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Developing a learning environment based on science, technology, engineering, and mathematics for pre-service teachers of early childhood teacher education

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Abstract

The purpose of this research is to describe the development of a STEM-based learning environment for early childhood teacher candidates that is valid, practical, and has potential effects. The research sample consisted of 25 pre-service early childhood teachers and 19 students Kindergarten. The research method used was design research with the type of development study. This research has produced a learning environment with the Campus-Application-School (CAS) model consisting of the stages of training, designing, mentoring, and testing. The validity of the STEM-based learning environment model was seen from the developed student worksheet (LKPD) instrument and the content in the learning environment, obtaining a value of 0.88, which was categorized as high validity. The practicality, as seen from the results of one-to-one teaching, small group, and field tests with an average of 94.2, was categorized as very good. Meanwhile, the potential effect was based on Kirkpatrick's four levels of training evaluation with an average of 83.73, which was categorized as very good. This research suggests that the CAS learning environment model can affect teacher approaches to teaching in a step appropriate way based on STEM to prepare student teachers to teach basic mathematics.

Keywords: Early Mathematics, Kirkpatrick, Learning Environment, Realistic Mathematics Education, STEM

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Early childhood is considered a "golden age" because during this period children experience rapid growth and development. They are easily stimulated during this period and this period cannot be replaced in the future (Chang, 2019; Dunphy et al., 2014; Fauziddin & Mufarizuddin, 2018). Early childhood is in the age range of 0-6 years. At this age, a child's intelligence has begun to form, so if the child's brain is not receiving maximum stimulation at this age, then the child's potential will not develop optimally (Darling-Hammod & Jossey-Bass, 2006; Kembuan et al., 2019). Therefore, the most efficient way is to provide quality education from an early age (Balat & Günşen, 2017; Evans et al., 2020).

According MoEC (2014) and Council (2015) about concerning the standard level of early childhood offerings called STTPA is a criterion regarding the abilities achieved by children in all aspects of development and growth. One aspect of children's growth and development that is important to learn is the cognitive aspect (Council, 2015; Kurniah et al., 2019; MoEC, 2014). The cognitive aspect consists of mathematics and science. These two subjects have relationships and integration that can increase students' understanding of mathematical concepts and contexts in everyday life (Al-Mutawah et al., 2022; Zulkardi et al., 2020). The importance of learning cognitive in early childhood can provide a broad foundation for children to further learn mathematics and science (Clements & Sarama, 2016; Gasteiger & Benz, 2018; Piasta et al., 2014).

Basic cognitive for children must be presented in a mathematical and science correct way. This affects the quality of further learning. However, the results of the 2018 PISA assessment showed that Indonesia obtained an average score of 379 for mathematics and 396 for science from the minimum average score of 489 (OECD., 2020). Thus, students in Indonesia are still in the category of low cognitive ability. The low quality of education is an indication of the need for professional teachers (Kristiawan & Rahmat, 2018). Whereas the integration of mathematics and science can make learners see the shared concepts and factors in a meaningful and enriched way. It means the subjects can help students learn to think critically and help develop a common core of knowledge necessary for success in the next century (Al-Mutawah et al., 2022; Fachrudin et al., 2019). Colwell & Enderson (2016) asserted that challenges remain when considering the integration of subject. In dealing with these challenges, teachers or pre-service teachers play a key role in regulating subject integration in learning (Colwell & Enderson, 2016; Lee, 2015). This is a challenge faced by prospective math and science teacher students. Professionalism can be a means to support the achievement of learning to a more advanced level (Beteille & Evans, 2019; Engel et al., 2018).

Teachers have an important role to play in helping students achieve success (Beteille & Evans, 2019; Chetty et al., 2014; Keiler, 2018). Teachers need to analyze and consider all components of the required knowledge and skills (Beteille & Evans, 2019; Gasteiger & Benz, 2018; Guerriero, 2013). The introduction of cognitive in early childhood is very possible if the teacher has a clear basic concept to understand and implement it gradually with a habitual approach to the habits that children usually do in their daily life (Abramovich et al., 2019; Acharya et al., 2021; Baroody et al., 2019). This is where the role of the teacher is needed in bridging the solutions that will be achieved by considering the linkages between material, learning theory, level of development, and children's activities in accordance with the principles and characteristics of children (Dunphy et al., 2014; Efriani et al., 2020). This professionalism can influence the practice of increasing confidence in teaching (Brunsek et al., 2020; Oppermann et al., 2016). A growing body of evidence shows that educators influence classroom quality and child outcomes (June et al., 2019; Taguma et al., 2012; Yoshikawa & Kabay, 2015).

The professionalism of a teacher can be created through a learning and teaching environment that allows students to learn mathematics with understanding (Crowe, 2010; Hoogland, 2019). The importance of creating and implementing a safe and supportive learning environment is especially important for novice teachers (Clapper, 2017; Yusuf & Pattisahusiwa, 2020). When creating a learning environment, it is necessary to consider all the factors that influence the development of students (Closs et al., 2022; Rusticus et al., 2023). Learning environment can support teaching because learning environment is able to stimulate student in learning activities so that learning becomes optimal (Li & Xue, 2023; Osborne, 2013; Sutarna, 2016). The cognitive education community suggests that one way is to provide a learning environment that supports the understanding of multiple representations of cognitive ideas (Dreher et al., 2015; Gulkilik et al., 2020; Sangadji, 2018).

Much research has been done on developing professionalism for teachers and prospective teachers, such as using PMRI (Ekawati & Kohar, 2016; Putri, 2011; Wahyudi, 2016; Zulkardi, 2002) using STEM (Chai, 2018; Gardner et al., 2019; Huang et al., 2022; Hurley et al., 2023). However, the development of existing learning has not been followed up and has not used STEM with the PMRI approach as a stage for learning mathematics (Khotimah, 2017; Mulbar et al., 2020). Therefore, researchers hope that the STEM-based learning environment can become a pattern of developing the pedagogic and professional competencies of prospective early childhood teacher students to study mathematics according to their stages.

METHODS

The purpose of this research is to describe the development of a STEM-based learning environment for early childhood teacher candidates that is valid, practical and has potential effects. The research method used was design research with the type of development study. The stages on the research are a preliminary stage, a prototyping (formative evaluation) stage, and an evaluation stage (Plomp, 2013; Tessmer, 1993).

Preliminary

In the preliminary stage, the researcher conducted a literature review on the basic mathematical competencies adapted to preschool, STEM, and RME curricula, and determined the location and subjects of the research, which were 25 student teachers enrolled in the Islamic early childhood education study program at Raden Fatah State Islamic University (UIN), Palembang, and 19 students from Uswatun Hasanah Integrated Islamic Kindergarten.

Prototyping

The prototyping stage uses a formative evaluation flow by conducting self-evaluations and expert reviews and one-to-one teaching, forming small group, and conducting field tests (Tessmer, 1993; Zulkardi, 2002). At the self-evaluation stage, the researcher designed Prototype 1 like a worksheet and learning environment model. At the expert review stage, the prototype 1 that has been designed is validated by experts to investigate content, constructs, and language. Expert review aimed to determine the validity of the worksheet and learning environment model. The developed worksheet is used in the process of implementing the learning environment model. At the one-to-one stage, which coincided with the expert review stage, individual trials were conducted with 3 students of Uswatun Hasanah Integrated Islamic Kindergarten with different abilities. The results of the one-to-one teaching stage were used to see the practicality of the product being developed. Comments and suggestions from the expert review and one-to-one teaching stages were used to improve Prototype 1 and to produce Prototype 2. At the small group stage, Prototype 2 was tested on 6 students with different abilities to gain practicality of the product being developed. The upgrade from Prototype 2 to Prototype 3 was tested in the field to determine the overall practicality of the instruments developed.

Assessment

The evaluation stage was conducted to obtain the potential effects of the learning environment, which was developed using the four levels of training evaluation in the Kirkpatrick Model (2013). At the first level, the student teachers' reactions to the learning process were measured using a questionnaire. The second level is learning, which is the extent to which student teachers acquire knowledge, skills, and attitudes, and was measured using photos, videos, observation of learning activities, and perception questionnaires after the learning process. The next level is behavior, which is the extent to which preschool student teachers can apply what they have learned, and was measured using photos, videos, and observations of teaching materials developed by preschool student teachers. The last level is results, which is the extent to which the targeted results occur as a result of learning events and subsequent reinforcement and was evaluated based on observations of portfolios and reports on the results of product trials by student teachers to students to obtain potential effects of the STEM-based learning environment model implemented during the learning process.

Data collection techniques used were documentation, questionnaires, observation, and interviews. Documentation data was in the form of photos, videos, and notes from validators and students. Observations and interviews were conducted at the stages of one-to-one teaching, small group, and field testing. Meanwhile, questionnaires in the form of initial questionnaires, perception questionnaires, satisfaction questionnaires were given to the research subjects doing training on campus. Furthermore, the data were analyzed qualitatively and then presented in the form of narratives and pictures, along with the percentage of each indicator in tabular form. Documentation analysis was performed by reviewing data in the form of documents, notes, and video recordings. Questionnaire analysis was done by assigning a score to each answer, which was then analyzed using the Aiken's V formula and categorized according to the validation criteria as shown in Table 1. Meanwhile, the observation analysis was done by giving a score for each indicator, which was calculated using the percentage formula and categorized according to Table 2 (Sugiyono, 2019).

Table 1. Validation criteria

Aiken index	Criteria
$0 \leq V < 0,4$	Low validation
$0,4 \leq V < 0,8$	Middle validation
$0,8 < V \leq 1$	High validation

Table 2. Practicality and potential effect criteria

Interval (%)	Criteria
$76 <$ score ≤ 100	Very good
$51 <$ score ≤ 75	good
$26 <$ score ≤ 50	Enough
$0 <$ score ≤ 25	Bad

RESULT AND DISCUSSION

This research developed a STEM learning environment for pre-service early childhood teachers. The learning environment was part of the mathematics and science courses in the Islamic Early Childhood Education Study Program at UIN Raden Fatah Palembang. The development of the learning environment started from product development, application of learning, and product testing. The stages were based on the development stages, namely preliminary research, prototyping, and evaluation.

At the preliminary research stage, the researcher determined the courses that were suitable for implementing the learning environment, which were mathematics and science courses and focused on cognitive aspects, which included learning and problem solving, logical thinking, and symbolic thinking. The ability of Uswatun Hasanah Integrated Islamic Kindergarten to transform the institution from a preschool playgroup to an Islamic kindergarten is good, and the teachers there, who were the subject of the research, are professional and have a background in early childhood education. Moreover, the school is strategically located between high-income and low-income neighborhoods. Meanwhile, early childhood student teachers were selected from the 3rd semester students of the Islamic Early Childhood Education Study Program who were taking math and science courses.

At the self-evaluation stage, the researcher developed a worksheet using the STEM learning stages and the RME approach. The developed worksheet was number content using the context of sweet potato balls. In STEM learning with this instrument, science was seen in the process of making sweet potato balls by mixing various ingredients and the changes in the texture from the hard to soft sweet potatoes after cooking. The aspect of technology could be seen in the culinary tools used in making sweet potato balls. The engineering aspect was in the process of making sweet potato balls, the process of boiling, and the process of mixing the dough. As for the aspect of mathematics, it was at the time of calculating the circled sweet potato balls that were made and sorting the pattern according to the rules, was using RME approach. Figure 1 is a stage of RME approach using iceberg.

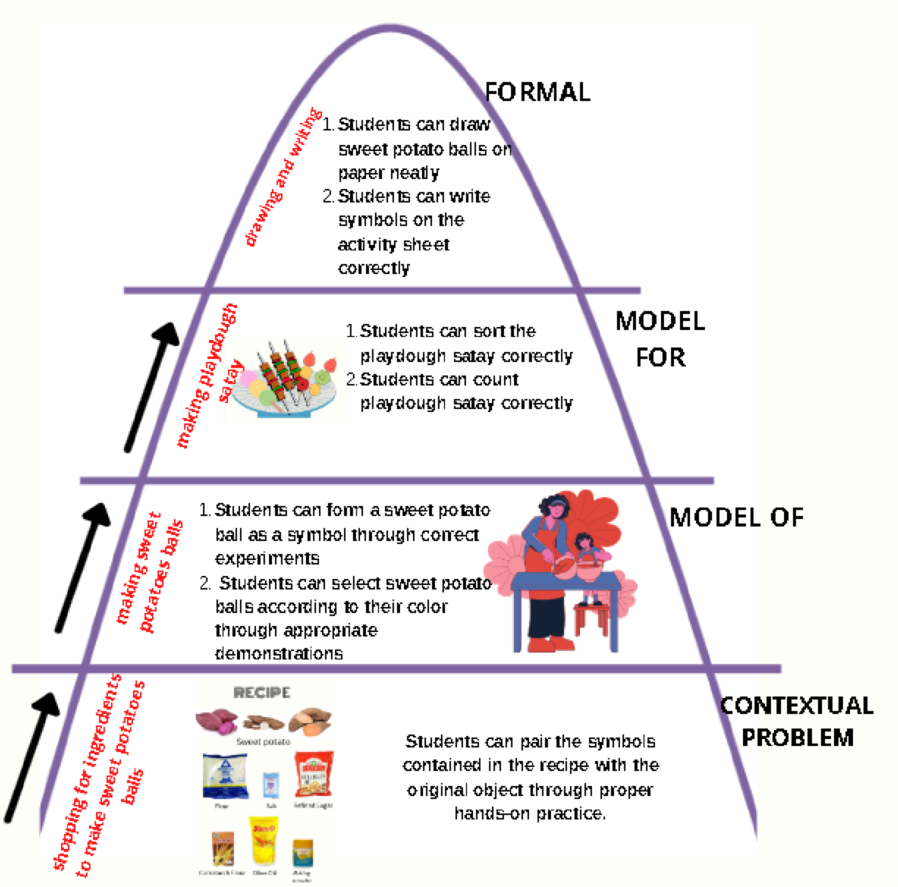

Figure 1. Iceberg of learning numbers using sweet potatoes balls context

From the Figure 1, in the "contextual" stage, the activities involved students shopping for ingredients to make sweet potato balls, with the goal of students being able to match recipes with ingredients sold at the grocery store. At the "model of" stage, the activities were done by making sweet potato balls from materials that had been purchased. At this stage, the students formed sweet potato balls and then from the results of the activities, the students grouped the symbols given by the teacher. The goal is to gain an initial understanding of the shape of the numeral symbol. At the "Model for" stage, the activity given was to make a replica of a sweet potato ball out of playdough. At this stage, the goal was to find out the shape of the numeral symbol. In the "formal" stage, the activities carried out were that the students were able to follow examples of writing numbers. Then, the researchers designed a STEM learning environment in the form of training, designing, mentoring, and testing activities that would be implemented in 16 sessions. The design of the learning environment model on prototype 1, namely campus, blended, and school. where training is carried out on campus, designing and mentoring by means of blended learning, and testing is carried out in schools. At the expert review stage, the worksheet and learning environment model design were given to 7 experts in the fields of

RME, STEM, and early childhood education from Indonesia, Malaysia, and Thailand. The results of content validity were based on the review of the expert reviewers and are presented in Table 3.

Table 3. Instrument validation

Aspect	Score	Criteria
Material Eligibility	0.85	High
Material Presentation	0.87	High
Diction	0.88	High
average	0.86	High

Table 4. Learning environment model validation

Aspect	Average	Criteria
Learning environment model	0.888	high
Lesson plan	0.882	High
Average	0.885	High

From the results of instrument validation, high validity results were obtained. This shows that the developed instrument met the validity criteria. In addition, the validators or reviewers provided some suggestions and feedback as shown in Table 5. The comments and suggestions have been adapted according to the instrument and model being developed. Regarding the instrument, there was a crucial change in the STEM learning steps, especially in the engineering section. Regarding the engineering section, improvements were made according to suggestions from the validators. The engineering steps used in STEM learning, which are problem identification, problem analysis, initiation of ideas and problem-solving designs, testing of problem solving designs, and communication, were adapted to the theory of Capraro et al. (2013) and Jang (2015). According to the experts, the instrument of Prototype 1 did not show any problems. Therefore, the researchers emphasized the problems in the lesson plan section. The activities conducted were shopping for ingredients to make sweet potato balls. The given problem was that children were given money to buy the ingredients needed to make sweet potato balls according to the recipe provided. The engineering stages conducted consisted of the identification section where the child identified the recipe and the money given by the teacher to buy ingredients to make sweet potato balls. In the analysis section, the children were expected to think about whether the money given was enough to buy the ingredients according to the recipe. In the idea generation and problem-solving section, the children were expected to experiment with the ingredients they were going to buy by matching the money available with the conditions of the price of the ingredients being sold. In the trial design section, the children should be able to make a payment for the ingredients they chose according to a predetermined recipe. In the communication section, the child was expected to decide whether the money could buy all the ingredients and whether there was any money left from the shopping.

Table 5. Comments and Suggestions from the Reviewers

Comments and suggestions
1. Clarify guidance on activities 3 and 4.
2. In the STEM section, the engineering process should be adapted to the EDP
3. Add captions to the image to make it much easier to understand.
4. Operational verbs should be adapted from the Bloom's taxonomy
5. Be sure to follow the ABCD rules in the development of learning objectives.
6. Add an evaluation at the end of the activity by considering the relevance of the objectives achieved.
7. Give an example at the beginning of each activity.
8. Add information before the activity.

In addition, the validation of the learning environment was also conducted. Table 4 explains the results of the validation of the learning environment are in the high validity category. This was also evident from the comments and suggestions made by the validators, which did not require major revisions. The validators only provided suggestions in the "Semester Lesson Plan" section, where the learning type should be added to the learning link used. In addition, the Course Learning Outcomes (CLOs) have been declared appropriate. However, the choice of operational verbs can be varied. the validator also gave advice on the naming of the model used, namely CAS (campus, Application, and school). This is because the implementation was done while training, designing, mentoring, and testing were included in the stages of creating the model. Thus, the resulting model is Campus, Application, School. "Campus" refers to the place where the student teachers were trained to understand STEM, RME principles and characteristics, character values, and early childhood teaching materials. "Application" refers to the implementation of designing and mentoring processes. The research subjects designed teaching materials in accordance with the theory obtained during the training and provided assistance to review the developed teaching materials. The application used at the design stage is a graphic design platform such as Canva, while the application used during mentoring is a virtual meeting application such as Google Meet. Meanwhile, "school" refers to the where the results of the teaching materials developed in the three previous stages were tested. The findings of the validity results at this stage indicate that the instrument in this learning environment has met the criteria for content and construct validity and can be used to develop the pedagogical and professional competencies of early childhood education student teachers. Content validity means that all interventions in this learning environment are in accordance with the "state of the art knowledge", while construct validity means that the various components in this learning environment are connected to each other (Bakker, 2018). Figure 2 shows an environmental model of the resulting learning.

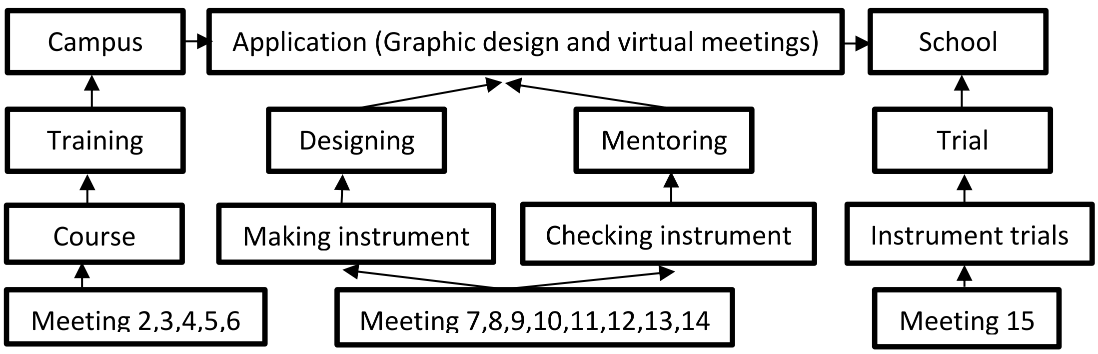

Figure 2. The CAS learning environment model

Table 6 presents the STEM-based learning environment model has also been rated as very practical and thus can be used for further research. This means that this learning environment can be considered for use under normal conditions (Bakker & Wagner, 2020). However, in the evaluation, the practicality decreased from 96.78% to 89.375%. It was because the implementation of the small group stage trials was on Friday, so the time in the learning process was very little and the number of subjects involved increased from the previous stage, resulting in the implementation of the number learning process using the sweet potato ball context conducted for 2 days on Friday and Monday. Between Friday and Monday during the implementation process, there was a long enough span of 3 days, which caused the children to forget the relationship between the activities performed before. So, for the implementation of the next stage, the researcher reconsidered the trial time by adjusting the activities to be done with the days to be tested. In this way, the value obtained at the field test stage increased. According to (Viennet & Pont, 2017; Yusuf & Pattisahusiwa, 2020), a conducive time must be considered in conducting trials to obtain maximum results.

Table 6. Practicality result

Activity	One to one	Small group	Field test
Activity 1	100	80	94.4
Activity 2	95.5	100	100
Activity 3	91.65	85	93
Activity 4	100	92.5	88.8
Average	96.78	89.375	94.05
		93.4	

The evaluation of the learning environment to determine the potential effects used four levels of development evaluation in the Kirkpatrick Model (2013). The results obtained are shown in Figure 3.

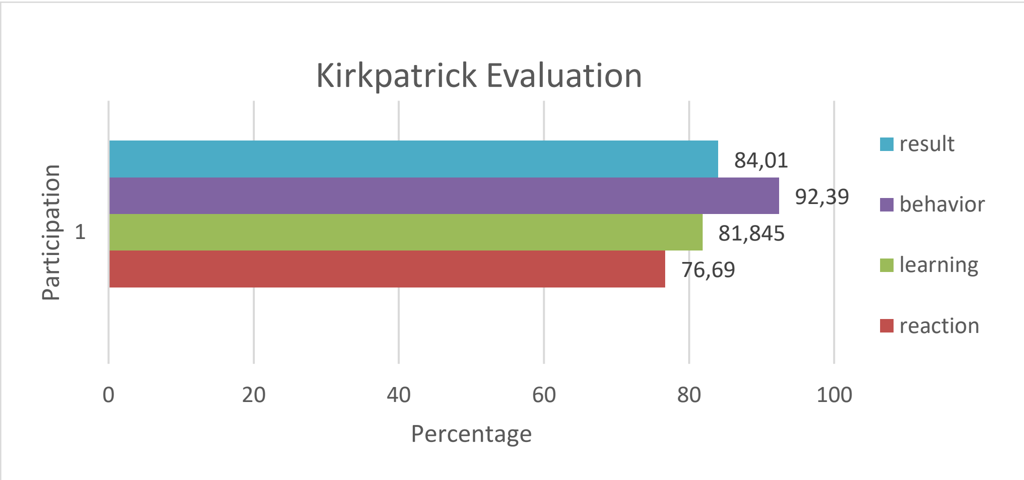

Figure 3. Kirkpatrick evaluation

At the first level, the participants' reactions could be seen in the enthusiasm and activeness of student teachers during the training process. The student teachers were able to collaborate with groups, get to know STEM and RME, and have an interest in making instruments. It is a new model in lectures. Based on the interviews with the student teachers, it can be concluded that they found the developed learning environment model interesting to study. This is because the learning environment model that was applied was something new and different from the lecture model used before. In addition, they felt that they gained knowledge and skills from the lectures given. From the results of the participants' reaction, there was one indicator that received a score below the average, which was 47, and this indicator was related to doing the task individually. After being interviewed, it was found that the student teachers felt comfortable doing assignments individually. This is contrary to the opinion proposed by (Coenders & Verhoef, 2019; Lee, 2015; Tong et al., 2022) that collaborative instrument making can help improve pedagogical abilities. Furthermore, the researchers interviewed these student teachers to find out more about the arguments from the treatment given. The results obtained after the interview show that the student teachers felt that they had their own responsibility when assignments were given individually, so they did not depend on other people and were aware that working individually could measure the knowledge they had gained. In addition, the process of working in groups is recommended only during discussions, so that through discussions, students get suggestions and feedback from the assignments given. This activity is relevant to the model that was implemented because in the implementation of the model, the student teachers still worked individually but with a group theme. After the individual assignments are completed, students can exchange ideas with each other about the design results that are created (Ayish, 2019; Chang, 2019; Tong et al., 2022).

The second level is participant learning. Participant learning was clearly visible in the use of RME and STEM approaches through a series of learning processes that were conducted when using the developed instruments. The principles and characteristics of RME were reflected in the stages of the given activities, while STEM was reflected in the process of the activities carried out. When the student teachers planned learning activities, the selection of themes and contexts became the precursor to the creation of subsequent instruments. This is because the role of context helps in the learning process (Fauziah et al., 2020; Putri, 2011; Risdiyanti et al., 2019). The student teachers had difficulty determining the right context for the identified material, therefore the role of the design stage was crucial. The design process took quite a long time, only 7 student teachers were consistent with their selected context, 14 student teachers changed one selected context and 4 student teachers changed the selected context twice. The changes in the context were based on the ease of use, the ease of providing materials, and suitability of the context to the material to be taught. This change in context was also based on consideration of the mentoring process in class, as well as suggestions and feedback from students and lecturers.

At the third level, participant behavior was observed in the student teachers who were able to apply what they learned in the learning environment through the teaching materials. The third level is carried out to indicate the extent to which the material in the training is applied to the participants' jobs and workplaces (Lantu et al., 2021; Yaqoot & Mat, 2021). In accordance with the opinion of Pateda (2020) and Simangunsong (2021) that the third evaluation relates to measuring changes in participants' behavior after attending training. The implementation of this STEM-based mathematics learning environment model received a positive response from the student teachers, although the process of making teaching materials took quite a lot of time and required repeated repairs to achieve maximum results. It shows that the important role of mentoring is in the training process so that the results are made in accordance with the expected learning. The student teachers who still felt that they were not optimal in designing learning were still given assistance treatment before the final product had been tried. However, the assistance was provided outside the specified schedule, so that the schedule for the designed learning environment model continued according to schedule. In addition, the attitudes of the student teachers who participated in the mentoring were observed. This can be a concern for future researchers to increase the intensity of assistance related to context development for teachers.

The fourth level is the result of the participants. From the results, it was found that 84.01% of the students had developed their knowledge through the application of STEM-based instruments. It was just that in the measurement material with the context of *cak engkleng*, which is a traditional game in South Sumatra, and sprouts, there were obstacles in the implementation process. In the context of *cak engkleng*, in the implementation, students were not informed enough or in the context of sprouts, they did not prepare enough tools and materials for testing. This was because the academic calendar of the campus and the school was not the same during the implementation process, so many students did not go to school because the learning process of the semester was over. In implementing the trial, it is better to coordinate the lecture calendar with the school calendar in advance, so that there is no catch-up between the school and campus schedules.

The overall results of the four levels showed an effect of the STEM-based learning environment. Student teachers felt great benefits from the learning environment and gained new knowledge. The findings of Fauziah et al. (2020) and Rusiyanti et al. (2022) revealed that the learning environment can be a means of developing the professional and pedagogical competencies of student teachers. The results of this study are linear with the statement that the learning environment is an important factor supporting the success of the teaching and learning process (Colbert, 2014; Durmus, 2016).

The STEM-based learning environment created by the researchers is a pedagogical and professional competence development program for early childhood student teachers through the CBS model with the stages of training, designing, mentoring, and testing. The program was developed because the learning environment that has been developed so far has not been followed up, so it has not created a habit for student teachers (Khotimah, 2017; Mulbar et al., 2020). This is in accordance with the goals of educational development, which also focuses on adaptive professional development processes, meaning that teachers not only have quality teaching routines, but also the capacity for pedagogical innovation and an understanding of how to improve professional content (Darling-Hammod & Jossey-Bass, 2006). Therefore, the researchers hope that the STEM-based learning environment can become a pattern for the development of pedagogical and professional competencies for early childhood student teachers. This is in line with what Bhakti and Maryani (2016) that the curriculum improvement process in Education Personnel Education Institutions should ideally focus on the teacher competency test component which is a national policy in Indonesia.

CONCLUSION

This research has produced a STEM-based learning environment with a CAS (Campus-Application-School) model that is valid, practical, and has potential effects. The CAS model of learning environment consists of the stages of training, designing, mentoring, and testing. The training stage was conducted on campus, the designing and mentoring stages were conducted using a graphic design application and virtual meetings application. The training phase is carried out on campus, the design and mentoring stage is carried out using a graphic design application and virtual meetings, and the trial phase is carried out at school. The validity of the STEM-based learning environment model was seen from the student worksheet instruments developed and the content in the learning environment, obtaining a value of 0.88, which is categorized as high validity. The practicality was demonstrated by the results of one-to-one teaching, small group, and field tests related to the instrument under development. Meanwhile, the potential effects were based on Kirkpatrick's levels and are shown by participants' reactions in the form of satisfaction from the training with an average of 76.69 categorized as very good, participants' learning in the form of perceptions and observations of activity planning carried out with an average of 81,845, categorized as very good, participants' behavior in the form of the attitude of student teachers in applying what they have learned through teaching materials with an average of 92.39, categorized as very good, and participants' results in the form of teaching materials that have been developed and implemented to students with an average of 84.01, categorized as very good. These results have the potential to influence early mathematics learning activities for student teachers and have been proven to have the potential to improve the academic and professional competencies of student teachers.

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Declarations

Author Contribution	:	AE: Conceptualization, Writing - Original Draft, Formal analysis, Methodology, Editing and Visualization. Z: Writing - Review & Editing, Validation and Supervision. RII: Writing - Review & Editing, Validation and Supervision. NA: Writing - Review & Editing, Validation and Supervision.
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