by looking at the test results on the pre-test and post-test. Based on the results of research data processing, it was obtained that the percentage of assessments from learning design experts was 77.5%, and the percentage of assessments from experts in teaching aids on the concept of rotating objects was 76%. It was concluded that the learning tool was feasible, usable, and required little revision. Meanwhile, the effectiveness test was obtained through the percentage of classical completion from 30.77% to 84.62%. This shows increased students' understanding of the concept of rotating objects after using teaching aids. Understanding the concept of rotating objects is not only obtained from the teacher's explanation, but students can immediately practice forming rotating objects and calculating the volume formed using the GeoGebra application. In addition, students get a real picture of the curve results rotated on the coordinate axes.

The results of this research align with Lestari¹⁵, which states that the application of Technology, Pedagogy, Knowledge, and Content (TPACK) significantly impacts teaching efficiently and effectively because mastery of technology helps educators deliver and distribute material more creatively and innovatively.

In classroom and laboratory learning, researchers also provide questionnaires for students to fill out regarding responses to the activities that have been carried out. Most students understand the volume of a rotating object better. They are motivated to try to solve problems using the GeoGebra application that has been taught.

¹⁵ Lestari, "The Application of Technology, Pedagogy, Content, Knowledge (TPACK) During The COVID-19 Pandemic."

Based on the questionnaire given after students used rotating object props, several things were obtained: (1) Students enjoyed learning to use rotating object props; (2) Students could understand the concept of rotating objects easily using these props; (3) Students felt that the props were easy to use; (4) Students felt that the props encourage curiosity about the concept of other rotating objects, and students find these props interesting to observe.

CONCLUSION

This research is developing a TPACK-based learning design by integrating the GeoGebra application and using rotating object props in the concept of rotating objects in high school mathematics lessons for class XII IPA. From the research results, it can be concluded that the learning tools developed, namely the learning design and teaching aids, provide valid and effective results and can be used with revisions. The weakness of this research is that it needed to be implemented in large classes. Hopefully, this research can be developed further with more detailed indicators and implemented in larger classes.

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