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STEM Learning for Enhancing Self-Efficacy and Control of Variables in Prospective Elementary Teachers: A Systematic Review for Quality Science Education

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Abstract: The objective of this study is to investigate how STEM (Science, Technology, Engineering, and Mathematics) education contributes to enhancing self-efficacy and control-of-variables strategy (CVS) skills among prospective elementary school teachers, using a Systematic Literature Review (SLR) methodology. This research examined 15 well-regarded international articles that were published between 2020 and 2025 and are indexed by Scopus. To guarantee a systematic, transparent, and responsible review process, the identification, selection, and inclusion of literature were carried out in accordance with PRISMA guidelines. The findings concerning STEM learning models, instructional strategies, and their effects on the psychological and cognitive aspects of prospective teachers were synthesized using thematic analysis. Studies show that STEM approaches based on inquiry, project-based learning, and engineering design consistently improve prospective teachers' self-efficacy in science teaching and strengthen their ability to regularly control variables in experiments. Furthermore, the implementation of the Flipped Classroom model and the integration of digital technology contributes to meaningful learning experiences (mastery experiences), enhanced collaboration, and the development of analytical thinking and problem-solving skills. However, several challenges remain, such as the gap between theory and practice, differences in program duration, and limitations in the development of computational literacy. Overall, STEM learning contributes to preparing prospective elementary school teachers who are confident, reflective, and competent in designing inquiry and technology based science lessons to support the creation of quality science education.

Keywords: Control variable; Prospective elementary teachers; Self-efficacy; STEM learning; Systematic review

Introduction

Development knowledge science and technology in the 21st century have push transformation paradigm education from learning based transmission knowledge going to learning that emphasizes skills think level high, breaking problem complex, as well as literacy science and technology. In context in this context, the Science, Technology, Engineering, and Mathematics (STEM) approach is one of the strategies that many implemented in system global education because can integrate various discipline knowledge in the learning process that focuses on problem solving problem authentic and

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design process engineering design process. A number of studies show that implementation STEM learning can increase understanding conceptual, ability think critical, and engagement cognitive participant educate in the learning process based on investigation scientific (Sepriyanti et al., 2022).

Prospective school teachers base own role important in integrate STEM approach through educational programs they, because they become foundation beginning in formation literacy science and technology to participants educate. Although so, some studies latest show that Lots prospective elementary school teachers have background behind limited science and often encounter difficulty in designing learning based experiment and design technology (Margot & Kettler, 2019). Circumstances this impact on low levels of trust self prospective teachers at the moment apply approach learning STEM based in the classroom. Therefore, the aspects psychological such as self-efficacy becomes element crucial in readiness prospective teachers for adopt innovation learning. Self-efficacy refers to the belief individual will his abilities in planning and implementing necessary actions for reach objective certain (Bandura, 1997). According to study recent (Lauermann & Ten Hagen, 2021), there are correlation positive between teacher self-efficacy and quality practice learning, creativity pedagogical, and teacher readiness to integrate STEM approach in the learning process.

Dimensions psychological and ability cognitive in reasoning scientific You're welcome influence success implementation STEM learning. One of the element crucial in reasoning scientific is the control of variables strategy (CVS), which is ability For designing experiment with control variables in a way systematic For identify connection cause and effect with valid. With mastering CVS, participants students and prospective teachers can designing fair experiment (fair test), conduct analysis critical to empirical data, as well as interesting based conclusions proof scientific (Sins et al., 2020; Zimmerman, 2021). In the context of STEM learning, CVS is related No only with experiment science, but also with engineering and technology components, because the design process engineering need testing various alternative solution through manipulation and control variables in a way systematic (Moore et al., 2020; Dare et al., 2021). Therefore that, mastery of CVS is one of the competence main in support STEM based learning research and design technology.

Although study about STEM, self-efficacy, and reasoning scientific has develop rapidly in a number of year lastly, the study literature show that part big study Still learn third aspect the in a way separate. Some studies research influence application of STEM to results Study or skills think critical students, meanwhile studies other examine teacher self-efficacy in context innovation learning. On the other hand, during this study regarding control-of-variables strategy (CVS) more Lots directed at development reasoning scientific students, in particular in designing and interpreting experiment science. In contrast, research examining deep CVS context readiness cognitive prospective teachers in STEM learning are still limited, so that topic this need study more carry on Schwichow et al. (2020). In addition that, research that is clear investigate connection between STEM implementation, strengthening self-efficacy, and CVS skills in prospective elementary school teachers are still classified as little and there are in various publication, so that not yet give description comprehensive about relatedness third construct (Cheng et al., 2023; Li et al., 2020).

Limitations the indicates existence gap research gap in literature STEM education. At the beginning, the study linked dimensions psychological (self-efficacy) and cognitive (CVS) simultaneously in context STEM learning in teacher education is still limited. Second, the majority STEM studies are still centralize attention to participants educate, whereas study about readiness conceptual and pedagogical prospective school teachers base in STEM implementation is still classified as little. Third, analysis explicit about connection conceptual between the control of variables strategy and the engineering design process and its use technology in STEM learning is still limited in study literature latest.

In connection with gap that, is necessary something study comprehensive that can integrate findings study previously in a way systematically. With thus, research This apply Systematic Literature Review (SLR) approach to identify, evaluate, and synthesize proof related empirics with contribution STEM learning in strengthening self-efficacy and control of variables strategy capabilities in prospective school teachers base.

Novelty study this located on the framework analysis integrative that connects dimensions psychological (self-efficacy) and dimensions cognitive (CVS) in context implementation of STEM in teacher education. In addition, research This in a way firm positioning CVS as competence key that supports the engineering process design and development solution based technology in STEM learning. Therefore that, the result study this expected can enrich understanding theoretical about STEM integration in teacher education and providing implications practical for development curriculum as well as educational program design more prospective teachers effective and based proof scientific.

Various study show that the self-efficacy of prospective teachers plays a role important in success they apply learning STEM-based. Prospective teachers who have high self-efficacy tend more believe self in face

challenge, dare try approach new, and can motivating student for involved active in study Şenyigit et al. (2025). On the other hand, prospective teachers who have low self-efficacy often feel doubtful about apply learning based project or experiment Because afraid will do error Täschner et al. (2024). With thus, increasing self-efficacy is one of the objective main in education prospective teachers in this modern era.

Prospective teachers need have strong self-efficacy as well as mastery to ability scientific basic, among others is a control strategy variables (control–of-variables strategy or CVS). CVS is ability for change one variables in experiment while guard other variables remain constant constant, so that connection cause and effect can analyzed with right (Van Vo & Csapó, 2021). Basis for understand method scientific with appropriate and constructive ability think logical is skills this. From various study known that majority prospective teachers still face challenge in implementing CVS in a systematic, especially moment designing experiment or activity learning based inquiry (Zoupidis et al., 2024).

STEM learning that combines approach inquiry - based learning and engineering design have proven effective in increase self-efficacy and ability prospective teachers in control strategies variables (control-of-variables strategy). Li et al. (2021) conducted research that shows that prospective teachers involved in project engineering technology experience improvement trust self in explain draft scientific and in-depth understanding they about connection intervariable in a way systematic. In addition In addition, the results of a meta-analysis conducted by Wijaya et al. (2022) showed that the STEM learning program is designed with approach collaborative and reflective give impact significant positive to increasing the self-efficacy of prospective school teachers basic. The program make they more ready and confident self in plan as well as carry out activity learning based experiment.

Similar study by Wang et al. (2023) shows that STEM- based training project, which is equipped with reflection self, mentoring intensive, and practice directly in the field, can in a way significant increase motivation intrinsic prospective teachers and strengthen belief they in ability pedagogical research Zoupidis et al. (2024) also confirms that prospective teachers can understand design experiment with more deepen and increase feelings of trust self they moment apply it in class through learning explicit about control strategies variables (control-of-variables strategy/CVS), making practice learning more structured and effective.

Various studies show varying results related findings said. Some studies take notes existence high influence, while study other find moderate results or even No significant. Varied findings this generally influenced by differences context education, duration training, design learning, as well as characteristics participants (Liu & Pásztor, 2022). According to meta-analysis study by Zhou et al. (2023), development program intensive, sustainable, and practice- oriented professional development (PD) more effective in increase teacher self-efficacy compared to with training short that only nature informational.

Implementation STEM learning in teacher education programs is still experience various challenges. The majority candidate educator more focuses on mastery material rather than integration between discipline science and application learning based problem. According to research by Rodríguez et al. (2024), prospective elementary school teachers in Indonesia still face difficulty in designing experiment in accordance CVS principles and tends to not enough believe self in apply inquiry-based learning approach, due to limitations facilities and lack of training methodological. For that, it is necessary designed teacher education programs that are not only emphasize mastery content, but also improvements competence pedagogical, reflective, and trust self in teach STEM-based.

Various findings the can concluded that STEM learning has potential big as a strategy to strengthen self-efficacy and control variables of prospective elementary school teachers. However, the majority existing research still separate and not yet review connection between second variables in a way deep. Besides that, longitudinal research is still own valid limitations and instruments for measure CVS capabilities in general comprehensive still not enough Atmojo et al. (2025).

Based on the description above is important done journal review study international most recent (five years last) for synthesize results study about influence STEM learning on self-efficacy and variable control abilities of prospective elementary school teachers. This study aim to: (1) Describe effectiveness various STEM learning models for improvement second variables; (2) identify component the most contributing instructional, such as approach inquiry, project-based learning, and engineering design; and (3) highlighting gap research that is still ongoing there are, including variation program duration, method measurement, and context institutions teacher education. With thus, the results study this expected capable give recommendation practical for institution teacher education in develop curriculum, activities practice field, and development programs more professional directed. Designed STEM learning in a way systematic, reflective, and based experience real will help form prospective school teachers foundation of belief self-motivated, innovative, and capable grow thinking generation scientific as well as Ready compete in the global era.

Method

This research uses the Systematic method Literature Review (SLR) to identify, evaluate, and synthesize research findings related to the implementation of STEM learning in improving self-efficacy and control abilities of variables strategy (CVS) for prospective elementary school teachers. The SLR method is a systematic, transparent, and replicable literature review approach, aimed at obtaining a comprehensive synthesis of scientific evidence from various previous studies (Kitchenham & Charters, 2007; Snyder, 2019). The SLR implementation procedure in this study follows the PRISMA (Preferred Reference List) guidelines. Reporting Items for Systematic Reviews and Meta-Analyses) developed by Page et al. (2021) to ensure that the literature search and selection process is carried out systematically and transparently.

The source literature is obtained from several reputable scientific databases, with Scopus as the main database, and supported by Web of Science, SpringerLink, ScienceDirect, Taylor & Francis Online, and SAGE Journals. Additionally, articles from accredited national journals and those published in the Journal of Science Education Research (JPPIPA) were also used to enrich the analysis in the context of science education research in Indonesia. Articles analyzed were limited to publications between 2020 and 2025 and must have a Digital Object (DOB). Identifier (DOI) to ensure the credibility of scientific sources.

The literature search was conducted using a combination of keywords arranged using Boolean operators. The keywords used included "STEM education", "STEM learning", "self-efficacy", and "preservice". “teachers”, “preservice elementary teachers ”, as well as “control of variables strategy”or “scientific reasoning”. The search string used is: (“STEM education” or “STEM learning”) and (“self-efficacy ”) and (“preservice teachers" or "preservice elementary teachers") and ("control of variables scientific" or "strategy reasoning"). Boolean operators are used to increase the relevance and accuracy of literature search results.

The article selection process follows the PRISMA steps: identification, screening, eligibility, and inclusion. In the identification stage, an initial search of articles across all databases was conducted. Duplicate articles were then removed. The screening stage involved selecting articles based on their title and abstract to ensure their relevance to the research topic. Articles that successfully passed this stage were then subjected to in-depth full-text analysis. review at the eligibility stage. Articles that meet the following inclusion criteria will be included in the analysis: (1) empirical research, (2) discussing the implementation of STEM learning, (3) examining self-efficacy or control of variables strategy, (4) involving prospective elementary school teachers, and (5) published in reputable journals with DOIs. Articles that were irrelevant, did not have full text, or were outside the research year range were excluded from the analysis.

Efforts to ensure the quality of the synthesized research were carried out through an assessment process for each selected article. This assessment included evaluating the clarity of the research objectives, the appropriateness of the research design used, the validity of the research instruments, and the accuracy of the data analysis methods. Articles that met the inclusion criteria were then systematically extracted and analyzed using a thematic analysis approach. This approach aims to identify patterns in research findings, methodological trends, and the contribution of STEM learning to improving self-efficacy and self control. of variables strategy (CVS) for prospective elementary school teachers.

This synthesis process allows researchers to obtain a more comprehensive picture of the development of STEM research in the context of teacher education, while also understanding its implications for strengthening the pedagogical competence and scientific thinking skills of prospective teachers.

Result and Discussion

Search literature in compilation this review study done in a way systematic with utilise various journal scientific reputable journals indexed in international databases, such as Scopus, Web of Science, DOAJ, and Google Scholar, with range year publication between 2019 and 2025. The search process focused on research that discusses Science, Technology, Engineering, and Mathematics (STEM) learning, especially those related with the self-efficacy of prospective school teachers base as well as control of variables strategy (CVS) capability in learning science and technology.

Search process literature done through various online scientific databases, including SpringerLink, ScienceDirect, Taylor & Francis Online, MDPI, Frontiers in Education, Sage Journals, and Google Scholar. Done with use several keywords, such as “STEM education”, “self-efficacy”, “preservice elementary teachers”, “control of variables strategy”, “STEM learning”, and “science learning in elementary teacher education”. Get results more searches relevant and specific in accordance with focus research, search process literature utilize Boolean operators, such as AND and OR, in combine the keywords used.

The Influence of STEM Learning on the Self-Efficacy of Prospective Elementary School Teachers

The results of the literature synthesis indicate that the implementation of STEM learning significantly increased the self-efficacy of prospective elementary school teachers. Self-efficacy is a person's belief in their ability to plan and implement the actions necessary to effectively achieve learning goals.

Indexed international journals Scopus shows that STEM-based learning experiences can increase prospective teachers' confidence in teaching science and technology. Teacher education that integrates STEM provides opportunities for students to hone problem-solving, critical thinking, and technology design skills that are relevant to the needs of 21st-century learning (Kelley & Knowles, 2019; Honey et al., 2020; English, 2021; Margot & Kettler, 2019; Dare et et al., 2021).

Other research shows that student involvement in STEM project-based learning can increase their self-efficacy in applying science learning at the elementary school level (Thibaut et et al. , 2019; Shernoff et al., 2020; Radloff & Guzey, 2019; Nadelson et al., 2020). This is because STEM learning provides authentic learning experiences through experiments, technology design, and problem solving that are relevant to everyday life.

STEM integration has been shown to improve pedagogical content knowledge (PCK) of prospective teachers, which directly contributes to increasing their confidence in teaching science (Park et al., 2020; Wang et al., 2021). With a project-based learning approach and technology design, students have the opportunity to develop their conceptual understanding and pedagogical skills in an integrated manner.

Various studies published in accredited national journals support the finding that STEM learning provides significant benefits for teacher education students. Several studies show that STEM-based learning can improve students' critical thinking skills (Sari & Susanto, 2020; Wahyuni et al., 2020; Lestari et al., 2020; Putra et al., 2021; Arifin et al., 2022). In addition, the implementation of the STEM learning model has also been shown to encourage student creativity in designing innovative and engaging science learning (Pratiwi & Rahmawati, 2022; Mulyani et al., 2021; Hadi & Kurniawan, 2022).

In addition to improving cognitive abilities, other studies show that STEM learning can increase student motivation in science courses as well as strengthen collaboration and scientific communication skills (Hidayati et al., 2020; Nugroho et al., 2021; Setiawan & Widodo, 2022; Wulandari et al., 2021; Yanto et al., 2022; Santoso et al., 2021). These findings confirm that the STEM approach impacts not only academic aspects, but also students' affective and social development, making it a comprehensive and holistic learning strategy.

Various studies published in the Journal of Science Education Research (JPPIPA) show consistent results regarding the effectiveness of STEM learning in improving higher-order thinking skills. For example, Rahmawati et al. (2020) found that STEM learning can improve students' critical thinking skills in science subjects. In addition, research by Yulianti et al. (2021) showed that the implementation of the STEM approach significantly improved students' science learning outcomes.

A study conducted by Saputra et al. (2022) also showed that STEM-based learning projects can improve students' problem-solving abilities. Putri et al. et al. (2021) also reported similar findings, indicating that STEM learning can improve students' analytical thinking skills in the context of science learning. Furthermore, other studies in JPPIPA also show that the STEM approach can significantly improve students' creative thinking skills and scientific literacy (Fitriani et al., 2020; Kurniawan et al., 2022; Lestari et al., 2021; Pramudya et al., 2022; Dewi et al., 2023).

Based on the description above, it can be concluded that STEM learning significantly contributes to improving the self-efficacy of prospective teachers because it provides learning experiences that emphasize scientific investigation, collaboration, and problem-solving activities. Directly engaging in the process of exploring and designing science and technology based solutions can help students build confidence in their abilities to design and implement science learning. This experience also strengthens the conceptual understanding and pedagogical skills needed in classroom teaching practices. Strengthening these competencies is crucial for preparing prospective teachers to implement innovative and meaningful science learning at the elementary school level.

The Role of STEM Learning in Strengthening Control of Variables Strategy (CVS)

STEM learning not only contributes to increased self-efficacy, but also plays an important role in developing self control. of variables Strategy (CVS). CVS is the ability to identify, organize, and manipulate variables in a scientific experiment, enabling one to draw valid conclusions from the results. This is an essential skill for scientific reasoning because experimental activities help students systematically understand cause-and-effect relationships.

Various international studies have shown that the implementation of STEM-based learning contributes to improving students' science process skills and scientific thinking abilities. Zimmerman (2020) stated that experiment-based learning activities within the STEM approach help students understand the relationships between variables in a scientific experiment. Bybee

(2019) also explained that the STEM approach encourages students to systematically apply the steps of the scientific process, from observation to data analysis.

A number of other studies have shown that the application of the STEM approach through a project-based learning model can improve students' abilities in designing scientific experiments and understanding the concept of variables in scientific research (English, 2021; Honey et al., 2020; Guzey et al., 2020; Dare et al., 2021). Project-based learning activities provide students with the opportunity to actively engage in the investigative process, from planning experiments to analyzing research results. This process helps students develop a deeper understanding of the relationships between variables in a scientific experiment.

Research results from national journals also show that implementing STEM learning can improve students' science process skills. Research by Ardiansyah et al., (2020) found that STEM learning can improve students' ability to conduct scientific experiments. Another study by Utami et al., (2021) showed that the STEM approach can improve students' abilities in designing scientific investigations.

Other national research also shows that STEM learning can improve scientific thinking skills and understanding of variable concepts in science experiments (Rahman et al., 2020; Siregar et al., 2021; Kusuma et al., 2022; Purnamasari et al., 2022; Hidayat et al., 2023).

Similar results were also reported in a number of studies published in the Journal of Science Education Research (JPPIPA). Research by Fitriani et al. (2020) showed that the implementation of STEM learning can significantly improve students' science process skills. Another study conducted by Kurniawan et al. (2022) revealed that the STEM approach contributes to improving students' ability to more accurately identify variables in science experiments. These findings indicate that STEM-based learning has great potential in developing students' scientific abilities.

A number of studies published in the Journal of Science Education Research (JPPIPA) also show that the application of the STEM approach is able to improve students' scientific investigation skills and analytical thinking skills in science learning (Pramudya et al., 2022; Dewi et al., 2023; Lestari et al., 2021; Ramadhani et al., 2023). These findings indicate that STEM learning makes a significant contribution to developing students' scientific abilities through activities that emphasize exploration, experimentation, and data analysis. Learning experiences that focus on the investigation and problem-solving process make STEM learning an effective strategy for developing control skills. of variables strategy (CVS).

The analysis of various scientific articles used as sources for this research indicates that STEM learning plays a significant role in improving the competency of prospective elementary school teachers. The implementation of STEM learning not only contributes to increasing prospective teachers' self-efficacy in teaching science but also supports the development of scientific thinking skills, science process skills, and self-control abilities. of variables strategy (CVS). This approach provides learning experiences that encourage students to actively engage in the process of scientific investigation and problem solving.

A number of studies show that the application of STEM learning is able to develop various important skills in students, such as critical thinking, creativity, collaboration, and problem-solving abilities (Margot & Kettler, 2019; Radloff & Guzey, 2019; Wang et al., 2021; Arifin et al., 2022; Santoso et al., 2021). The integration of STEM in teacher education provides authentic learning experiences through experiments, design projects, and scientific investigations related to real-world problems. These learning activities encourage students to connect and apply concepts from science, technology, engineering, and mathematics in an integrated manner, thus making the understanding gained more meaningful. The implementation of STEM learning in elementary school teacher education programs has the potential to be an effective strategy for preparing prospective teachers with strong pedagogical and professional competencies, supported by strong scientific thinking skills.

The initial search yielded several articles relevant to the research topic. The next step was a screening stage, which involved selecting articles based on the suitability of the title, abstract, relevance to the research topic, and availability of DOI. This stage yielded several articles that met the research inclusion criteria. Each selected article was then analyzed in more depth, considering several aspects, including the article title, author's name, year of publication, research method used, variables studied, and key findings related to the implementation of STEM learning, strengthening prospective teachers' self-efficacy, and self-control abilities. of variables strategy in science learning.

The analysis process in this international journal review aims to identify patterns of research findings, trends in research methods used, and the contribution of STEM learning to improving the pedagogical competence of prospective elementary school teachers. The results of the literature search and analysis are then systematically compiled and presented in Table 1. The table contains a summary of the research articles that served as the primary sources in this review, including information regarding the authors, year of publication,

research methods, and key findings relevant to the research topic.

Based on Table 1, from the 15 journals analyzed, we can see the importance of the institutional role of schools or universities in equipping prospective teachers with technological competencies. In the context of instructional design content creation conducted by Liu (2025), support in the form of training, resources, or pro-technology policies can increase prospective teachers' self -efficacy in using tools such as generative AI. High self -efficacy, in turn, will motivate prospective teachers to create innovative learning content more frequently and effectively. This is in line with research conducted by Dong (2019) stated that institutional support is a key external factor that influences teachers' self efficacy regarding technology.

Table 1. List of Reputable International Journals about STEM Learning, Self-Efficacy, and Control of Variables in Prospective Elementary School Teachers (2019–2025)

Journal Title	Main Author (Year)	Research Methods	Key Findings	Journal Categories
Pre-service elementary teachers' science and engineering teaching self-efficacy and outcome expectations: exploring the impacts of efficacy source experiences through varying course modalities	Hammack et al. (2024)	Survey pre- and post-tests (Pre/post-surveys)	Belief efficacy self teach science and engineering, as well as hope results teach PST science and engineering all increase in a way significant from pre-ke post-test. There is no difference significant in improvement efficacy based on modality course.	International Journal of STEM Education
Preservice teachers' science learning and self-efficacy to teach with robotics-based activities: Investigating a scaffolded and a self-guided approach	Jaipal-jamani (2023)	Mixed Methods (Quantitative: Self-Efficacy for Teaching Integrated STEM pre- and post-test instruments; Qualitative: two semi-structured interviews) with 10 participants)	Structured (scaffolded) robotic interventions are more effective increase knowledge concepts and self-efficacy of prospective teachers for teach activity based robotics.	Frontiers in Education.
The effectiveness of professional development in the self-efficacy of in-service teachers in STEM education: a meta-analysis	Liu et al. (2025)	Meta-Analysis (Systematic Review) of 18 studies empirical selected.	Overall Professional Development (PD) had a moderate positive effect on self -efficacy. (Hedges' g ≈ 0.55). Participant size and PD training hours contributed significantly to the effect size .	Behavioral Sciences
Systematic review and meta-analysis of the impact of STEM education on students' learning outcomes	Lu (2025)	Systematic review and meta-analysis	Findings beginning show that STEM education has impact positive on the results Study student.	Frontiers in Psychology
Does the understanding of managing variables among pre-service early childhood teachers correspond to distinct teaching methods in their future careers?	Zoupidis & Tselfes (2024)	Quantitative survey of prospective teachers; statistical analysis.	Teaching explicit about control-of-variables increases prospective teachers' CVS understanding and tendencies they use future inquiry methods.	Education Sciences
Profiling pre-service teachers' motivational and behavioral profiles	Zhou et al. (2025)	Quantitative, Analysis Latent Profile (Latent Profile Analysis)	Identified four profile: Low Functioning (24.2%), Vulnerable (31.8%), Low Motivation (6.9%), and High Functioning (37.1%). Profile This different in welfare psychological and commitment Work.	Teaching and Teacher Education

Journal Title	Main Author (Year)	Research Methods	Key Findings	Journal Categories
Pre-service primary teachers' STEM design experiences and STEM self-efficacy	Sule & Kiyic (2025)	Mixed methods (self-efficacy scale, product design analysis).	Experience STEM design in significant increase efficacy self prospective teachers. Teachers experience difficulty in identify problem, choosing tools, and counting costs. Design is associated with Good with science and mathematics, but no with technology and engineering.	Journal of Pedagogical Research
Pre-service teachers in STEM education: an integrative review and mapping of the Indonesian research	Nugraha et al. (2023)	Review Integrative and Analytical Bibliometrics	STEM education for PST in Indonesia begins reported in 2017 and experienced growth rapid. Review disclose diverse perception STEM implementation, and recommended framework work (STEM-DIMRECS).	Eurasian Journal of Mathematics, Science and Technology Education
Factors influencing confidence in STEM practices among preservice teachers	Teoh et al. (2024)	Survey & factor analysis	Understanding microteaching content and practices are correlated positive with trust self -efficacy in STEM practices.	International Journal of Technology
How School Support Influences the Content Creation of Pre-Service Teachers' Instructional Design	Liang (2025)	Mixed methods; path analysis.	Support school own effect predictive significant positive to creation content design instructional prospective teachers. Generative AI technology and efficacy self prospective teachers play role mediation chain between support school and creativity content design instructional.	Behavioral Science
Development & validation of TSTSIS instrument to measure teachers' STEM self-efficacy	Khut (2024)	Instrument development (validation & reliability)	TSTSIS instrument has been proven to be valid and reliable. STSIS is divided into become six factors, of which five is "Integrated STEM Instructional Self-Efficacy" (based on problems, robots, inquiry, engineering, and technology).	European Journal of STEM Education
STEM integration: teacher perceptions and practice	Wang et al. (2011)	Case study	For get greater understanding Good about beliefs, perceptions, and practices teacher class uses STEM integration.	Journal of Science Education and Technology
Investigating the development of pre-service teachers' attention for inclusive translingual instruction in secondary education: an intervention study	Weger (2025)	Qualitative/quantitative (longitudinal) studies	Show improvement significant in noticing (the teacher's ability to pay attention/analyze incident class), reflected in more statements more sophisticated and focused strong in the learning process student.	International Journal of Inclusive Education
Enhancing pre-service teachers' science teaching efficacy beliefs and attitudes toward science	Ribeirinha (2025)	Mixed methods	The Flipped Classroom Model (FCM) has effect significant on belief efficacy self teach science prospective	Frontiers in Education.

Journal Title	Main Author (Year)	Research Methods	Key Findings	Journal Categories
using the flipped classroom model			teachers, especially in Personal Science Teaching Efficacy (PSTE). FCM also has effect significant on attitude they to science.	
Self-efficacy in computational thinking: pre-service teachers' perceptions Through a Portuguese tool	Rodrigues (2025)	Descriptive survey & analysis	efficacy period self think computational proven to be valid and reliable. The absence of difference significant in perception efficacy self between prospective undergraduate and master's teachers show lack of exposure structured to draft the.	Eurasia Journal of Mathematics, Science and Technology Education,

Apart from the factors external, in the research of Khut (2024) also explained that tool valid measurement also holds role Importantly, the validity of the TSTSIS instrument is also crucial because it allows researchers and teacher education program developers to measure teachers' self-efficacy beliefs specifically across dimensions critical to integrated STEM instruction. STEM integration models (such as robotics-based or engineering-based) require unique pedagogical and content expertise. This instrument ensures that teacher training interventions can be accurately targeted and evaluated across these dimensions. This is in line with Isha's (2018) research that the measurement of teacher self-efficacy in the STEM context is strongly supported by the literature. Research shows that teachers' self-efficacy beliefs influence how effectively they implement learning models, including STEM-integrated problem-based models.

Although thus, STEM integration faces challenge significant in the form of gap between understanding theoretical (perception) and application practical in the classroom (Amanda Berry, 2025). The gap this appear Because STEM implementation demands shift paradigm going to approach interdisciplinary. The problem of mismatch between perception and practice is issue common in many discussed in literature reputable (Budiman et al., 2023). Challenges main STEM implementation often related with limitations competence teacher pedagogy and misalignment between policy or theory with effective practices in the classroom (Sari & Rosdiana, 2025). Research emphasize that without deep understanding and support adequate practice, perception positive towards STEM not will come true in optimal learning.

For overcome challenge practice and improve teacher professionalism, development noticing skills become very important. Noticing is teacher's ability to observe, analyze, and respond incident important in class (Copur, 2021). In the context of inclusive translingual teaching, skills This enables teachers to recognize and utilize source Power Language diverse students, instead only focus on the deficit language. Weger's research (2025) shows that noticing skills can trained, and appropriate interventions can divert focus prospective teachers from teacher's actions alone to cognitive processes as well as interaction students. Support other literature confirms that noticing capabilities allow teachers to interact with student in a way more meaningful and personal, and become prerequisite for taking effective decisions in the classroom (Li & Chunxia, 2025). With Thus, development noticing skills, particularly those directed at problem solving problems and dynamics learning inclusive, to be key For create environment responsive and professional learning.

In terms of learning models, the Flipped Classroom Model (FCM) also shows superiority like in study reibenhart. Where the Flipped Model Classroom moves basic information-receiving activities outside the classroom (through videos or reading) and uses face-to-face time for active, collaborative learning. These results align with research conducted by Kwan (2017) showed that active interaction, team-based problem solving, and the role of the teacher as a facilitator emphasized in FCM can be the main source of mastery experiences for prospective teachers. This successful experience, according to Bandura (1982) self -efficacy theory, is the strongest predictor of increased PSTE and positive attitudes toward the content being taught.

Flipped Effectiveness Classroom Modeling (FCM) in education has been extensively researched, although the results are mixed. Some studies suggest that FCM does not always have a significant impact on cognitive outcomes or self-regulation skills student learning (Kwan, 2018). However, other studies confirm that FCM is effective in improving higher-order thinking skills and encouraging student engagement in the learning process (Rong, 2019). Furthermore, the research findings of

Ribeirinha et al. (2025) add evidence that FCM is specifically capable of strengthening the affective aspects and self-confidence of prospective teachers, which are important prerequisites before they undertake teaching practice. These findings indicate that the implementation of FCM not only impacts academic abilities but also supports the development of professional attitudes and the readiness of prospective teachers.

Instrument validation is the first step to measure the success of Computational Thinking (CT) integration in curriculum implementation (Sutojo, 2024). The most important finding shows no difference in CT self efficacy based on level of study. This implies that, although CT is integrated into the curriculum, teacher education programs at the advanced (master's) level have not provided more in-depth or structured CT training than at the undergraduate level. Failure to build strong CT self efficacy in prospective teachers will hinder the successful implementation of CT in schools . CT literacy is recognized as skills important and associated 21st century with efficacy self, failure build efficacy strong CT self will hinder implementation of CT in schools (Yadaf 2016). To address the lack of self -efficacy identified by Rodrigues et al. (2025), another study emphasized the need for project - based interventions or structured activities. Therefore that, is necessary intervention based project or activity structured, as well as an explicit, structured, and progressive CT curriculum for build belief self prospective teacher.

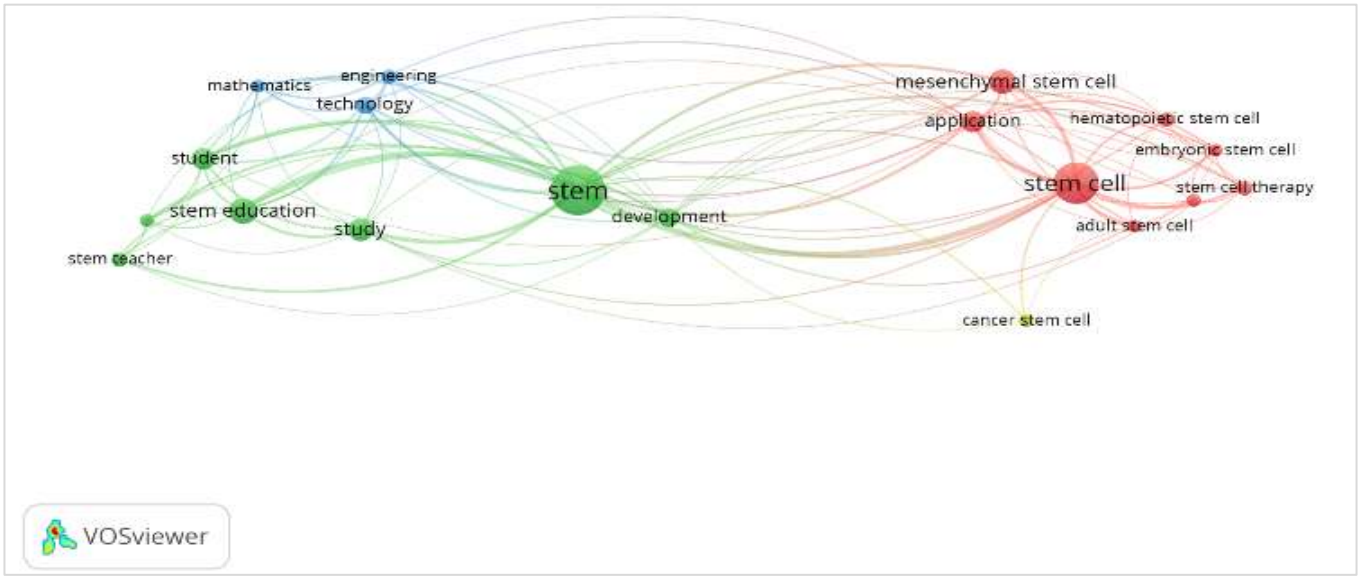

Figure 1. Visualization keyword co-occurrence network in research stem education using vosviewer

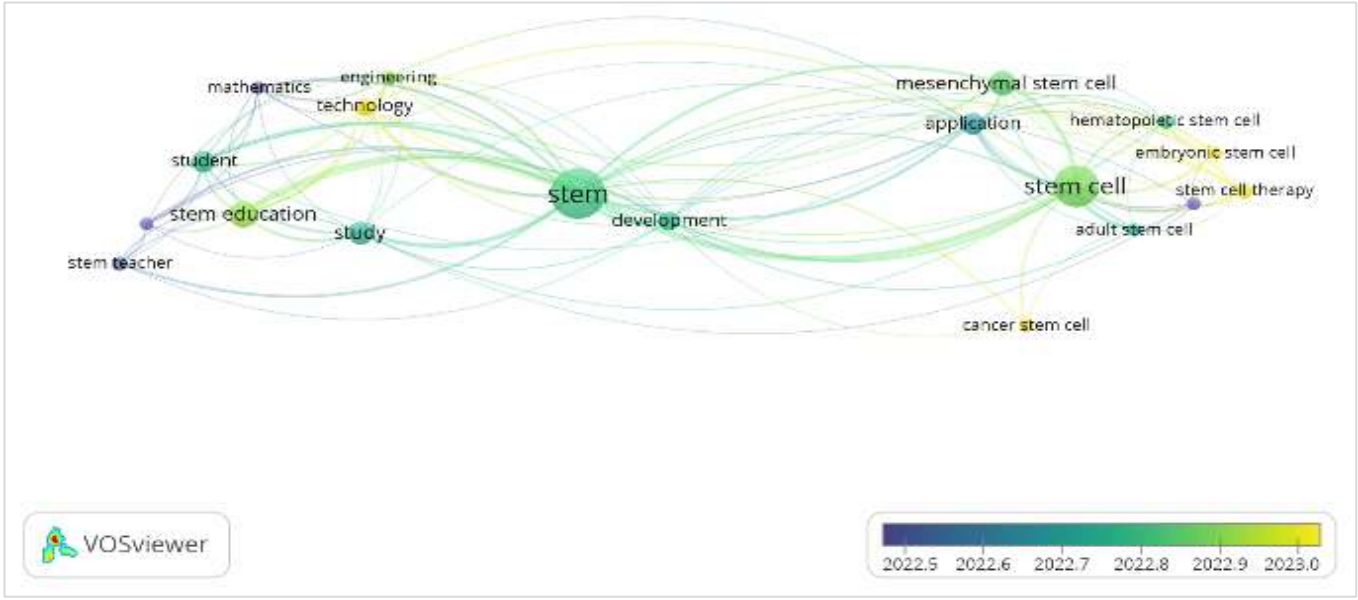

Figure 2. Overlay visualization of keyword Co-occurrence network using vosviewer

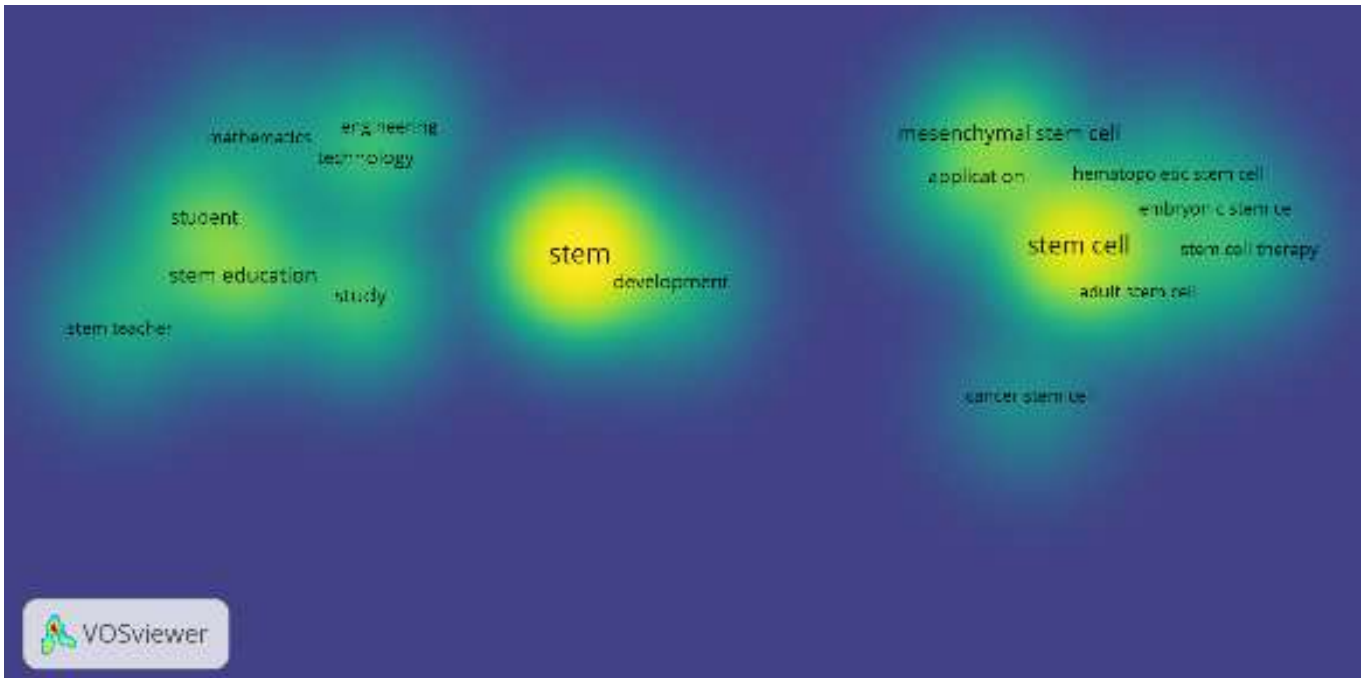

Figure 3. Density visualization of keyword Co-occurrence network generated using vosviewer

Figure shows visualization keyword co-occurrence network in study STEM education analyzed use VOSviewer. Visualization This describe how keywords STEM connected primary with other keywords such as "stem cell", "technology", and "STEM education". It can be seen that there is strong relationship between STEM with the keywords "stem cell" and "student", which shows focus research on the application of STEM in context students and technology related to Education, while Figure 2 displays an Overlay Visualization of the keyword co-occurrence network. Use VOSviewer, which provides view the importance of STEM in context education. STEM is depicted as the main pillar education 21st century because play a role in prepare student face global challenges, encouraging innovation, as well as equip skills essential for the future (Jamali et al., 2022). Change color from purple (more old) to yellow (more new) shows existence shift focus topic research, for example from "human pluripotent stem cell" to "application". The shift topic study from time to time is phenomenon complexes influenced by interactions various factors, including progress technology, urgency need public or market, as well as funding research (Quemener et al., 2024). Figure 3 displays the Density Visualization of generated keyword co-occurrence network use VOSviewer. Visualization This describe frequency and strength connection between keywords, with STEM as center network. Area with intensity light more high, such as around the keywords "STEM" and "Stem Cell", indicating that topics the often emerged and was deemed highly relevant in literature, at the same time become focus main study global scientific (Liu et al., 2022).

Conclusion

Based on synthesis analyzed studies, increased efficacy self prospective teachers in STEM education is influenced by interactions between factor pedagogical, experience learning and support institutional findings show that learning model based experience, especially the Flipped Classroom Model (FCM), is effective in increase Personal Science Teaching Efficacy (PSTE) and attitudes positive prospective teachers towards learning science. Effectiveness this related with mastery experience mechanism, namely involvement prospective teachers in activity learning that allows they develop understanding conceptual and skills teach in a way direct. In addition, some studies highlight importance mastery draft scientific such as control of variables strategy (CVS) and development of computational thinking (CT) as component important in build competence pedagogical prospective teachers in STEM context. Mastery second aspect this contribute to the improvement ability analytical and problem solving the problem that is needed in practice STEM learning.

External factors, such as support institutional and availability technology, also play a role in support development efficacy self prospective teachers, including in utilization digital technology for compilation content learning. Findings This confirm that development efficacy self prospective teachers in STEM education requires combination between learning

strategies based experience, strengthening competence conceptual such as CVS and CT, as well as creation environment supportive and conducive education.

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Conceptualization, NPM and S.; methodology, NPM, S., and A.; formal analysis, NPM and S.; investigation, NPM, S., A., CD, SK, and NH; resources, NPM and S.; writing original draft preparation, NPM; writing review and editing, S., A., and C.D.; visualization, NPM; supervision, S.; project administration, NPM; funding acquisition, NPM and SK All authors have read and approved the published version of the manuscript.

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