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PCK Based Learning Design: Development Through Design Research to Improve Matematics Teachers' Teaching Skills

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Abstrak

Untuk dapat mengajar secara efektif, seorang guru tidak hanya dituntut memahami konten materi, tetapi juga mampu menyampaikannya sesuai dengan karakteristik siswa melalui penguasaan Pedagogical Content Knowledge (PCK). Keterampilan ini menjadi kunci pencapaian tujuan pembelajaran. Penelitian ini bertujuan mengembangkan desain pembelajaran berbasis PCK yang dapat meningkatkan keterampilan mengajar guru matematika. Metode yang digunakan adalah design research model Plomp, yang terdiri dari tahapan preliminary research, prototyping phase, dan assessment phase. Subjek penelitian adalah tiga guru matematika, dengan instrumen berupa RPP dan lembar observasi. Hasil penelitian menunjukkan bahwa: (1) Desain pembelajaran berbasis PCK dapat dikembangkan dalam bentuk RPP yang mengacu pada konsep PCK John K. Lannin, dengan adaptasi berupa penekann pada identifikasi student thinking, pemilihan representasi matemais yang bervariasi, serta perencanaan antisipasi kesulitan siswa berdasarkan PCK Mathematics Lesson Plan Template; dan (2) RPP tersebut terbukti efektif dalam meningkatkan keterampilan mengajar guru. Secara keseluruhan, desain pembelajaran berbasis PCK mampu memfasilitasi pengembangan keterampilan praktis mengajar secara nyata, serta meningkatkan kemampuan esensial dalam pembelajaran matematika yang bermakna. Implikasi dari penelitian ini aalah bahwa adaptasi model PCK Lannin dapat dijadikan acuan dalam penyusunan perangkat pembelajaran yang lebih kontekstual, sehingga guru lebih siap menghdapi keragaman cara berpikir siswa di kelas.
Kata Kunci: Desain Pembelajaran; Keterampilan Mengajar; PCK; RPP

Abstract

To be able to teach effectively, a teacher is not only required to understand the content of the material, but also to be able to convey it according to the characteristics of the students through mastery of Pedagogical Content Knowledge (PCK). This skill is the key to achieving learning objectives. This study aims to develop a PCK-based learning design that can improve the teaching skills of mathematics teachers. The method used is the Plomp design research model, which consists of the stages of preliminary research, prototyping phase, and assessment phase. The subjects of the study were three mathematics teachers, with instruments in the form of lesson plans and observation sheets. The results of the study indicate that: (1) PCK-based learning designs can be developed in the form of lesson plans that refer to John K. Lannin's PCK concept, with adaptations in the form of emphasis on identifying student thinking, selecting varied mathematical representations, and planning to anticipate student difficulties based on the PCK Mathematics Lesson Plan Template; and (2) the lesson plans have proven effective in improving teachers' teaching skills. Overall, PCK-based learning design is able to facilitate the development of practical teaching skills in real terms, as well as improve essential abilities in meaningful mathematics learning. The implication of this research is that the adaptation of Lannin's PCK model can be used as a reference in compiling more contextual learning tools, so that teachers are better prepared to deal with the diversity of students' ways of thinking in the classroom.
Keywords: Learning Design; Teaching Skills; PCK; Lesson Plan

I. INTRODUCTION

Teachers play a central role in determining the quality of education in a nation (Saputra & Cesaria, 2024). In the context of the national education system, the existence of quality teachers is the primary foundation for realizing an effective, efficient, and meaningful learning process (Toheri, Kismeina, & Persada, 2022; Octaviani et al., 2023). Many factors determine the quality of teachers in addition to academic ability, such as the capacity to deal with changing times, technological advances, and the dynamics of student needs. As the 21st-century educational paradigm requires critical, creative, collaborative, and communicative thinking skills, teachers are required to constantly improve their competence, both in mastering the material and in the pedagogical delivery strategy of material (Trilling & Fadel, 2009; OECD, 2018; Arwadi, Sidjara, & Suarlin2023).

In carrying out their duties as a learning facilitator, it is not enough for a teacher to understand the content of the subject matter. He is also required to teach the material in a practical, engaging, and suitable way that meets the needs and characteristics of students. Susilowati (2015) stated that the success of a teacher in teaching is greatly influenced by his ability to combine his mastery of the material and his teaching skills. This concept is reflected in the framework of Pedagogical Content Knowledge (PCK), which is knowledge that integrates the content of the material with pedagogy or learning strategies. According to Resbiantoro (2015), PCK includes an in-depth understanding of the teaching material, how to present it, as well as knowledge of how students understand the material. This is emphasized by Rahayu, Muhtadi, and Ridwan (2022), Hanggara (2015), and Damawati (2015), who stated that PCK is a crucial element in improving the quality of learning processes or activities.

In the context of mathematics learning, the importance of PCK is becoming increasingly evident, considering the characteristics of mathematics as an abstract discipline. Mathematics teachers are required to have a deep understanding of how to manage the complexity of teaching materials and turn them into concrete and meaningful learning experiences for students (Ball, Thames, & Phelps, 2008; Sumartini et al., 2020; Saepuloh, Luritawaty, & Afriansyah, 2024). PCK is a conceptual framework that can bridge theory and practice in mathematics learning (Ali, Suarlin, & Arwadi, 2024). Therefore, the development of PCK skills in mathematics teachers is a necessity to achieve optimal learning quality.

Several previous studies have emphasized the importance of PCK in improving the quality of mathematics learning, but most of them still focus on teachers' conceptual understanding of the PCK components (Ball, Thames, & Phelps, 2008; Susilowati, 2015; Helsa et al., 2024). This research advances the study by developing a learning design that explicitly adapts John K. Lannin's PCK model. Adaptation is carried out through an emphasis on identifying students' ways of thinking, variations in mathematical representations, anticipatory planning for learning difficulties, and integration of

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assessment strategies, as formulated in the PCK Mathematics Lesson Plan Template. With this approach, PCK is not only understood as a conceptual framework but also operationalized in the form of learning tools that teachers can use in real life (Nuraeni & Juandi, 2023).

However, the challenge faced is how to design PCK-based mathematics learning systematically in order to improve teachers' teaching skills. This is important because good learning design not only determines the effectiveness of the learning process but also serves as an operational guide for teachers in implementing the right strategies. To address these challenges, the researcher employed a development-through-design research approach, comprising preliminary research, prototyping, and assessment phases (Arwadi et al., 2024).

Thus, this research has a long-term goal to produce new theories and innovations in the development of teachers' Pedagogical Content Knowledge skills, especially in the field of mathematics learning. In particular, this study aims to find an alternative to PCK-based learning design that is appropriate to improve the teaching skills of mathematics teachers at various levels of education. This research is important and relevant in answering real needs in the field, as well as making a theoretical and practical contribution to improving the quality of mathematics education in Indonesia.

The expected output of this study is the availability of a valid, practical, and effective PCK-based mathematics learning design in improving teachers' teaching skills. In addition, the results of this study are expected to provide theoretical contributions in the form of developing the adaptation of the Lannin PCK model in the context of mathematics learning in Indonesia, as well as practical contributions in the form of learning tools that can strengthen teachers' capacity in dealing with the diversity of students' ways of thinking in the classroom.

II. METHOD

This study uses a design research method that aims to design, develop, and evaluate educational interventions in the form of Pedagogical Content Knowledge (PCK)-based learning design (Putrawangsa, 2018). This approach was chosen because it is in accordance with the research objectives, namely, finding alternative learning designs that can improve the teaching skills of mathematics teachers and produce theoretical contributions related to the development of PCK in the context of mathematics learning.

The design research model used refers to the Plomp framework (Plomp & Nieveen, 2010), which consists of three stages: (1) preliminary research includes needs analysis, literature review, and context study; (2) prototyping phase in the form of development and testing of learning design prototypes; and (3) assessment phase to assess the validity, practicality, and effectiveness of the resulting design.

The subjects of the study are three mathematics teachers who are studying at the Master of Mathematics Education Study Program, Siliwangi University. The

selection of a relatively small number of subjects is due to the characteristics of design research that emphasize the depth of exploration and iteration of the design rather than the generalization of results. To minimize potential bias, data were collected from various sources (lesson plans, observation sheets, and interviews) and then triangulated.

The data collection instruments include: (1) Learning Implementation Plan (RPP) developed by teachers based on the adaptation of the Lannin PCK model, and (2) teacher teaching skill observation sheets. The observation sheet was developed based on the PCK component, with assessment criteria that include: (a) the ability to present material with varied representations; (b) pedagogical strategies in explaining concepts; (c) the ability to anticipate students' difficulties and provide scaffolding; (d) the effectiveness of interaction and communication with students; and (e) reflection on the implementation of learning.

Before the research was carried out, all participants were explained the objectives, procedures, and potential benefits of the research. Participation is done voluntarily by expressing informed consent. Qualitative data is analyzed through the following stages: (1) data reduction, namely selecting important information according to the focus of the research; (2) categorization based on the four main components of PCK Lannin; (3) the presentation of data in the form of narrative descriptions and teaching skill matrices; and (4) concluding triangulation between data sources. Quantitative data obtained from observation scores were then analyzed descriptively to see the tendency to improve teachers' teaching skills after the implementation of the learning design.

III. Result and Discussion

The first stage is the preliminary research phase. The primary focus in this stage is on collecting initial data through needs questionnaires, analyzing teacher learning documents, and conducting literature studies to understand the structure and real needs in the field. The subjects in this stage are three mathematics teachers who are studying at the Master of Mathematics Education Program at Siliwangi University, Tasikmalaya City. The instruments used include: 1) Teacher needs analysis questionnaire, covering aspects of PCK understanding, difficulties in teaching abstract concepts, learning planning, and assessment; 2) Analysis sheet of learning tools, to assess the integration between content, pedagogic, and student understanding in the RPP and LKPD documents that the teacher has prepared. The results of the processing of the teacher needs questionnaire are presented in Table 1 below:

Table 1.
Recapitulation of the Results of the Teacher Needs Questionnaire on the Implementation of PCK

No	Aspek yang Diukur	Skor Rata-rata	Kategori
1	Pemahaman konsep PCK	2,58	Cukup
2	Kesulitan mengajarkan konsep abstrak matematika	4,30	Tinggi
3	Kemampuan merancang strategi pembelajaran sesuai karakteristik siswa	2,73	Cukup
4	Penggunaan asesmen formatif untuk mengukur pemahaman siswa	2,41	Rendah
5	Integrasi konten dan pedagogi dalam dokumen RPP	2,54	Cukup

From the data above, teachers face a high level of difficulty in teaching abstract concepts in mathematics, especially those related to topics such as spatial geometry.

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This difficulty is in line with the findings of Ball, Thames, and Phelps (2008), who stated that the main challenge of mathematics teachers lies in the ability to relate abstract content to appropriate pedagogical strategies. This indicates that teachers' conceptual understanding of the material is not yet fully mature, particularly in presenting abstract concepts in a more concrete and meaningful way for students.

Teachers' understanding of Pedagogical Content Knowledge (PCK) is still in the sufficient category, indicating that they do not fully grasp the interplay between content, pedagogy, and student characteristics. According to Shulman (1986), the essence of PCK is the ability to transform content into a form that can be understood by students, through appropriate delivery strategies and based on understanding of student characteristics. A lack of a deep understanding of the integration between content and pedagogy can lead to purely procedural learning, without touching on the deep conceptual aspects (Depaepe, Verschaffel, & Kelchtermans, 2013).

In addition, the use of formative assessments that should be part of the PCK component—especially knowledge of assessment—is still low. In fact, according to Heritage (2010), formative assessments are an integral part of the learning process because they can provide direct feedback to teachers and students, as well as help in adjusting teaching strategies. The low use of formative assessments shows that teachers have not fully integrated the assessment results information in the learning decision-making process (Popham, 2008; Lele, Marsigit, & Retnawati, 2024).

The results of the analysis of teacher learning documents in the form of lesson plans and LKPD used by teachers were analyzed based on the four components of PCK according to the John K. Lannin model as follows: 1) Knowledge of Instructional Strategies: The learning strategies used are still conventional (lectures and practice questions); 2) Knowledge of Student Understanding: There is no adjustment of learning strategies based on the possibility of student misconception; 3) Knowledge of Curriculum: Teachers have followed the syllabus, but have not been able to map the order of the material based on the student's level of difficulty; 4) Knowledge of Assessment: Assessment is dominated by summative tests; Diagnostic and formative assessments are rarely used. These results highlight the need to develop a learning design that operationalizes the four aspects of PCK explicitly and integrates them, serving as a reference for implementing the next phase (prototype phase).

In the second stage (prototype phase), the researcher designed a mathematics learning design in the form of a lesson plan aimed at producing a learning design prototype based on pedagogic content knowledge in improving the teaching skills of mathematics teachers based on the John K. Lannin PCK model which consisted of: (1) knowledge of instructional strategies for mathematics which included how to choose and organize instruction, The specific actions that the teacher can take during teaching, the activities that will be

used for certain math content, the materials needed to be used for teaching, determining what repertoire is best for a particular content; (2) knowledge of student understanding within mathematics which includes: student misconceptions, student difficulties, students' discovery or approach to concepts in solving problems, strategies used by students in solving problems and students' initial knowledge; (3) knowledge of curriculum for mathematics which includes: curriculum resources, textbook content, scope and order of mathematics topics, national standards; (4) Knowledge of Assessment for Mathematics which includes: Reasons or background of assessment, how to assess students, What is done about the assessment results, assessment challenges, assessment strategies, potential teacher responses based on assessment results, assessment objectives, and what should be assessed.

In the prototype stage, this study adapts the 4D (Define, Design, Develop, Disseminate) development model to 3D (Define, Design, Develop). The selection of 3D models is based on their suitability to the research context, in particular the needs of teachers and real conditions in the field. With this approach, mathematics learning tools are developed to be more useful in the learning process in schools. The focus of development is directed at the material learning tool "Geometry Transformation" for class X MAN 1 Ciamis, which is validated in the form of lesson plans.

A. Define

The definition stage involves identifying the problems faced by teachers in compiling learning tools. Data was obtained through interviews with mathematics teachers at MAN 1 Ciamis and observations of devices that have been used. The goal of this stage is to establish the needs and development criteria of the device. In more detail, the activities carried out include:

1) Initial Analysis: The applicable curriculum is the 2013 Curriculum. Based on the results of observations, the syllabus is already available, so teachers only need to implement it without having to rearrange it. The lesson plans are mainly compiled from the syllabus, with some adaptations from other sources, such as the internet. The lesson plan is made separately per subject, in a table format, and includes a learning model to help achieve the goals.
2) Student Analysis: Student characteristics are learned through direct observation and student learning activity sheets. Aspects considered include seriousness in learning, motivation, background of learning experience, ability to receive lessons, and class activeness. Theoretically, MAN students are already at the formal operational stage, so they should be able to solve abstract problems. However, the results of observations show that there are still students who have difficulty understanding abstract mathematical problems. This condition highlights the need for learning tools that facilitate the learning process and help students

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rebuild mathematical concepts, such as through specially designed lesson plans.

3) Task Analysis: Teachers study the main tasks that students need to master to achieve minimum competence. The tasks analyzed included evaluation activities, which were associated with the learning objectives in the lesson plan. This analysis aims to identify the steps students must take to complete the task and achieve basic competencies.
4) Concept Analysis: At this stage, the teacher analyzes the important concepts of the learning material and arranges a logical sequence of presentation. Analysis includes mastery of the material, mapping the subject matter, and planning of learning steps. All analysis results are outlined in the draft lesson plan as a guideline for the implementation of learning in the classroom.

B. Design

In the technical implementation, the researcher first maps the elements that must be present and then determines the steps in making the RPP design by referring to the John K Lannin PCK framework. The elements in the RPP that are made are adjusted to the provisions determined by the Government. The steps taken are based on the Lesson Plan, which is grounded in PCK. The stages of designing the lesson plan are as follows: 1) Determining the elements that must exist, including: class, date, teacher name, subject, keywords, learning objectives, learning indicatorsm, assessment, learning stages; 2) Create the layout and template to be used; 3) Filling out the template; 4) Create a learning flow based on PCK; 5) Intrinsically analyze and evaluate.

C. Develop

At this stage, the activities carried out are the validation stage carried out by the validated validators, namely: 1) Prototype validation: There are two types of validation used in mathematics learning tools, namely: a) Content validation, namely whether the learning tool in the form of a lesson plan designed is in accordance with the subject syllabus and Geometry Transformation material for class X MAN 1 Ciamis; b) Construct validation, namely the suitability of the components of the learning tool in the form of lesson plans in accordance with the indicators that have been set; 2). Practicality: Trials are conducted to see the practicality or applicability of the designed learning tools.

The third stage (assessment phase) aims to evaluate the effectiveness of the PCK-based mathematics learning design that has been developed and revised in the prototyping phase. The evaluation focused on its impact on improving the teaching skills of mathematics teachers, both cognitively (knowledge) and practically (application in the classroom). The instruments used to measure the effectiveness of this design include: 1) Teacher Reflection Questionnaire to obtain data on teachers' perceptions and understandings of the concept of PCK and their experience in applying it during the

learning process; 2) Teaching Skill Test which is prepared to assess several indicators of teachers' teaching skills, including: 1) Preparation of PCK-based learning plans; 2) Explanation of mathematical material (especially abstract concepts); 3) Preparation and use of assessments (diagnostic and formative). The data was analyzed using a quantitative descriptive statistical method, namely by comparing the average scores before and after the implementation of the design.

Teachers' responses to the implementation of learning design showed significant changes in perception. A summary of the results of the reflection questionnaire is presented in Table 2 below:

Table 2.
Recapitulation of Teachers' Perceptions of the Implementation of PCK

No	Pernyataan	Sebelum	Sesudah
1	Saya memahami konsep Pedagogical Content Knowledge (PCK)	2,67	4,33
2	Saya terbiasa mengajar materi matematika yang abstrak	2,75	4,25
3	Saya dapat menyesuaikan strategi mengajar berdasarkan karakteristik siswa	3,00	4,42
4	Saya dapat menyusun asesmen formatif yang relevan	2,58	4,17
5	Panduan desain pembelajaran ini membantu saya dalam merancang pembelajaran	2,89	4,75

Based on the data in the Table, there is an increase in teachers' perception and confidence in understanding and applying the concept of PCK. Teachers find it more helpful because of the systematic guidance provided in the learning design. This positive perception supports the sustainability of PCK practice in the classroom. Teachers show improved skills in translating knowledge of mathematical content into learning strategies that suit the needs of students, which is the core of PCK (Shulman, 1986). There has been a significant improvement in assessment design, especially in the ability to prepare diagnostic and formative assessments. This reflects the successful integration of knowledge of assessment in learning design (Depaepe et al., 2013). Teachers feel more confident in teaching abstract material, as they have gained systematic guidance in a learning design that is responsive to students' understanding. These results support the idea that PCK is not only a conceptual framework, but also a practical tool to improve the quality of teaching (Gess-Newsome, 2015; Loughran et al., 2012).

Teaching skill test scores were analyzed before and after the implementation of the learning design. The results are presented in Table 3.

Table 3.
Comparison of Teacher Teaching Skills Test Scores

Aspek yang Dinilai	Skor Sebelum	Skor Sesudah	Kategori Awal	Kategori Akhir
Penyusunan RPP berbasis PCK	63	81	Cukup	Baik
Penjelasan materi (abstraksi & visualisasi)	65	83	Cukup	Baik
Penyusunan asesmen formatif dan diagnostik	57	81	Kurang	Baik

Based on the data in the Table, the aspect with the highest improvement is in the preparation of formative assessments, showing that the design has succeeded in strengthening the knowledge of the assessment component in PCK. The teacher's ability to explain abstract concepts more visually and contextually has also increased significantly. PCK-based learning design has been proven to facilitate the development of practical teaching skills in real life. These results show that learning design can improve essential skills in teaching mathematics in a meaningful way. These findings are supported by Kind (2009), who states that PCK-based interventions significantly improve the quality of assessment preparation and learning planning.

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The results of the study showed that there was an improvement in teachers' skills in integrating aspects of Pedagogical Content Knowledge (PCK) into learning practices. The most notable improvement can be seen in the knowledge of the assessment component, especially in the preparation of diagnostic and formative assessments. This can be explained because the assessments developed serve not only as a tool for evaluating learning outcomes but also as an instrument to understand students' ways of thinking and anticipate difficulties that arise. Systematic guidance in PCK-based learning design encourages teachers to be more structured in designing assessments that suit student needs. Thus, assessment is no longer seen as a learning conclusion activity, but rather as an integral part of the teaching and learning process.

In addition, there is an improvement in teachers' skills in presenting abstract mathematical concepts more contextually and visually. This improvement is closely related to the adaptation of the PCK Mathematics Lesson Plan Template, which emphasizes variations in representation and anticipation of student difficulties. Teachers feel more confident because they get concrete and applicative guidance in translating content knowledge into teaching strategies that suit students' characteristics.

The findings of this study are in line with Kind (2009), who reported that PCK-based interventions can improve the quality of teacher assessment and learning planning. These results also support the view of Gess-Newsome (2015) and Loughran et al. (2012) that PCK is not only relevant as a conceptual framework but can also be operationalized as a practical tool to improve the quality of teaching. In the context of mathematics learning, the results of this study corroborate the findings of Ball, Thames, and Phelps (2008) who emphasized the importance of PCK in overcoming the complexity of abstract mathematical concepts.

The results of this study are relevant to the direction of education policy in Indonesia, especially the strengthening of teacher competence in the implementation of the Independent Curriculum, which emphasizes differentiation of learning and formative assessment. The adaptation of the PCK Lannin model can serve as a reference for developing more contextually relevant learning tools, thereby better preparing teachers to address the diversity of students' thinking styles in the classroom.

For further development, this study recommends that PCK-based learning designs be piloted in more diverse contexts, both at different levels of education and in teachers with varied backgrounds and school environments. The developed model must not only be effective in a limited scope, but also have a broader usefulness as a contribution to improving the quality of mathematics learning nationally.

IV. CONCLUSION

The learning design based on Pedagogical Content Knowledge (PCK) developed through design research has proven to be effective in improving the

teaching skills of mathematics teachers. The most significant improvement was seen in the knowledge of the assessment component, especially the teacher's ability to compile and use formative and diagnostic assessments, as well as in the ability to explain abstract concepts more visually and contextually. Systematic guidance in the design of lesson plans based on the Lannin model provides an applicable framework for teachers to transform content knowledge into learning strategies that are responsive to student understanding.

These findings show that PCK not only serves as a conceptual framework but can also be operationalized into a practical tool that significantly improves the quality of teaching. Therefore, this PCK-based learning design deserves to be further developed and piloted in various, more diverse contexts as a contribution to enhancing the competence of mathematics teachers.

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