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Designing Web-Based Knowledge Building for Pedagogical Content Knowledge Development of Prospective Teachers

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***Abstract*—Prospective teachers need to be competent in teaching mathematics. Web-based Knowledge Building is designed to train prospective teachers to have knowledge and skills in teaching mathematics to elementary students. The research and development studies using the ILDF model consist of three phases: exploration, enactment, and evaluation. In the exploration phase, 175 prospective teachers respond 5 points Likert scale for need analysis. We get information that prospective teachers have moderate abilities and conceptual knowledge but high abilities in procedural knowledge. Also, they highly intend to improve their competence in teaching mathematics. They have high skills in learning in an online environment. In the enactment phase, the Moodle application was designed and developed Web-based building knowledge running by LMS. Arithmetic's instruction course installed in LMS organized in 16 sessions and facilitated by document video, and quiz. The prototype was validated by three subject matter and three learning media experts. In the evaluation phase, the prototype was validated by 40 prospective teachers. The results were that the prototype has a higher score in easy to use, subject matter organizing, adequacy and breadth of subject matter, and benefit. In conclusion, web-based knowledge building is valid and appropriate for developing prospective teacher education. The web-based knowledge building is advantaged in information access, collaboration, knowledge construction, and learners' responsibility in knowledge acquisition.**

***Keywords*— Web-based knowledge building; pedagogical content knowledge; prospective teachers.**

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I. INTRODUCTION

Pedagogical content knowledge (PCK) is the knowledge of teaching certain materials to students. Research over the past two decades has proven that PCK influences learning quality and relates to learning outcomes. Educators are responsible for preparing prospective teachers (PTs) to teach mathematics correctly and appropriately to elementary school students. PTs need to make their students active and collaborative as well as have higher-order thinking skills as required by 21st-century society. In addition, PTs also need to be prepared to use technology following learning in the 21st century.

However, some studies show PTs lack in some ways. PTs had limited knowledge of explaining the procedures of adding and subtracting fractions [1] and solving fraction division tasks [2]. PTs have difficulty solving problems in fraction division. They were much less likely to exhibit a conceptual understanding of fraction division through a problem-solving task involving graphical representation or a problem-posing task [3]. Thanheiser [4] found that PTs who have mastered whole number arithmetic (WNA) for years have not understood how the settlement procedure was correct and how to get the algorithms. They added that although PTs master the procedure, they are often limited in conceptual understanding. This means that PTs have good procedural knowledge but are not enough to teach whole number arithmetic in elementary school. It does not motivate PTs who view mathematics as merely procedural to be involved in the course. As a result, they cannot carry out meaningful and enjoyable learning and lack vision as professional teachers later [4]. Also, most studies conducted in mathematics methods courses show a lack of learning opportunities designed around PCK development in the mathematics course [5].

Research on PTs' PCK development has been done, including Almerich et al. [6] that examined the impact of seminars on self-efficacy and argumentative skills on teacher professional development. In a workshop called "On the Shoulders of Giants," a group of teachers meets once a month. The results showed that teacher involvement in dialogue-based training improved learning effectiveness, which improved students' learning outcomes. Chen [7] examined the Visual Learning Analysis (VLA) approach for video-based teacher professional development. The results showed that

teachers who received a visual learning analysis approach had more positive beliefs and higher self-regulated learning than teachers who received conventional-based workshop treatment. Yurniwati [8] studied the application of Web-based Blended Learning to improve the pedagogical content knowledge of Primary Teacher Education students. The study found that Web-based Blended Learning gives students a broader learning opportunity to understand mathematical pedagogy from various online sources.

Unlike the PCK development of PTs before, Web-Based Knowledge Building (WBKB) is online learning based on Knowledge Building. Knowledge Building emphasizes the wandering of shared knowledge in a community and explains what the student community must achieve to improve ideas and develop an understanding [9]. Students receive information and must acquire and process knowledge using the learning facilities and resources provided. WBKB operates a website that plays the role of a Learning Management System (LMS). LMS includes learning resources, assignments, evaluation, and monitoring of overall learning achievement. Students' learning resources are arranged according to the syllabus equipped with learning objects (text, PDF, video, quiz).

WBKB has five characteristics: 1) students can access information online easily; 2) participants can get to know each other and build togetherness; 3) there is an exchange of information; 4) Knowledge construction occurs through sharing opinions from multiple perspectives; 5) Participants are responsible for their learning, using critical and self-reflective strategies, developing themselves according to their learning goals. Therefore, this research aims to design WBKB for developing the PCK of PTs. In this context, this paper outlines our project's analysis and design stages and examines the insight and design implications of various contributors and their roles.

II. Materials and Methods

A. Pedagogical Content Knowledge.

Quality teachers are needed to make students successful in learning Mathematics. The role of mathematics teachers is to engage students in physics and mental activities—both direct students to do math by exploring mathematics objects. Also, students develop reasoning, higher-order thinking, and mathematics disposition. Knowledge and skill to teach a particular subject are known as pedagogical content knowledge (PCK).

Mishra and Koehler [10] define PCK as knowledge concerned with the representation and formulation of concepts, pedagogical techniques, and understanding of what makes concepts difficult or easy to learn. In the case of mathematics, teachers need to design learning strategies based on the difficulty level of the concepts. Ball, as cited in Lo [11], argues that PCK is knowledge of content related to students, teaching, and content related curriculum. A teacher should consider the students' development when aligning a certain level. Furthermore, the teacher considers the learning methods and media applied according to the learning objectives. PCK is a combination of understanding, knowledge, skills, and dispositions effectively used by teachers in teaching [11]. Besides, there is a strong correlation between PCK and content knowledge, so it is impossible to provide instruction on pedagogical content knowledge without being related to the content knowledge [12].

Especially for mathematics learning, pedagogical knowledge in mathematics is the knowledge of teaching, including how and why concepts are related to each other and how a procedure solves a problem [13]. Moreover, within PCK, combining knowledge about teaching, mathematics content, and instructional design, such as strategy, introduces content [14]. According to Tröbst et al. [12], the central aspects of pedagogical knowledge in mathematics is learning technique and representation of mathematical concepts and how to teach mathematics

Tröbst et al. [12] argued that PCK consists of pedagogical and content knowledge. Pedagogical knowledge has defined a combination of understanding, knowledge, skill, and disposition that teachers effectively teach [15]. Also, Liepertz and Borowski [16] defines pedagogical knowledge as teaching students, instructional methods, educational theory, and assessments that can be applied to all subjects. Good pedagogical knowledge helps teachers choose proper teaching tools, skills, and techniques to teach specific content to make topics understandable to students.

Mathematical content knowledge consists of conceptual knowledge and procedural knowledge. Conceptual knowledge (CK) is defined as knowledge of concepts richly connected to pre-knowledge and increases with expertise rather than defining it [17]. Van de Walle [18] extends the definition of CK as understanding or structure of concepts and the relationships between concepts. On the other hand, CK is information related to each other, a network where interrelationships are as crucial as separate information [19].

Some studies have found that conceptual knowledge plays a role in learning mathematics. Zulnaidi and Zamri [20] report that conceptual knowledge positively influences learning achievement and conceptual considerations for obtaining procedural knowledge. Good conceptual understanding allows children to develop strategies when solving problems, for example, making connections between concepts. Therefore children with good conceptual knowledge usually have good procedural skills [21].

Meanwhile, procedural knowledge (PK) is a rule to solve problems through mathematical representation [18]. The mathematical representation includes symbols, notation, mathematics equations, graphics, tables, words, etc. Procedural knowledge is the ability to execute action sequences (i.e., procedures) to solve problems [17]. Moreover, students should initially develop a foundation of conceptual understanding, and procedural knowledge should not be created before the extended development of conceptual knowledge. Besides, Teachers with higher CK and PK apply their knowledge better in classrooms, successfully providing meaningful learning environments to initiate student learning [18].

Earlier study proves that content knowledge provides a significant contribution to PCK. Gess-Newsome [22] studied the impact of teacher content knowledge, pedagogical knowledge, and PCK on instructional quality and student achievement. They conclude that there is a positive correlation between content knowledge and PCK. Norton [23] concluded that mathematical content knowledge is highly predictive of mathematical pedagogical content knowledge

performance and suggests merit in developing the two aspects of teacher knowledge in tandem rather than in different courses. Therefore, mathematical knowledge for teaching combines content knowledge and pedagogical content knowledge. It is impossible to give instructions on pedagogical content knowledge without implicitly supplying some education on understanding appropriate content [12].

B. Web-Based Knowledge Building Framework

The internet has become a medium to deliver learning. The World Wide Web allows information to students from different locations and at other times. One of the advantages of internet use is that students can discuss and interact with fellow students synchronously or asynchronously. Communication using a computer allows the transfer and exchange of information. It makes learning that focuses on the acquisition and collaborative knowledge building, such as student engagement, produce deep understanding.

Knowledge building emphasizes the acquisition of shared knowledge in a community and explains what must be achieved by the student community to improve ideas and develop an understanding [9]. The study is in line with Harasim [24]; web-based learning provides easy access to fast learning resources, can be accessed anywhere and anytime, and helps students have knowledge and skills on time and act as active in collaboration in the information-based society. Moreover, the online collaborative learning process involves cooperative learning and the construction of knowledge through convergent and divergent thinking, much like group brainstorming. The collection of numerous questions and ideas leads to alternative responses and solutions.

Darling-Hammond [25] states five criteria for developing influential teacher professions that can also be adapted to extend PTs' PCK. The requirements are (a) content focus: activities focused on the content of the subject matter and how students learn the content; (b) active learning: an opportunity for teachers to observe, receive feedback, analyze student work, or make presentations; (c) coherence: content, objectives, and activities consistent with government curriculum and policies; (d) continuous duration; and (e) collective participation: groups of teachers activities to build an interactive learning community.

C. Research Design

This research and development used the Integrative Learning Design Framework (ILDF) model. According to Plomp and Nieveen [26], the ILDF model can be used in various online learning contexts, including developing e-courses for universities, corporate training, online learning communities, or electronic performance support systems. This ILDF model consists of three phases of development or three stages: exploration, enactment, and evaluation. Exploration phase, investigation of PTs' weakness in content knowledge and PCK. Enactment phase, design a prototype according to teachers' needs. We consider mathematics knowledge for teaching and technology-enhanced learning, including knowledge building. Evaluation stage, prototype review by experts and users (PTs) about prototype use and role to solve learning mathematics problems.

We conducted a needs analysis in the exploration stage by providing questionnaires to 195 pre-service teachers. The data was collected by questionnaire referring to Atmacasoy and Aksu [27]. PCK instrument consists of three-part: CK (7 items), PCK (7 items), and intention for self-improvement (8 items). We used the 5-point Likert scale, each: 1 (strongly agree), 2 (agree), 3 (unidentified), 4 (disagree), 5 (strongly disagree). The average scores of items in each group (CK, PK, and PCK) are calculated.

The enactment stage, the development of the WBKB prototype that will be used for one semester, includes learning activities such as learning resources, video meets, discussion forums, and chats. Also, identify teaching materials, disseminate materials, and reference learning objects in text, videos, and images. Then continue with product development.

The prototype was validated by three media experts and three subject matter experts in the evaluation stage. Media experts assess the use and features contained in LMS, and subject experts determine the organization of matter and the adequacy and breadth of the material. Meanwhile, the prototype is validated by a small group of PTs to determine whether the LMS can be used easily and relevant to overcome problems in teaching and learning activities. Instruments in a 5-point Likert scale consisting of four aspects: 1) ease of use, 2) material organization, 3) Adequacy and breadth of matter, and 4) benefits. Prototype revised after validated by expert and small group. Finally, the prototype evaluates by prominent group participants (40 students).

III. Results and Discussion

A. Prospective Teacher Needs for PCK Development

The research begins by distributing questionnaires to 175 PTs based on the PCK aspect discussed and the basic abilities of participants. Participants' responses to the knowledge aspect of mathematical content (Table. 1), it is known that participants know mathematical materials taught in elementary school (mean = 3.7897) procedurally high (mean = 3.7854). But participants had insufficient knowledge of the relationship between concepts (mean = 1.9333), how to find formulas (1.8564), and understand concepts (mean = 2.769).

TABLE I
CONCEPTUAL KNOWLEDGE RESPOND

Items	Mean
1. I know mathematics concepts for elementary school students	3.7897
2. I can explain a concept exactly.	3.4974
3. I can understand the concept well.	2.0769
4. I know the relationship between concepts well.	1.9333
5. I know the prerequisite knowledge of a concept	3.4103
6. I know how to get formulas.	1.8564
7. I can use strategies to solve math problems.	3.7854

The participant's response shows that the knowledge of the mathematical content of PTs excels at procedural knowledge. They can solve mathematical problems using formulas but are weak in understanding a concept. Because at the previous level of education, they were trained in computation. Mastery of matter is not through experience but through the transfer of information and memorization.

In PCK aspect (Table. 2), participants showed a high score on the knowledge of elementary students needing learning media (mean = 4.4103) and elementary students needing

exploration (mean = 4.3179). Students need to work in groups (mean = 4,318). Instead, they have low scores in learning tools selection (mean = 2.0154), the ability to present concepts in different presentations (mean = 2.7385) and modify mathematical problems (mean = 2.9179).

TABLE II
PCK RESPONDS

Items	Mean
1. I understand that elementary students need props in learning mathematics.	4.4103
2. Elementary students need to get exploration opportunities of various fields to know the nature of the field	4.3179
3. Elementary students need to work in groups so they can discuss	4.3128
4. I can determine the right props to teach you a particular concept.	2.0154
5. When students learn using learning media, classes will become noisy and messy.	3.7795
6. I can use different presentation techniques that are appropriate for the topic	2.7385
7. I modify the problem to be easier or more difficult according to the student's abilities.	2.9179

Participants show that they know how to teach theoretically. They study children's development, so they know elementary students in the concrete operational stage. But knowledge is not enough to make someone become a quality teacher. Students need learning tools, hands-on activities, and collaboration, and PTs need teaching experience through observation, practice, or simulation.

In the self-development aspect, participants showed high intentions. Especially in the awareness of teaching competence (mean = 4.4718), and increased knowledge of mathematics (mean = 4.4513). Participants were interested in improving their teaching skills in an online environment (mean = 3.7538) because they could repeat learning objects (mean = 3.8462) and provide information in diverse forms (3.8872).

TABLE. III
PTS INTENSION

Items	Mean
1. My knowledge is still lacking in learning activities to build students' mathematical concepts	3.9487
2. I need to increase my knowledge of mathematics that I teach.	4.4513
3. I need to improve my math teaching competence	4.4718
4. I can use the internet, including browsing, to find supporting references	4.3487
5. I'm used to looking for references to add insight	4.1179
6. Improving my online skills is more precise because I can learn certain materials over and over again.	3.8462
7. Developing a web-based teacher profession is more appropriate because it provides information in text, images, and videos	3.8872
8. I am interested in developing a web-based online profession	3.7538

Information obtained through the analysis of needs leads us to the conclusion that the conceptual knowledge of PTs is relatively low. These findings align with Copur-Gencturk [28] that prospective student teachers are weak in fraction conceptual knowledge. Weaknesses in conceptual knowledge need attention from lecturers. Conceptual knowledge has an important role in forming procedural knowledge [29]. Conceptual knowledge is also essential in designing a strategy to solve mathematical problems because conceptual knowledge is the information linked to each other, networks in which linkages are as crucial as separate pieces of information [19].

In addition, conceptual knowledge is the foundation for a teacher's learning strategy. In line with NCTM (2000), the basic aim of mathematics teacher education is to teach mathematics to understand. Therefore, the development of conceptual knowledge must be focused on the teacher's education [19].

Therefore WBKB, in the efforts to develop PCK of PTs in this case, addressed conceptual knowledge through text, direct discussion, and video. The advantages are that prospective teacher students have awareness, and high learning motivation. Supported by adequate technological capabilities, PCK development through LMS is the right solution for them.

B. Prototype Development

Based on the needs analysis, we developed LMS named Arithmetic Instruction. We identified arithmetic subject matter learned in the elementary school curriculum. We collect references for related concepts to develop learning objects. Based on the criteria for developing an effective teacher profession [25], [30], we designed the WBKB model framework (Table 4) and LMS Flowchart. (Figure. 1).

TABLE IV
THE WBKB FRAMEWORK

Component	Activity	Amenities of WBBK
Participants learn online	Elementary teachers in the department but also provide opportunities to PTs and pre-department teachers.	Sign Up/Sign In the menu, Announcements, technical explanations,
Material refers to the development and needs of elementary students (coherent)	The material consists of: ▪ Content Knowledge: Numbers, integers, fractions, KPK and FPB ▪ Pedagogic Knowledge: mathematical learning theory, props, evaluation ▪ 3. Pedagogical Content Knowledge	▪ Content Knowledge is packaged in e-books, PPT, photos, weblinks. ▪ Pedagogic knowledge is delivered in text. ▪ Pedagogical Content Knowledge in the form of learning videos
Active participation in elaboration	Participants interact, generate ideas, collaborations, and team products	▪ Discussion Forum ▪ Workshop ▪ Weblink ▪ Kuiz online ▪ Link to YouTube
Active participation in assignment	▪ Evaluation of mathematical skills ▪ Self-evaluation ▪ Learning video analysis ▪ Participants upload *best practices of* math learning	

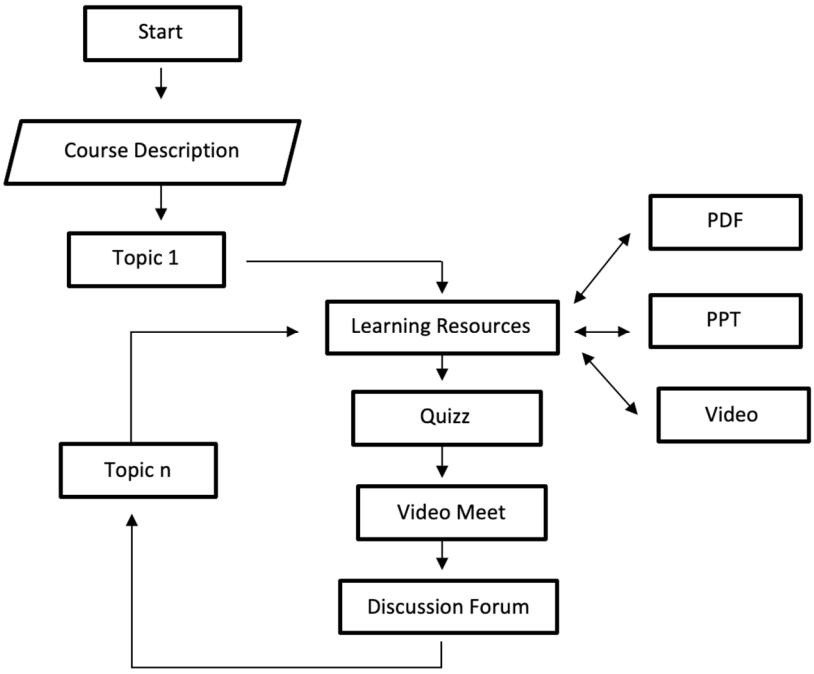

Fig. 1 WBKB Flowchart

Learning objects installed in LMS consist of documents (PDF, PPT) and videos. Videos were recorded by smartphones and edited using Imovie. LMS is created using the Moodle application.

C. *Prototype Validation*

After all learning objects are installed in the LMS, they are validated by subject experts and media experts. Based on input from content experts, improvements are made, namely: 1) Each topic is numbered in line with course meeting ; 2) The learning resources accessed at each course meeting following the topic ; 3) online meeting conducted at any odd meeting or when necessary; 4) There are an individual or group assignment and projects; 5) Quiz. There is no advice from media experts because this LMS can be used easily by users and all facilities are appropriate.

The LMS design for one semester. The learner will join the LMS after registering and logging in (Fig. 2). Then in the general section appears the course description and session in order (Fig. 3). In the left navigation, there are topics contained in every session. Each session contains topics, learning resources, quizzes, online meeting, and discussion forums are organized in LMS (Fig. 4).

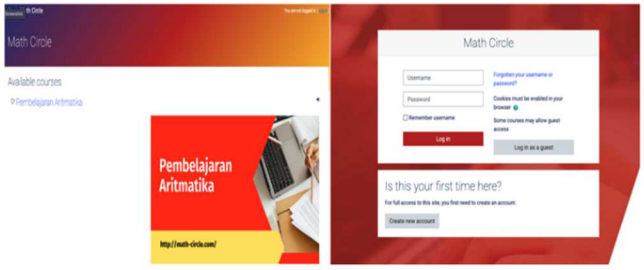

Fig. 2 Register and Login Menu

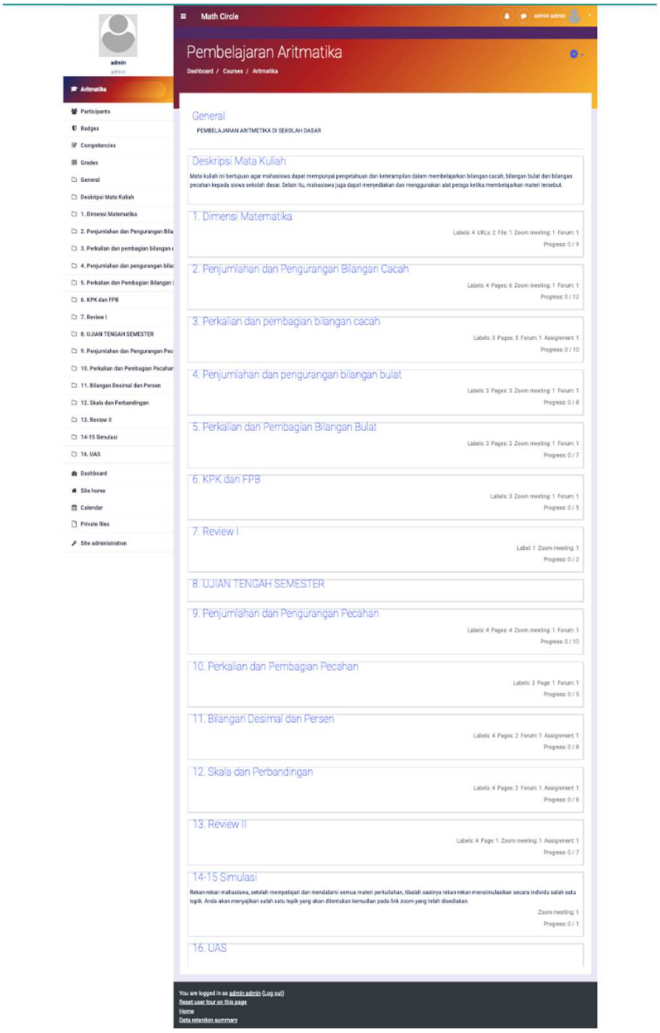

Fig. 3 Course Session

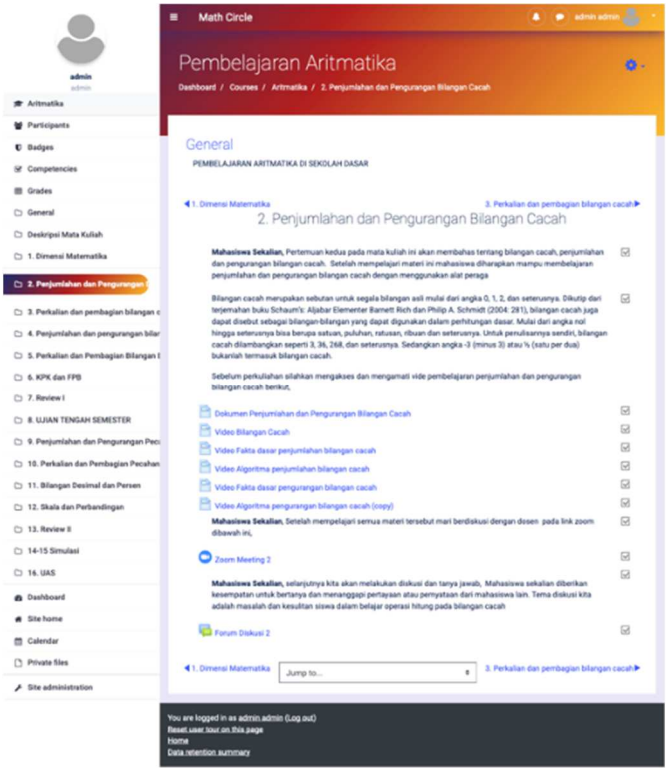

Fig. 4 Addition and Subtraction

Large group evaluation of prototype validity is presented in Table 5.

TABLE V
PROTOTYPE VALIDITY

Usedness	Mean
1. I can use LMS arithmetic learning easily	4.225
2. Command operated easily	4.100
3. I can move from one meeting to another quickly.	4.425
4. Learning resources can be accessed easily	4.525
5. Videos can be accessed directly easily	4.300
6. I can open a discussion forum and create a discussion topic without difficulty	4.125
7. I can open the LMS any time	4.675
Content organization	
1. The resources I need are already available in LMS	4.450
2. I can access all resources in the LMS	4.575
3. The resources is varied and exciting and can motivate me to learn.	4.175
4. Document can be understood easily	4.075
5. Videos provide clear and complete information about teaching math in elementary school	4.400
6. Course meetings in LMS have been well-coordinated and amounted to 16 sessions.	4.475
7. Each course contains study materials, zoom links for virtual face-to-face and discussion forums	4.375
8. Courses through LMS make the learning process effective and efficient	4.025
9. I can discuss in meetings with other student friends for work on assignments or increase understanding.	4.025
Adequacy and breadth of subject matter	
1. The available resources contain math topics that are taught in elementary school.	4.450
2. The available resources contain mathematical concepts following explanations and examples.	4.375
3. Available resources explain strategies for solving mathematical problems	4.325
4. Video or document contains conceptual and procedural knowledge described using learning tools and images	4.450
5. Video or document contains strategies to teach mathematical concepts	4.400
Benefits	
1. The explanations that contained videos and document helped me understand mathematical concepts.	4.350
2. video and document helped me understand how to teach mathematics.	4.350
3. Videos provide clear and easy to understand knowledge and illustrations	4.375
4. I am sure I can teach mathematics well and appropriately to my students later.	4.231
5. I enjoy learning using LMS	4.050
6. This LMS helped me learn a lot.	4.275
7. This LMS makes it easier for me to learn.	4.275
8. This LMS inspired me to teach mathematics later.	4.275

The validity of the prototype is reviewed from four aspects and obtains an average high category score. In the aspect of using LMS, it is known that PTs can use LMS WBKB easily, including commands, transfer between lecture meetings, and access to materials. Likewise, lecture materials are accommodated in 16 sessions and are interpreted by zoom, quiz, and discussion forums. Resources that contain knowledge of mathematical, pedagogical, and PCK that are delivered by documents, and videos provide easy-to-understand, clear, and complete information.

IV. CONCLUSION

This study aims to design and develop PCK of PTs through web-based knowledge building. The web-based knowledge building is created on a website and plays a learning management system and is implemented in elementary school teacher education. This article has presented the construction of a prototype framework for the design and development of WBKB, validating the prototype by experts and PTs. We have improved based on experts' suggestion and made a more detailed and complete. LMS is organized in 16 sessions and facilitated by documents (PDF), videos, and quizzes. The prototype was validated by three subject matter and three learning media experts and 40 PTs. The results were that prototype has a higher score in easy to use, subject matter organizing, bread of subject matter, and benefit. The conclusion is that web-based knowledge building is valid and appropriate to develop prospective teacher education. The web-based knowledge building is advantaged in information access, collaboration, knowledge construction, and learners' responsibility in knowledge acquisition. Based on the findings, we suggest that similar LMS can be applied to develop another knowledge and skills specially for prospective teachers.

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