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CoMCoRe-LS: an instructional design to enhance pedagogical content knowledge of pre-service physics teachers

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ABSTRACT
This study aims to develop, implement, and evaluate an instructional design model to enhance the pedagogical content knowledge (PCK) of physics student teachers. Model development is accomplished in five stages over two years: 1) problem identification, 2) preliminary identification of the product and design concepts, 3) preliminary theories and products, 4) prototypes and assessments of early products and theories, and 5) final product and theory quality improvement. This study included three sets of participants: four professional teachers, four science education experts, and 54 physics student teachers. Following validation, revision, and implementation, it was determined that the Concept Mapping Content Representation—Lesson Study (CoMCoRe-LS) model was beneficial in enhancing pre-service teachers' PCK. This study demonstrates an increase in student teachers' capacity to plan and implement courses, regardless of whether they have a strong or weak conceptual understanding. This model may serve as an alternative for assisting pre-service teachers in building PCK while enrolled in courses that combine classroom lectures and internships in schools.

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Introduction

Pedagogical Content Knowledge (PCK) is a fundamental construct in the realm of education, providing teachers with an integrated approach to deliver effective learning experiences. While both content knowledge and pedagogical knowledge are essential for educators, PCK uniquely melds these domains, resulting in a profound impact on instructional quality (Meier, 2021; Park, 2019; Seung, 2013). İntroduced by Shulman (1987), PCK represents a fusion of subject-specific insights with effective teaching strategies, positioning teachers as transformative agents in the educational landscape (Park et al., 2011).

Recognising the significance of PCK, it becomes imperative to cultivate this knowledge domain from the early stages of teacher education. However, global research underscores a concerning trend: many pre-service teachers, regardless of their geographic context, exhibit inadequate development in PCK (Hale et al., 2016; Zhou et al., 2006). This challenge is not isolated but resonates even within the educational milieu of Indonesia, where studies have highlighted similar gaps in PCK preparedness among pre-service teachers (Fitrianawati et al., 2020; Purwaningsih, 2015).

In the educational framework of Indonesia, universities occupy a crucial position in molding the future of teaching professionals by providing specialised programmes specifically designed for disciplines like physics education. These programmes aim to equip pre-service physics teachers with the competencies required to deliver high-quality instruction in secondary schools. Central to this endeavour is the "field practice course," blend of academic learning and on-the-ground teaching experience. Such real-world exposure is instrumental in moulding a holistic PCK framework for pre-service teachers (Bradbury et al., 2018; Nilsson & Loughran, 2012; Torbeyns et al., 2020). Despite these efforts, there exists a noticeable gap in the exploration of the intricate dynamics of actual classroom instruction, particularly in the context of enhancing PCK. This study aims to fill this gap by introducing alternative teaching designs tailored to improve the PCK of pre-service teachers, contributing valuable insights to the international educational discourse.

Literature Review

Pedagogical Content Knowledge (PCK): An Overview

It is insufficient for a teacher to possess only content or pedagogical knowledge. A teacher must integrate content and pedagogical knowledge that refers to Pedagogical Content Knowledge (PCK). At the 2012 PCK summit in Colorado, PCK was characterised as knowledge that is distinct from the conventional understanding of teacher professionalism (Gess-Newsome, 2015). PCK is defined by Shulman (1987) as an amalgam of content knowledge and pedagogy that enables teachers to teach successfully. PCK can be compared to a chemical reaction in which reactants (in the form of content and pedagogical knowledge) and products (in the form of content knowledge and pedagogical knowledge) in the form of PCK can be identified. As a result, one may argue that PCK is integrative knowledge.

PCK is the knowledge that a teacher possesses to teach a particular topic in a unique manner and is widely thought to facilitate learner comprehension (Lee & Luft, 2008; Rollnick, 2017; Shulman, 1987). The important role of PCK is related to planning learning, implementing learning, learning quality, and learning outcomes (Baumert et al., 2010). PCK is the knowledge that is directly related to the teacher's primary responsibility, which is to design, execute, and evaluate classroom learning.

Factors Influencing PCK Development

As the domain of knowledge that has the greatest impact on how learning is implemented (Loughran et al., 2012b; Nilsson & Vikström, 2015; Rollnick et al., 2008), a person's PCK is influenced by a variety of factors, including the depth of material knowledge, teaching experience, and individual adaptability to change (Rozenszajn & Yarden, 2014; Williams & Lockley, 2012). Numerous studies demonstrate that three factors can help teachers and pre-service teachers improve their PCK: 1) The Lesson Study (LS) (Agricola et al., 2020; Akerson et al., 2017; Coenders & Verhoef, 2019; Karim & Danaryanti, 2020); 2) The Content Representation (CoRe) and Pedagogical and Professional–Experience Repertoires (Pap-eR) (Bertram & Loughran, 2012; Loughran et al., 2012a; Williams & Lockley, 2012); 3) The combination of CoRe and Lesson Study (Juhler, 2016, 2018).

1. Lesson study (LS):

   Lesson study is a kind of teacher professional development based on collegiality and reciprocal learning to create a learning community. LS can strengthen subject matter knowledge, learning strategies, and the capacity to watch students (sensitivity to the behavior of students who are or are not learning), develop a robust collegial network, and improve the quality of learning planning (Lewis, 2002). In Indonesia, LS is composed of three steps: Plan, Do, and See/reflect. It is a never-ending cycle of constant improvement (Saito et al., 2006). Despite numerous obstacles, LS in Indonesia continues to grow (Suratno, 2012). Coenders and Verhoef (2019) demonstrate that LS can help develop PCK and enhance learning quality. This finding is consistent with Karim and Danaryanti (2020) study in which students' PCK increased after completing the LS. According to Akerson et al. (2017), LS can allow peer feedback in order to make multiple inputs in learning apparently. Meanwhile, Agricola et al. (2020) reported that PCK increased significantly as a result of the reflection process from actual practice and from students.

2. Content Representation (CoRe) and Pedagogical and Professional–Experience Repertoires (Pap-eR):

CoRe and Pap-eR are both useful tools for assessing PCK (Hume & Berry, 2011; Kind, 2009; Loughran et al., 2012b). Additionally, PCK can be bolstered by including Content Representation (CoRe) and Pedagogical and Professional–Experience Repertoires (Pap-eR). Bertram and Loughran (2012) and Williams and Lockley (2012) found that using CoRe and Pap-eR, inexperienced teachers' PCK and content understanding improved. CoRe and Pap-eR enable novice teachers to develop a deeper understanding of the curriculum and to identify the key material that must be presented to their students. Williams and Lockley (2012) conducted a study to explore the use of CoRe as a mediating tool for the development of teachers' PCK. The finding indicated that CoRe formed collaboratively can assist teacher in focusing on the big picture of the topic, emphasising highly relevant content areas, and considering alternative lesson planning strategies.

3. Integrated Approach of LS and CoRe

Juhler (2016) successfully integrated two interventions, LS and CoRe, to help pre-service teachers develop their PCK. The combined results of CoRe and LS assist teachers in paying closer attention to all critical components when developing lesson plans. The critical component in question is that of the PCK model (Magnusson et al., 2002). The PCK is said to be rising if each of these components grows. In Juhler's research, the LS cycle consists of six steps: 1) objectives, 2) planning, 3) conducting and observing, 4) discussing and refining, 5) repeating, and 6) disseminating. This study still has limitations such as the small sample size and content knowledge aspects that were not specifically trained. Therefore, further studies are still needed in this domain.

Concept Maps: Addressing Subject Comprehension Gaps

The three solutions outlined above for enhancing pre-service teachers' PCK do not address the issue of subject comprehension. In other words, the method is effective when applied to subjects who do not have difficulty comprehending the content. If used to pre-service physics teachers who continue to struggle with conceptual understanding, the learning interventions that must be applied are certainly different.

Many studies show that physics is a difficult subject. Harrell et al. (2021) showed how prospective teachers have a low understanding of the concept of buoyancy. Similarly, Taslidere and Yıldırım (2023) reported that teachers still have difficulties in the concept of electricity. Likewise, in the concept of energy, teachers still have difficulties and misconceptions (Irmak et al., 2023). This needs to be addressed because one of the competencies that teachers need to have is a mature understanding of concepts.

There are nuanced approaches that can be taken to increase pre-service teachers' understanding. A concept map is one of the approaches used in this investigation. Concept maps were chosen to aid in subject comprehension since, according to findings from various works of literature, pre-service teachers' grasp of physics topics was disorganized. Students teachers' understanding of physics concepts is frequently partial, incomplete, and messy (Loughran et al., 2008; Purwaningsih, 2015).

Numerous studies have demonstrated that using concept maps in the teaching and learning process can aid teachers and pupils in focusing on key concepts and ideas (Novak et al., 1984). Koc

(2012) research demonstrated that concept maps were beneficial for comprehending complex topics and commenting on misconceptions. Hartsell (2021) showed how concept maps might aid the pre-service teacher in improving knowledge through visualisation.

The construction of concept maps requires learners to understand the content appropriately and then visually explicit it. Concept maps also allow one to draw connections between concepts which is a reflection of the relationship between concept maps and meaningful learning (Llinás et al., 2020). Creating concept maps allows learners to monitor what they have learned, what they have understood, and what they have not understood (Montpetit-Tourangeau et al., 2017).

Research Objectives

1. To develop an instructional design to enhance pre-service teachers' pedagogical content knowledge in teaching physics.
2. To implement an instructional design that can improve pre-service teachers' pedagogical content knowledge in teaching physics.
3. To evaluate the instructional design developed in terms of enhancing pre-service teachers' pedagogical content knowledge in teaching physics.

Method

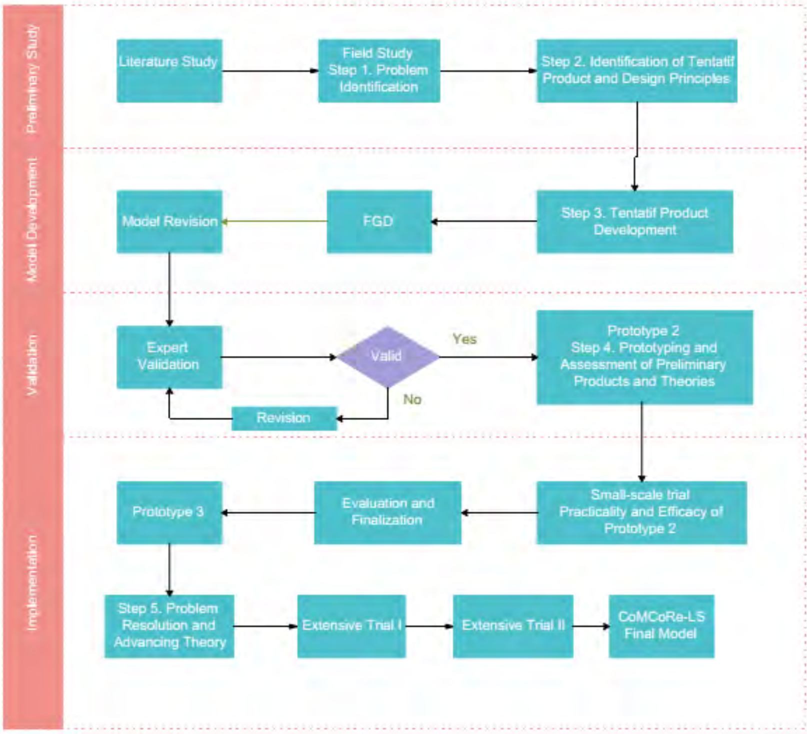
This research is an instance of Educational Design Research (EDR). This is a systematic study to design, develop and evaluate educational interventions as solutions to complex problems in education, which also aims to advance our knowledge of the characteristics of these interventions and the process of designing and developing them (Nieveen, 1999).

Procedure

In general, the development of the instructional design in this study was divided into four stages over two years, namely: 1) the preliminary study stage, which includes literature review, field research, and the description and analysis of findings; 2) the instructional design development stage, which includes the steps for instructional designs model, instructional design guidelines, and learning tools such as lesson plans, students worksheet, assessment sheets, and Focus Group Discussion (FGD) guidelines; 3) the validation stage; and 4) the instructional design implementation stage, which consists of the first trial and the second trial experiment. The stages of the investigation are depicted schematically in Figure 1.

Figure 1

Flowchart of research and development of CoMCoRe-LS



Stage 1: Preliminary stage

The preliminary investigation was conducted in two stages: problem identification and tentative instructional design principle. The first phase, identifying the problem, was accomplished through literature research and field studies. A critical examination of the PCK literature was conducted in order to create an initial draft of the learning instruction. The field study examined four professional physics teachers' PCK representation in four junior high schools in Malang, Indonesia. Additionally, a preliminary study was conducted on pre-service physics teacher students to ascertain the nature of PCK and the hurdles encountered during its development. Following the identification of the problem, an early draft of the instructional design was created based on the description of the preliminary analysis's results. The constructed instructional design must adhere to content ideas and construct validity, practicality and efficacy.

Stage 2: Development of Instructional Design

Prototype 1 was developed in this step. The developed instructional design is based on Concept Mapping and CoRe+Pap-eR, and it has been implemented through the lesson study cycle's stages. Experts reviewed the initial draft in the Focus Group Discussion (FGD) forum. The components of the instructional design are as follows: 1) syntax, 2) social system, 3) reaction principle, 4) support system, and 5) instructional and accompanying influence (Joyce & Weil, 2015).

Stage 3: Validation

Three physics education experts validated the instructional design. This stage is designed to review prototype 1 in terms of the learning instructional design's content and structure. Validation was accomplished through the use of a Likert scale-based instrument. Various inputs are allowed during this stage until prototype 2.

Stage 4: Implementation

External validation was performed in this step by deploying Prototype 2 of the CoMCoRe-LS. This task assesses the developed instructional design's validity, reliability, efficacy and practicability. Three cycles of implementation were conducted. The first cycle was a small-scale trial with fewer participants. This single-group pretest-posttest design was used in this trial. At the end of the trial, prototype 3 would be developed. The second cycle consisted of an extensive trial I. The experiment reflection results were utilized to refine the instructional design employed in the third cycle, extensive trial II. Additionally, a one-group pretest-posttest experimental design was also conducted in the extensive trials I and II. Following the extensive trial II, the CoMCoRe-LS can be considered valid, effective, and feasible for enhancing pre-service physics teachers' PCK.

Participants

This study includes two distinct groups of participants. First, the participants involved three education experts (experts in learning and instruction, assessment and physics content). The three experts have teaching and research experience in physics teacher professional development in Indonesia. This three experts is involved in the process of expert validation and FGD in improving the quality of learning design with CoMCoRe-LS. The second group of participants is actively involved in the experimental trial. Participants were pre-service physics teachers enrolled in the "field practice course I and II." The course is mandatory by providing students with theoretical and practical expertise relevant to physics learning in school.

Along with lecturing on campus, this course requires pre-service teachers to complete teaching/internships at schools. We applied for the field practice course on-campus, specifically at the Universitas Negeri Malang, Department of Physics Education. Field practice course II was carried out in collaboration with senior high schools. The small-scale trial involved 12 pre-service physics students and lasted ten meetings. The extensive trials I and II enrolled a total of 27 pre-service physics teachers during ten meetings. The extensive trial II was conducted in nine schools throughout Malang City, Batu City, and Malang Regency in East Java, Indonesia.

Research Instrument

In the implementation of the CoMCoRe-LS instruction, the following instruments were utilised: Learning Planning Skills Instrument, Learning Implementation Skills Instrument, Pap-eR Writing Skills Instrument, Concept Map Assessment Instrument, and Pre-service Physics Teacher Response Questionnaire to Learning via the CoMCoRe-LS. Prior to deployment, each instrument underwent a comprehensive validation procedure. This process was executed in two distinct phases, in accordance with Focus Group Discussion (FGD) guidelines and specialised validation sheets. The initial phase involved FGDs led by subject-matter experts, and the instruments were subsequently revised based on the feedback received. In the second phase, experts completed the provided validation sheets, which were designed to assess both content and construct validity, while also offering recommendations for further improvements. The finalised instruments and validation sheets are available in the appendix materials.

Data Analysis

Experts rate the instructional design's validity on a scale of 1 to 4 (1=poor, 2=fair, 3=good, and 4=very good). The PCK of pre-service physics teachers was assessed in this study using their ability to design and implement learning. These two skills are based on the performance of pre-service physics teachers who created concept maps, responded to CoRe questions, and wrote Pap-eR narratives. The skill score for planning physics learning was determined by the skill assessment form prior to and following participation in CoMCoRe-LS-based learning. The paired sample *t*-test (parametric) and the Wilcoxon signed-rank test (non-parametric) were used to know the effect of the instructional design intervention. We also analysed the teaching skill scores obtained from observations throughout the lesson.

Findings

Preliminary Study

Preliminary studies have been conducted and published previously. As an overview, this section will briefly present some of the findings. The study's findings revealed that teachers' PCK skill remains inadequate, and their comprehension of the content being taught remains incomplete (Purwaningsih, 2015). For instance, the teacher is unconcerned with whether or not the material being taught is necessary for students to master in order to accomplish the goal. Because the book contains an explanation, the teacher instructs in this manner. Students were asked to memorise the information discussed in greater detail at the subsequent level. As a result of the teacher's lack of familiarity with the teaching materials, the teacher is forced to teach according to the textbooks' order.

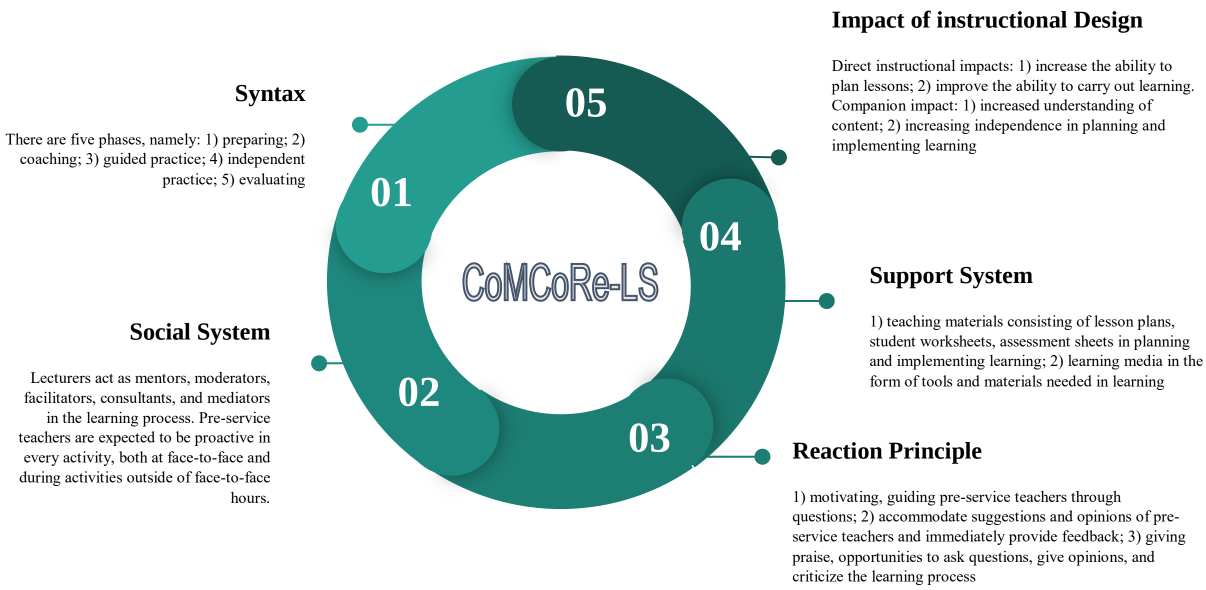
The pilot study was done with pre-service physics teachers enrolled in the "physics learning development" course. The findings indicated that the majority of pre-service physics teachers struggle with organizing physics content, understanding physics concepts, particularly determining essential material, and many of them struggle with compiling assessment instruments for higher-order thinking as well as assessment rubrics (Purwaningsih & Yuliati, 2015). The findings indicated that pre-service physics teachers struggled to arrange physics concepts and identify the fundamental materials that students needed to master, indicating that their PCK skill remained relatively low (Purwaningsih, 2015; Purwaningsih & Yuliati, 2015). The findings of the preliminary study indicated that the conceptual competence of pre-service physics is still problematic and needs to be improved.

Instructional Design Development

Based on the literature review and focus groups with experts, we designed an instructional design called CoMCoRe-LS that combines Concept Mapping and Content Representation in Lesson Study. Five instructional design components comprise the CoMCoRe-LS. As illustrated in Figure 2, these five components were met during the implementation of the CoMCoRe-LS in a small-scale trial and extensive trials I and II.

Figure 1

CoMCoRe-LS overview



Component 1: Syntax (Instructional Process)

The syntax of the CoMCoRe-LS consists of five phases. The instruction had designed to facilitate the physics teaching and learning process and enhance PCK. Based on theoretical and empirical studies, a learning instructional design syntax is developed that consists of five phases: 1) Preparing, 2) Coaching, 3) Guided Practice, 4) Independent Practice, and 5) Evaluating. Each phase's activities are summarized in the following paragraph.

The first phase is preparing. This phase is designed to motivate and prepare pre-service physics teachers to plan and implement lessons and equate perceptions between pre-service physics teachers and their educators. The pre-service physics teacher showed that "field practice course" is the only subject with real practice in schools. In this preparation phase, pre-service physics teachers were also challenged to learn the existing lesson plans. This process was done in the class, and the lesson plan review were submitted to the teacher educator's email and then discussed together. Pre-service physics teachers were grouped; one group consisted of three people. The activity in the group is the same as the activity of planning a lesson called "Plan in Lesson Study." The Do and See activity was carried out on the following day, namely the practice of presenting the lesson plan, conducting peer teaching (Do), and reflection (See). Planning lessons using the CoMCoRe-LS is different from planning lessons that pre-service physics teachers usually do. This preparation phase is to measure initial abilities and equip pre-service physics teachers with content knowledge that will be used to develop learning designs. The activity in phase 1 is a preparation that bridges the initial abilities of pre-service physics teachers with the skills to plan lessons. At this stage, the pre-service physics teacher met with the tutor teacher (professional physics teacher where pre-service teachers practice learning in real schools) and agreed on the content, which will be practiced in real class learning.

Coaching is the second phase of the CoMCoRe-LS. This phase involves pre-service physics teachers developing lesson plans with the assistance of teacher educators and then implementing them in class (peer teaching). Collaboratively, learning plans were developed. Even though it is a collaborative effort, each individual is still accountable for their contributions and ideas. Each group is responsible for developing a lesson plan for a single meeting (3 hours of lessons). This second phase entails a number of steps. The first step is to synthesise the learning objectives according to the existing curriculum. The second stage entails creating a concept map. In the form of propositions, concept maps are used to express meaningful relationships between concepts. The third and fourth steps are the compilation of CoRe and the development of learning designs. Because CoRe has never been introduced before, it is a novel problem for pre-service physics teachers. They create learning designs using the appropriate format for schools, based on the CoRe matrix. These designs include lesson plans, pupils worksheet, and assessments. The fifth, sixth, seventh, and eighth steps are design presentation, peer teaching+reflection, and Pap-eR. In peer teaching, pre-service physics teachers implement prepared instructional designs.

The third phase of the CoMCoRe-LS, Guided Practice, requires pre-service physics teachers to plan their learning in groups. Each group chose the topic. The learning design was developed on campus and implemented in real schools. The third phase of the CoMCoRe-LS begins with determining the learning objectives. Step 2 was completed by compiling a concept map with assistance from the teacher educator as needed. Steps 3 and 4 involve the creation of a CoRe and a learning design. The fifth step is presenting the lesson design (Evaluating Plan) followed by reflection and revision. Each pre-service physics teacher presented the lesson design they had prepared for 30 minutes. Teacher educators observed and provided feedback, improving their respective learning designs. The first five steps were completed on campus; the subsequent steps were completed in real classes. The third phase of the CoMCoRe-LS is comprised of the following steps: Real Teaching 1 + Reflection + Revision; repeated learning in other classes via Real Teaching 1 (repetition) + Reflection + Revision; and Pap-eR. During Real Teaching 1, teacher educators and tutors assessed students using the learning implementation assessment sheet. Teacher educators and tutors provide feedback during reflection to help improve the following lesson. Pre-service physics teachers were provided with opportunities to enhance their instructional design. The outcomes of the enhanced learning design were used to inform teaching practices in other classes, to improve the quality of learning, and increase pre-service teachers' self-confidence.

The fourth phase of the CoMCoRe-LS, Independent practice, occurs when the pre-service physics teacher is already in real teaching practice. Steps 1, 2, 3, and 4 were self-contained compilations of learning designs, similar to the third phase. The completed learning design was emailed to the teacher educator for assessment as a post-test of learning planning skills. The fifth step was not conducted (no design presentation activity). Real Teaching II+Reflection+Revision; Real Teaching II (improvement) + Reflection + Revision; and Pap-eR are the fourth phase steps 6, 7, and 8 of the CoMCoRe-LS. Pre-service physics teachers were evaluated by the teacher educator and another observer during the Real Teaching II, which entails teaching practice in a second real class. After the lesson, feedback was given for the next lesson's improvement, and pre-service physics teachers were given the opportunity to revise their learning design and implement it in other classes. The pre-service physics teacher constructs a narrative based on his teaching experience (i.e., Pap-eR).

In the fifth phase of the CoMCoRe-LS, evaluating, teacher educators and pre-service physics teachers engage in the following activities: 1) after pre-service teachers have completed their training school assignments, teacher educators conduct program evaluations. 2) pre-service teachers complete questionnaires about student responses; 3) pre-service teachers offer suggestions and opinions about how the course should be implemented. This was justified on the grounds that when pre-service teachers were involved in the assessment process. Additionally, pre-service teachers' involvement in assessing learning enables them to conduct a thorough self-assessment of their future careers and teaching skills.

Component 2: Social System (Activities)

The social system defines the roles and relationships of teacher educators, tutor teachers, and pre-service physics teachers; the relationships of pre-service physics teachers with another pre-service physics teacher. Teacher educators and tutors serve as mentors, moderators, facilitators, consultants, and mediators during the planning and learning processes. Cooperation, mutual evaluation, and motivation among students also contribute to the social system's environment. Pre-service physics teachers are expected to be proactive in all activities, both face-to-face and off-campus. Outside of face-to-face hours, communication is conducted via WhatsApp (WA) and email. The student response data also demonstrates a well-implemented social system. The well-implemented social system in the small-scale trial, extensive trial I, and extensive trial II resulted in a significant increase in pre-service teachers' PCK.

Component 3: Reaction Principle (Teachers' Reaction to Students' Response)

In the CoMCoRe-LS instructional model, the "Reaction Principle" serves as a crucial component that dictates how teacher educators interact with pre-service physics teachers. This principle is driven by the teacher educator's engagement and responsiveness to various facets of the pre-service teacher's academic involvement, including posed questions and expressed attitudes. Specifically, the Reaction Principle is founded on three key tenets:

1. Facilitation and Motivation: The teacher educator aims to guide pre-service physics teachers through a series of questions designed to build confidence in their pedagogical decisions.
2. Immediate Feedback: The educator attentively considers the suggestions and viewpoints of the pre-service teachers, offering immediate and constructive feedback.
3. Fostering Open Dialogue: The environment is structured to encourage praise, while also providing pre-service teachers with opportunities to ask questions, share opinions, and critically assess the learning process.

Empirical evidence supports the effectiveness of this principle. Data on pre-service teacher responses indicate a successful implementation of the Reaction Principle. A significant majority of pre-service teachers exhibited a positive attitude towards learning physics when both the CoMCoRe-LS model and student response data were employed. Further, the application of this principle in various trial phases—including a small-scale trial, extensive trial I, and extensive trial II—resulted in a marked enhancement of the pre-service teachers' PCK.

Figure 3

Syntax of CoMCoRe-LS instruction

Component 4: Support System (Teaching Materials)

A support system is required for the CoMCoRe-LS. The support system, in this case, refers to all the infrastructure, materials, and tools required to support the implementation of the CoMCoRe-LS, including: (1) learning tools associated with the CoMCoReLS, which include a lesson plan, students worksheet, and planning and implementing learning assessment sheets; (2) learning media, which include investigative tools and materials, as well as ICT media and supporting systems such as laptops, projector, and internet network. (3) Perhaps most significantly, the availability of authentic classroom facilities in which pre-service physics teachers can practice teaching, complete with students, laboratory facilities, and tutor teachers. This is a result of the Universitas Negeri Malang close collaboration with the Senior High School that was involved in this study. Non-physical facilities include a conducive learning environment and the teacher educators' and pre-service teacher readiness to engage in learning in order to facilitate mutual communication. Awareness of pre-service teachers implementing PCK will be evident when the teacher truly understands the physics concept the teaching process, the rationale for the decisions made to assist students, the rationale for the content taught, the rationale for facilitating the diversity of student needs, and the rationale for conducting an assessment of the learning process (Bertram & Loughran, 2012; Chordnork & Yuenyong, 2014). The pre-service physics teachers' response data also demonstrates a well-implemented support system. The well-implemented social system in the small-scale trial, extensive trial I, and extensive trial II resulted in a significant increase in pre-service teachers' PCK.

Component 5: Impact of Instructional Design

The effectiveness of an instructional design model is often gauged by its impact, both direct and indirect, on the learning outcomes. In the context of the CoMCoRe-LS model, these impacts serve as key performance indicators that substantiate the model's efficacy.

Direct Impacts: These are deliberate outcomes that the instructional design aims to achieve. In the case of CoMCoRe-LS, the direct impacts are twofold: 1) Enhanced Lesson Planning: The model aims to elevate the pre-service physics teachers' competencies in lesson planning. 2) Improved Learning Implementation: The model is designed to augment the ability of pre-service teachers to effectively execute instructional plans. Indirect Impacts: These are secondary benefits that emanate from the application of the CoMCoRe-LS model: 1) Deepening Content Knowledge: The model facilitates a more profound understanding of subject matter content. 2) Fostering Autonomy: The model encourages growing independence in both planning and executing educational activities.

The model's effectiveness is corroborated by data gathered from various phases of its implementation, including a small-scale trial, extensive trial I, and extensive trial II. The results demonstrate that teacher educators have implemented the instructional design phase proficiently, aligning with positive feedback from pre-service teachers in physics education. The findings indicate that the CoMCoRe-LS model not only supports but also enhances the role of teacher educators in classroom learning processes. Consequently, this suggests that teacher educators can be effectively trained in leveraging PCK to improve the instructional competencies of pre-service physics teachers.

Validation

Expert validation occurs in two stages. The first validation was conducted through FGD, and the second was completed on the content and construct validity criteria. The following is one of the suggestions implemented during the development process.

> Based on the illustration of the instructional design chart (Diagram of the first instructional design/prototype 1). The chart contains the components necessary to construct the instructional design, but the chart cannot explain what you want. Improve the chart by describing or illustrating the Lesson Study activities. (Expert A)

The validity of the CoMCoRe-LS instructional model was ascertained through expert evaluations, employing a scoring range of 1-4. While both content and construct validity encompassed six criteria, each serves a distinct purpose in the validation process.

The content validity specifically addresses the instructional design's suitability and relevance to its intended educational objectives. It comprises six criteria: 1) the need for instructional design development, 2) the CoMCoRe-LS is designed based on the latest knowledge, 3) theoretical support for the CoMCoReLS, 4) planning and implementation of the instructional design, 5) learning environment management, and 6) use state-of-the-art evaluation techniques. The results of the study showed that the CoMCoRe-LS design is declared valid and very valid with a score of 4.00; 4.00; 4.00; 4.00; 4.00; and 3.00, respectively.

In contrast, construct validity evaluates the extent to which the CoMCoRe-LS design measures the educational constructs it purports to measure. The criteria for construct validity are: : 1) the need for instructional design development, 2) the instructional design was designed based on the latest knowledge, 3) empirical support for the instructional design, 4) planning and instructional design implementation, 5) learning environment management, and 6) use of the latest evaluation techniques.

The primary difference between content and construct validity lies in their focus: content validity emphasizes the relevance and appropriateness of the content, while construct validity assesses the efficacy of the instructional design in measuring educational constructs. For construct validity, specific evidence was drawn from empirical studies that validated the instructional design's effectiveness in achieving its intended educational outcomes.

The data showed that the reliability based on Cronbach's Alpha coefficient of 0.826 is classified as high-reliability criteria, which indicated that the results of the content validation of the CoMCoRe-LS are reliable. The results of the validator's assessment indicated that the content validity of the CoMCoRe-LS includes very valid criteria. The CoMCoRe-LS had met the criteria for content validity, namely meeting the need and state of the art, having a strong theoretical and empirical basis, and having consistency between the components that make up the instructional design, so that it can be used in learning to improve learning.

Evaluation of the Instructional Implementation

The results of statistical tests of data on planning skills for pre-service physics teachers in a small-scale trial, extensive trial I, and extensive trial II Wilcoxon Signed Ranks Test are presented in Table 1.

Table 1

Results of Wilcoxon Signed Ranks Test of "physics learning planning skills" for pre-service physics teachers

Group	N	Pretest		Posttest		Wilcoxon Signed-Rank Test	
		Mdn	IQR	Mdn	IQR	Z	P
Small-scale trial	12	2.400	0.350	3.800	0.500	-3.071	0.007
Extensive trial IA	9	2.000ri	0.600	3.400	0.700	-2.716	0.007
Extensive trial IB	9	2.000	0.500	3.400	0.700	-2.701	0.007
Extensive trial IC	9	2.000	0.400	3.200	0.700	-2.687	0.007
Extensive trial IIA	9	2.200	0.400	3.800	0.600	-2.701	0.007
Extensive trial IIB	9	2.000	0.500	3.200	0.600	-2.716	0.007
Extensive trial IIC	9	2.000	0.600	3.400	0.800	-2.701	0.007

Note. Mdn=Median; IQR=Interquartilre Range

The Wilcoxon Signed Ranks Test results showed a significant increase in the physics learning planning. These results were seen in all cohorts: the small-scale trial group, extensive trial IA, extensive trial IB, extensive trial IC, extensive trial IIA, extensive trial IIB, and extensive trial IIC, $p < 0.05$.

The PCK scores of pre-service physics teachers are also manifested when they carry out learning. Observations on real teaching were carried out twice, namely on real teaching I in phase 3 and real teaching II in phase 4. The score of the ability to implement the pre-service teacher instructional design can be seen in Table 2.

Table 2

Results of the Wilcoxon Signed Ranks Test of "implementing physics learning skills" for pre-service physics teachers

Group	N	Real teaching I		Real Teaching II		Wilcoxon Signed-Rank Test	
		Mdn	IQR	Mdn	IQR	Z	P
Small-scale trial	12	3.290	0.300	3.500	0.380	-2.125	0.034
Extensive trial IA	9	3.170	0.290	3.420	0.250	-2.670	0.008
Extensive trial IB	9	3.170	0.460	3.420	0.540	-1.604	0.109
Extensive trial IC	9	3.080	0.460	3.420	0.500	-2.692	0.005
Extensive trial IIA	9	3.250	0.500	3.330	0.550	-2.108	0.035
Extensive trial IIB	9	3.170	0.540	3.330	0.630	-2.675	0.007
Extensive trial IIC	9	3.080	0.500	3.330	0.420	-2.539	0.011

Note. Mdn=Median; IQR=Interquartilre Range

Table 2 shows that there are significant differences in the participants' skills to carry out physics learning when doing real teaching I and real teaching II. The ability of participants significantly increased in almost all groups of participants. To evaluate the effectiveness of the CoMCoRe-LS, student responses were also recorded in this study. The results of student responses to the use of the developed instructional design are presented in Table 3.

Table 3

Responses of Pre-service Physics Teachers to Learning with the CoMCoRe-LS

Aspect	Small-scale trial				Extensive trial I												Extensive trial II											
					IA				IB				IC				IIA				IIB				IIC			
	Percentage (%)				Percentage (%)				Percentage (%)				Percentage (%)				Percentage (%)				Percentage (%)				Percentage (%)			
	P	F	G	VG	P	F	G	VG	P	F	G	VG	P	F	G	VG	P	F	G	VG	P	F	G	VG	P	F	G	VG
I	8	17	25	50	0	0	22	78	0	11	22	67	0	0	33	67	0	0	33	67	0	0	33	67	0	0	22	78
II	0	8	8	83	0	0	33	67	0	0	33	67	0	0	33	67	0	0	33	67	0	0	22	78	0	0	33	67
III	0	8	8	83	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78	0	0	33	67	0	0	33	67
IV	0	8	8	83	0	0	11	89	0	0	11	89	0	11	33	67	0	11	33	67	0	0	22	78	0	0	22	78
V	0	8	8	83	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78
VI	0	8	8	83	0	0	22	78	0	0	33	67	0	0	0	100	0	0	0	100	0	0	11	89	0	0	11	89
VII	0	8	8	83	0	0	33	67	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78	0	0	44	56
VIII	0	8	8	83	0	0	22	78	0	0	3	67	0	0	33	67	0	0	33	67	0	0	22	78	0	0	33	67
IX	0	8	8	83	0	0	33	67	0	0	22	78	0	0	22	78	0	0	22	78	0	0	33	67	0	0	22	78
X	0	8	8	83	0	0	33	67	0	0	11	89	0	0	33	67	0	0	33	67	0	0	11	89	0	0	22	78
XI	0	8	8	83	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78	0	0	11	89
XII	0	8	8	83	0	0	11	89	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78	0	0	11	89
XIII	0	8	8	83	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78	0	0	22	78
XIV	0	8	8	83	0	0	22	78	0	0	33	67	0	0	44	56	0	0	44	56	0	0	33	67	0	0	22	78
Rerata	1	9	10	80	0	0	25	75	0	1	23	76	0	1	25	74	0	1	25	74	0	0	23	77	0	0	25	75

Note: A: participants in Malang city, B: participants in Batu City, C: participants in Malang regency. VG: Very good; G: good; F: Fair; P: Poor; I: What do you think about the learning instructional design in this course?; II: What do you think about the way teacher educators explain teaching materials?; III: What do you think about the motivation given by the teacher educator at every face-to-face meeting?; IV: What do you think about the skills being trained?; V: What do you think about the novelty of the study material discussed?; VI: What do you think about the benefits of the learning topics discussed in lectures?; VII: What do you think about the relationship between learning in this course and the ease of producing lesson plans?; VIII: What do you think about the relationship between learning using the CoMCoRe-LS and the ease of implementing real teaching?; IV: What do you think about the classroom atmosphere during learning using the CoMCoRe-LS?; X: What do you think about the benefits and smooth communication with teacher educators outside of face-to-face hours by using online facilities?; XI: What is your opinion whether the learning activities carried out always invite students to think?; XII: What is your opinion, does this CoMCoRe-LS learning instructional design in lectures clarify the understanding of concepts in the material discussed?; XIII: Have you been able to independently design the CoMCoRe-LS learning design to teach students in high school by taking this course?; XIV: What do you think, can the learning activities using the CoMCoRe-LS learning instructional design change your level of belief in the truth of the concept?

Table 3 demonstrates that the overall percentage of students responding positively to learning using the CoMCoRe-LS approach is relatively high. This result is shown by the high number of "very good" ratings in nine aspects tested during the small-scale experiment (about 80 percent), the extensive trial I (about 75 percent), and the extensive trial II (about 75 percent). One may argue that the excellent response to the CoMCoRe-LS demonstrates that it is deserving of consideration for application in learning design and real teaching courses.

Discussion

Contextual Significance and Relevance

In schools, real teaching practice is a cumulative form of lecture results. In Indonesia, this activity occurs during the final semesters or fourth year of a pre-service teacher's undergraduate physics education program. Students are required to attend a series of lectures on campus prior to beginning their internships. As a result, activities become more complex as they are carried out on campus and in the schools where they practice. If this internship is conducted properly, it will boost students' confidence and readiness for real-world practice. This is consistent with the ARCS theory (Attention, Relevance, Confidence, and Satisfaction) (J. M. Keller, 1987; J. Keller & Suzuki, 2004), which states that motivation will occur when the teacher educator's material is directly related to the needs (relevance) of pre-service physics teachers (J. M. Keller, 2010). In other words, this preparation is critical in the process of developing a pre-service teacher into a professional educator.

This study considers the use of concept mapping, content representation, and lesson study as tools to develop the PCK of prospective physics teacher students. This is based on previous theoretical studies and empirical studies where the PCK of students tends to be low with the level of mastery of concepts which is still problematic. (Purwaningsih, 2015; Purwaningsih & Yuliati, 2015). The developed learning instructional design was dubbed the concept mapping content representation lesson study or CoMCoRe-LS. This instructional design was specifically developed to address the PCK of prospective teachers with low conceptual knowledge.

Unpacking the CoMCoRe-LS

The CoMCoRe-LS instructional design's syntax is as follows: 1) Preparing, 2) Coaching, 3) Guided Practice, 4) Independent Practice, and 5) Evaluating. This syntax takes into account the various activities that pre-service teachers engage in two distinct settings, namely on campus and in the schools where they practice. The CoMCoRe-LS is centered on the student. Scaffolding is provided and removed as the learning process progresses. According to Vygotsky's constructivist theory, there are four principles of learning: (a) pre-service physics teachers are facilitated to carry out social interactions in the form of collaborative discussions to construct knowledge by combining personal experiences and experiences with other people or the environment, (b) pre-service physics teachers are able to complete their assignments without assistance if the tasks given in The Zone of Proximal Development (ZPD), there needs to be assistance if the task given is of a high level of complexity, (c) cognitive apprenticeship, a process in which pre-service physics teachers gradually acquire intellectual skills through interaction with more skilled people, (d) teacher educators can use scaffolding to help pre-service physics teachers overcome certain problems that are beyond their developmental capacity (Arends, 2014; Schunk, 2012). Feedback given by the teacher can help the development of the learning process and increase the learning performance of pre-service physics teachers (Wilbert et al., 2010).

Empirical Validation and Insight

Following validation by four experts and three rounds of testing on pre-service physics teachers, this study demonstrates that the CoMCoRe-LS learning instructional design is valid, feasible, and effective for developing pre-service teachers' PCK. In general, these findings corroborate previous research indicating that PCK is a skill that can be developed through learning experiences (Bertram & Loughran, 2012; Etkina, 2010; Kaya, 2009; Nilsson & Loughran, 2012).

The CoMCoRe-LS model has been observed to induce a significant improvement in the planning aspects of physics education. Through structured guidance and a well-conceived pedagogical framework, pre-service teachers are better equipped to create effective lesson plans, thereby demonstrating the model's immediate applicability in educational settings. This may be due to an increase in participants' content knowledge. One of the CoMCoRe-LS's advantages is that it is effective at developing the PCK of pre-service teachers who struggle with conceptual understanding. This is interesting because previous studies have shown that content knowledge has a correlation with PCK (Baumert et al., 2010; Depaepe et al., 2015; Großschedl et al., 2014, 2019; Jüttner et al., 2013). In CoMCoRe-LS, there is a learning section where pre-service teachers develop concept maps. By using concept mapping, as introduced by Novak et al. (1984), concept mapping has become an alternative that can also be used to reveal conceptual development (Harrell et al., 2021). The research findings support the assertion that concept maps are an extremely effective tool for describing the content (Liu et al., 2014). By making a concept map, pre-service teachers can externalize their knowledge comprehensively. This is important because epistemologically, the view that physics material is not related to each other very often appears among novice teachers (L. Chen et al., 2019; Hammer, 1994).

Moreover, the CoMCoRe-LS model contributes to a marked improvement in the participants' abilities to implement physics lessons effectively. This suggests that the model not only aids in the planning phase but also has a tangible impact on the execution of these plans in a classroom setting. Along with concept mapping, this instructional design makes use of the benefits of content representation. The incorporation of CoRe into lectures can help pre-service teachers have a better understanding of the PCK component (Hume & Berry, 2011). Other research indicates that CoRe and Pap-eR are valid methods for assessing science teachers' PCK (Bertram & Loughran, 2012). Preparing Pap-eR is an activity in which participants describe their experiences teaching specific materials in a format consistent with the Pap-eR guidelines. The use of Pap-eR has been shown to improve pre-service teachers' PCK ability from the pre-PCK stage to the growing PCK stage (Anwar et al., 2012). In addition, these two components show their role as material for reflection by prospective teachers. This is important because reflection can also raise awareness of the attitude to life of pre-service physics teachers, as long as it is accompanied by the example of the teacher educator (Avraamidou, 2018; J. Chen, 2018; Purwaningsih et al., 2020).

Conclusion and Implications

The CoMCoRe-LS has been demonstrated to be valid, practical, and effective in enhancing pre-service physics teachers' PCK. After two years of study and development, it has been demonstrated that the CoMCoRe-LS is capable of increasing the PCK of pre-service teachers with both high and poor subject knowledge. The CoMCoRe-LS satisfies all of the criteria for an effective instructional instructional design. The development of this instructional design demonstrates how concept mapping, CoRe, and Pap-eR can assist pre-service teachers with limited subject knowledge in planning and implementing classes.

As a result, this instructional design deserves to be used as an alternative instructional design for equipping pre-service teachers with PCK, particularly those who are currently enrolled in the teacher preparation program (pre-service or in-service teacher). The CoMCoRe-LS can also be used in fields other than physics. However, several factors must be considered during implementation. For instance, when compiling a concept map, it was discovered that some pre-service physics teachers still struggle. If possible, it is recommended that training on the creation of concept maps occur prior to the beginning of the course implementation. Additionally, in each subject that contains a physics concept, there is an activity that involves compiling a concept map for each topic discussed. When compiling CoRe, it is necessary to provide guidance, as CoRe is unfamiliar to the majority of students.

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