Exploring Pre-Service Biology Teachers' PCK-STEM in the Context Waste Management

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ABSTRACT

This study aimed aimed to explore the Pedagogical Content Knowledge STEM education (PCK-STEM) in the contecxt waste management among pre service biology teachers through an analysis of their teaching modules and teaching simulations. The research employed a qualitative design with an exploratory case study approach involving document analysis and classroom teaching simulations. Data were collected from document four participants and analyzed using a score rubric (Likert scale 1-4). Results showed that the highest score was in Curriculum Knowledge (89.06%), followed by Content Knowledge (80.36%), indicating strong alignment with national learning standards and accurate conceptual integration. However, lower scores were found in Knowledge of Students' Understanding (63.75%) and Assessment Knowledge (72.32%), reflecting limited attention to student misconceptions and formative assessment practices. Data obtained from the results of teaching simulation observations, participants demonstrated strong performance in assessment strategies (78,75%) and STEM-based pedagogy (75,0%), moderate performance in scientific content clarity (70,0%), weakest area was attention to student learning difficulties (57,5%). This study highlight the need for pre service teacher to provide structured opportunities for reflective practice, support in student centered pedagogy, and authentic assessment with STEM processes.

Keywords: Pedagogical Content Knowledge, STEM Education, Pre-service Biology Teachers, Waste Management

INTRODUCTION

Education in the 21st century requires a shift in how teaching and learning are approached. STEM education encompassing science, technology, engineering and mathematics has emerged as a prominant strategy to meet these evolving educational needs (Stehle et al., 2019; Marzuki et al., 2024; Grancharova 2024; Kalaian; 2017; Rahmania; 2021). STEM based learning has been proven effective in developing essential 21st century skills such as critical thinking, creativity, collaboration, and digital literacy (Singh 2024; Lesseig, 2016; Murray, 2019; Stracke et al., 2019; Ping, 2021; Zein 2022). Despite these well-known benefits, the implementation of STEM in actual clasroom practices still faces several challenges including a lack of understanding about STEM itself (Ring et al., 2017). Teachers also report difficulties in adopting STEM pedagogy (Bell 2016; Herro & Quigley, 2017) and integrating content accros multiple STEM disciplines (Shahali et al., 2016).

Research indicates that pre-service teachers are often not yet proficient in STEM related subjects due to limited content knowledge and low confidence in teaching STEM (Epstein & Miller, 2011; York, 2018; Menon et al., 2024). One of the most critical factors influencing the success of STEM implementation is teachers' readiness to understand and apply appropriate instructional strategies (Thibaut et al., 2018). Therefore, teacher preparation must include the development of both content knowledge and pedagogical knowledge, which allow educators to deliver content more effectively (Shulman, 1987).

In this context, Pedagogical Content Knowledge (PCK) serves as a crucial framework for bridging biological concepts with technology, engineering and mathematics, thus making science learning more contextual and meaningful. However, research has shown that many teachers still face challenges in developing PCK within a STEM context (Correia & Baptista, 2022; Losenara & Jugar, 2023). These difficulties include a lack of understanding of how to integrate technological and engineering aspects into biology instruction (Klabukov, 2023; Zhan et al, 2021; Siglos, 2022), limited use of inquiry-based and project-based learning approaches (Nicol, 2021) and insufficient experience in implementing formative assessments to evaluate students' understanding effectively (Khajeloo et al, 2021; Furtak et al, 2016; Windyariani & Setiono; 2024).

One of the most urgent and relevant socio-environmental issues today is waste management and pollution (Budjav, 2022; Sanchez et al., 2024). Environmental degradation, driven by unprocessed organic and inorganic waste, has become a global challenge that demands educational responses. Topics such as the management of organic waste, recycling, pollution prevention, and renewable energy production (e.g., bioethanol from food waste) offer rich contexts for STEM-based teaching and learning (Mukholifah, 2023). Integrating these issues into science instruction not only promotes scientific literacy but also cultivates environmental responsibility among students (Fernandu, et al 2022).

For biology and science education, using waste management and pollution as thematic learning contexts provides meaningful opportunities for students to apply scientific principles, engage in engineering design processes, and perform quantitative analysis (Vicario et al., 2024). Moreover, these topics align closely with the values of sustainability, systems thinking, and action-oriented science principles that are central to both STEM education and environmental education.

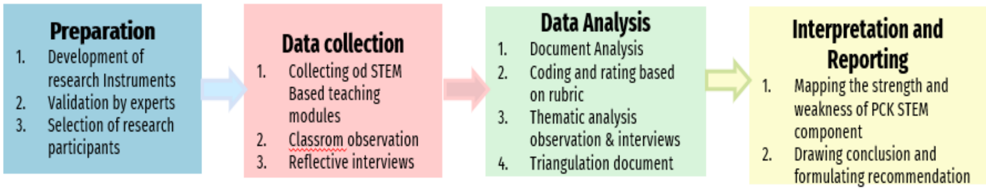
Although STEM and PCK integration holds significant promise, empirical investigations into how pre-service biology teachers embed these frameworks into practical teaching modules, especially on the topic of waste management are still limited. Existing literature tends to focus on in-service teachers or relies heavily on self-reported data such as surveys and interviews. As a result, there is a lack of understanding about the ways in which pre-service teachers translate their STEM pedagogical knowledge into real instructional designs, particularly when addressing authentic environmental contexts like pollution and waste treatment (Veen, 2023). Through document analysis and classroom learning observation, this research aims to explore the Pedagogical Content Knowledge (PCK) with STEM based education as demonstrated in the teaching modules and teaching simulation developed by pre service teachers.

Such research is urgent and timely, as it provides empirical insight into the readiness of pre-service teachers to implement integrated STEM instruction on environmental topics that are both scientifically significant and socially relevant. Furthermore, the findings of this study can inform the design of teacher education programs that better foster the development of PCK-STEM, particularly in the context of socio-environmental issues.

METHOD

This study employed a qualitative design with an exploratory case study approach. The purpose of the research was to explore the respresentation of Pedagogical Content Knowledge (PCK) in STEM based teaching practices developed by pre service biology teachers. The study focused on two sources of data: (1) teaching modules designed by the participants, and (2) teaching simulation conducted by the same participant using their modules. The study was conducted in a microteaching classroom setting at a Program Studi Pendidikan Biology FKIP Universitas Muhammadiyah Sukabumi. The participants in this study were pre service biology teachers. A total 4 participants were selected using purposive sampling based on the following criteria: 1) They had complete STEM based teaching modules, 2) Their modules focused on theme of waste management, 3) They were willing to conduct teaching simulation using their modules. The research was carried out in four main stages:

Figure 1: Research stages



PCK-STEM document analysis rubric was developed based on the PCK framework by Magnusson et al., (1999) and the integrated STEM education frameworks by Bybee (2010) and Kelley & Knowles (2016). The rubric assessed six component: 1) Content Knowledge (CK), 2) Pedagogical Knowledge (PK), 3) Knowledge of Students' Understanding (KSU), 4) Instructional Strategies (IS), (5) Curriculum Knowledge (CurrK), (6) Assessment Knowledge (AK). Each component was rated on a 1-4 scale (Likert scale) and included descriptive indicators for qualitative interpretation.

Teaching simulation observation sheet was design to assess how PCK-STEM elements were manifested in actual teaching practice. Observation focused on indicators: 1) Learning outcome and learning objective, 2) Acuracy and clarity of science content, 3) Learning activities relevan of STEM based pedagogical approach, 4) Consideration of student learning difficulties, 5) Implementation of assessment. Semi structured interviews were conducted after teaching simulations to explore participants' rationale, pedagogical decision, and reflections on their module design and implementation.

The rubric PCK-STEM and observation sheet were reviewed by two expert validators in STEM education and biology instruction. Pilot testing was conducted with other students to test clarify and usability. Interarrater agreement was employed during data analysis to ensure reliability and consistency between coders.

FINDINGS AND DISCUSSION

This study addresses that gap by exploring the representation of PCK-STEM in teaching modules developed and implementation of teaching by pre-service biology teachers on the theme of waste management. The following are the result of the STEM component description of each module compile by pre service biology teachers (table 1).

Table 1: STEM Component of Each Module

Context	Module 1	Module 2	Module 3	Module 4
	Waste Utilization	Water Pollution (1)	Organic Waste Treatment	Water Pollution (2)
Science	1. The Impact of organic waste on the environment 2. Utilizing leftover rice waste to produce bioethanol	1. Types of water pollution 2. Environmental impacts of water contamination	1. The impact of waste on environment 2. The concept of recycling and organic waste	Understanding water pollution and its effect on the ecosystem
Technology	Applying simple technology to procedure bioethanol from leftover rice waste	Using smartphone to search for supporting project information and identifying tools and materials needed for the project	Using internet to research waste treatment techniques	Developing tools materials to support solutions for water pollution
Engineering	Designing formulations for fermenting rice waste into bioethanol product	Designing project solutions for water pollution water problems	Designing prototypes of products from organic waste	Designing effective tools and materials to solve water pollution problems
Mathematics	1. Calculating the ratio of materials required 2. Calculating the ethanol concentration produced	1. Estimating the amount of waste entering the water 2. Calculating pollutant concentration (e.g., PH level)	1. Calculating cost, potential profit from organic waste product	Measurement and analysis of experimental data

From the table 1, the integration of STEM component focus on biological concepts, these contexts allow students to relate scientific principles (fermentation, pollution indicators) to observable phenomena in their surroundings. This aligns with Bybee (2010) emphasis on real-world problem relevance in STEM education and reinforces Content Knowledge (CK) within PCK. Technology is applied in two complementary was as a tool (smartphone, software, digital platforms) to search, design and document learning processes, and as a product to develop practical solution. Engineering aspects are seen in the process of designing, testing and improving products or solution to environmental issues, such as creating prototype for waste based bioethanol, or tools for water filtration. This reflects Engineering Design Process (EDP) component of STEM and Instructional Strategies dimension of PCK. The presence of trial and error, prototype evaluation and design iteration mirors the authentic practices of engineers and allow students to engange in problem based learning as suggested by Kelley & Knowles (2016). Mathematics is applied in supporting planning production processes an evaluating the feasibility of innovations.

In general, several deficiencies were found in the context presented in each teaching modul compiled by student. In Module 1, includes concepts of science, technology, engineering and mathematic. In modul 1 there is a discussion waste impact and bioethanol production, applies simple technology, includes basic calculations. The weakness module 1 in science there is no depth study of biochemical concepts (e. g. fermentation, enzymes), in engineering lack of explanation about the design optimization process and iteration, in mathematics no graphic or data application or efficiency estimates yet. In Modul 2, includes concepts of science, technology, engineering and mathematic, the weakness module 2 in science, does not explore water quality indicators (e. g., pH, DO, BOD, COD), in engineering missing systematic explanation of engineering design process, in mathematics no integration of data visualization or comparative data analysis. In Modul 3, includes concepts of science, technology, engineering and mathematic. The weakness module 3 in technology there are no concrete/visualized technological products resulting from student designs. In Module 4 includes concepts of science, technology, engineering and mathematic. The weakness module 4, in engineering missing systematic explanation of engineering design process (EDP).

The result of the PCK STEM analysis of the teaching module are shown in table 2 below.

Table 2: PCK-STEM of the teaching Module

Component	Average Score (%)	Category
CK	80,36 %	High
PK	70,31 %	Moderate
KSU	63,75 %	Moderate to low
IS	71,25 %	Moderate
CurrK	89,06 %	Very high
AK	72,32 %	Moderate

The data from tabel 2 shows that while pre service biology teacher demonstrate high score of content knowledge (CK) and curriculum knowledge (CurrK). CK as the foundation of effective science teaching (Magnusson et al., 1999). The ability to relate content to authentic environmental issues also reflects the principles contextual learning in STEM education frameworks (Bybee, 2010). Their pedagogical knowledge (PK), is still developing. This align with previous studies (Aydin et al., 2020; Yildrim & Topalcengiz, 2019) showing that novice teacher often struggle with the more dynamic and adaptive aspects of PCK-STEM. The lowest performance (63,75%) was found in the component related to understanding students' learning processes, modules lacked identification of potential student misconception and there was minimal evidence of differentiated instruction or diagnostic strategies. Assessment scores 72,32%) moderately, pre service teachers used assessment (projects or reports) but few reflective feedback.

The result of the PCK STEM analysis of the teaching module are shown in table 3 below.

Table 3: PCK-STEM of the Teaching Simulation

Component	Average Score (%)	Category
Accuracy an Clarity	70 %	Moderate
Relevance of STEM-based pedagogical Approach	75 %	Moderate
Consideration of Student learning difficulties	57,5 %	Low
Implementation of formative an summative assessment	78,75 %	Moderate to high

From the in table 3 pre service teachers adequate understanding of biological content and its contextual relevance. Moderate performance was found In STEM based pedagogy. The weakest area was attention to student learning difficulties and moderate to high in assessment strategies. The findings indicate that while participants were able to design contextually relevant and innovative STEM modules, but lacked sufficient scaffolding, diagnostic teaching, and structured feedback mechanisms.

Pre service biology teachers are generally able to design content knowledge align with curriculum, but their delivery lacks clarity ang responsiveness during teaching simulation. The finding align with Akcay & Avci (2022), who observed that pre service teachers often possess basic content knowledge but lack conceptual depth and confidence in scientific reasoning practice. Correia & Baptista (2022), emphasize that effective STEM teaching requires more than disciplinary integration, it demands pedagogical coherence with problem solving process. At the module and simulations demonstrated limited attention to student misconceptions and learning styles. Assessment strategies relatively well represented.

However, formative assessment and feedback were inconsistently implemented during simulations.

Interviews were conducted with participant about their difficulties in compiling modules and conducting teaching simulations. Here are the answer participants.

> *It was difficult to create learning activitiesthat combine science, technology, engineering and mathematic meaningfully.* (participant 1)

> *One of the difficulties when compiling STEM learning modules was linking the four aspect STEM in one learning activity. When teaching STEM learning included limited implementation time, because STEM learning requires a lot of time, conditioning students during learning inadequate facilities at school.* (participant 2)

> *Takes time and mature ideas for the compiling teaching module.* (participant 3)

> *When teaching STEM students are required to think critically and creatively, not all students are accustomed tothis way of learning, so they tend to be confused or passive.* (participant 4)

Participants expressed a strong pedagogical commitment to using STEM approaches due to their contextual relevance. This supports the strong score in the previous analysis, where participants successfully embedded interdisciplinary thinking into their modules. Participants admitted difficulty integrating the four STEM disciplines, this finding especially IS and KSU, is still development and requires support during teacher education consistent with Mientus et al (2022) and Park & Oliver (2008).

CONCLUSION

The study examine the PCK STEM of pre service biology teachers through teaching module analysis, teaching simulation and interviews. The result showed strengths in designing contextual STEM learning and project based assessment on context waste management. In Integrating all STEM component, addressing student learning difficulties and delivering clear scientific explanation, it requires further support in planning and assessment.

REFERENCES

Akçay, B., & Avci, F. (2022). Development of the STEM-Pedagogical Content Knowledge Scale for Preservice Teachers: Validity and Reliability

Study. *Journal of Science Learning*, *5*(1), 79-90.

Aydin-Gunbatar, S., Ekiz-Kiran, B., & Oztay, E. S. (2020). Pre-service chemistry teachers' pedagogical content knowledge for integrated STEM development with LESMeR model. *Chemistry education research and practice*, *21*(4), 1063-1082.

Bell, D. (2016). The reality of STEM education, design and technology teachers' perceptions: A phenomenographic study. *International journal of technology and design education*, *26*, 61-79. https://doi.org/10.1007/s10798-015-9300-9

Budjay B. (2022). Evaluation of Environmental Pollution and Waste Management Strategies on the Ecosystem. *Journal of Enterprise and Bussiness Intelligence, 223-234* https://doi.org/10.53759/5181/jebi202202022

Bybee, R. (2010). Advancing STEM education: a 2020 vision. Technology and Engineering Teacher, 70(1), 30–35.

Cain, C. R., & Graves, S. B. (2018). *Biology Teacher Preparation and PCK: Perspectives from the Discipline.* (pp. 133–144). Springer, Cham. https://doi.org/10.1007/978-3-319-97475-0_7

Correia, M., & Baptista, M. (2022) mSupporting the development of pre-service primary teachers PCK and CK through a STEM program. *Education Sciences*, , *12*(4), 258. https://doi.org/10.3390/educsci12040258

Epstein, D., & Miller, R. T. (2011). Slow off the mark: Elementary school teachers and the crisis in science, technology, engineering, and math education. *Education Digest: Essential Readings Condensed for Quick Review*, *77*(1), 4–10. https://files.eric.ed.gov/fulltext/ED536070.pdf

Furtak, E. M., Kiemer, K., Kizil Circi, R., Swanson, R. D., de León, V., D Morrison, D., & Heredia, S. C. (2016). Teachers' Formative Assessment Abilities and Their Relationship to Student Learning: Findings from a Four-Year Intervention Study. *Instructional Science*, *44*(3), 267–291. https://doi.org/10.1007/S11251-016-9371-3

Grancharova, D. Innovating STEM education: Teacher reflections on challenges, strategies, and development. (2024). *International Journal of Emerging Trends in Social Sciences*, *17*(2), 37–45. https://doi.org/10.55217/103.v17i2.836.

Herro, D., & Quigley, C. (2017). Exploring teachers' perceptions of STEAM teaching through professional development: implications for teacher educators. *Professional Development in Education*, *43*(3), 416-438. https://doi.org/10.1080/19415257.2016.1205507

Kalaian, S. A. (2017). *Pedagogical Approaches for the 21st Century Student-Driven Learning in STEM Classrooms.* (pp. 72–86). IGI Global. https://doi.org/10.4018/978-1-5225-1689-7.CH006

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM education*, *3*, 1-11.

Khajeloo, M., Birt, J. A., Kenderes, E. M., Siegel, M. A., Nguyen, H., Ngo, L. T., Mordhorst, B. R., & Cummings, K. (2021). Challenges and Accomplishments of Practicing Formative Assessment: a Case Study of College Biology Instructors' Classrooms. *International Journal of Science and Mathematics. Education.* 2021. 1–18. https://doi.org/10.1007/S10763-020-10149-8

Klabukov, I., & Baranovskii, D. (20230. The Engineering Biology Problems Book: Bridging the gap between biomedicine and engineering. *Biomedical Research and Therapy*, *10*(8), 5801–5803. https://doi.org/10.15419/bmrat.v10i8.821

Lesseig, K., Nelson, T. H., Slavit, D., & Seidel, R. A. (2016). Supporting middle school teachers' implementation of STEM design challenges. *School Science and Mathematics. 116* (4), 177-188. https://doi.org/10.1111/ssm.12172

Ling, L, S., Pang, V., & Lajium, D. (2020*).* A Case study of teachers' pedagogical content knowledge in the implementation of integrated STEM education. *Jurnal Pendidikan Sains & Matematik Malaysia*. *10* (1), 49–64. https://doi.org/10.37134/jpsmm.vol10.1.6.2020

Loseñara, J. M., & Jugar, R. R. (2023). Technological, Pedagogical, and Content Knowledge of Diploma in Professional Education Graduates Teaching Biology. *Journal of Biological Education Indonesia (Jurnal Pendidikan Biologi Indonesia)*, *9*(1), 1-14. https://eric.ed.gov/?id=EJ1386953

Loughran, J. (2014). *Developing Understanding of Practice: Science Teachers' Professional Learning.* DOI:10.1007/978-94-6091-821-6

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-132). Dordrecht: Springer Netherlands.

Marzuki, O. F., Teo, E. Y. L., Zainol Abdullah, W. N. Z., Khairuddin, N., Inai, N. H., Md Saad, J., & Abdul Aziz, M. H. (2024) Innovating Education: A Comprehensive Review of STEM Education Approaches. *International Journal of Academic Research in Progressive Education and Development*. https://doi.org/10.6007/ijarped/v13-i1/20490

Menon, D., Wieselmann, J. R., Haines, S., & Asim, S. (2024). A Meta-Synthesis of the Literature on Science & Engineering Teaching Self-Efficacy: Current Gaps and Future Research Directions. *Journal of Science Teacher Education*.. https://doi.org/10.1080/1046560x.2023.2297499

Mientus, L., Hume, A., Wulff, P., Meiners, A., & Borowski, A. (2022). Modelling STEM teachers' pedagogical content knowledge in the framework of the refined consensus model: A systematic literature review. *Education Sciences*, *12*(6), 385.

Mukholifah, M., Dafik, D., & Suroyo, S. (2023). Framework of Problem-Based Learning Activities with STEM Approach: Utilizing Plastic Waste with Ecobrick Method in Improving Students' Ecological Literacy to Solve Environmental Problems*International Journal of Current Science Research and Review, 06 (04)*. https://doi.org/10.47191/ijcsrr/v6-i4-46

Murray, J,. (2019). Routes to STEM: nurturing Science, Technology, Engineering and Mathematics in early years education. *International Journal of Early Years Education.*. https://doi.org/10.1080/09669760.2019.1653508

Nicol, C. B. (2021). An Overview of Inquiry-Based Science Instruction Amid Challenges. *Eurasia Journal of Mathematics, Science and Technology Education*, 17(12). https://doi.org/10.29333/EJMSTE/11350

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in science Education*, *38*, 261-284.

Ping, He. Stem Education and Engineering Education in 21st Century. Reality and Perspectives. (2021). *Social Science Research Network,*. *doi: 10.2139/SSRN.3763043.*

Rahmania, I. (2021). *Project Based Learning (PjBL) Learning Model with STEM Approach in Natural Science Learning for the 21st Century*. *4* (1), 1161–1167. https://doi.org/10.33258/BIRCI.V4I1.1727

Ring, E. A., Dare, E. A., Crotty, E. A., & Roehrig, G. H. The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *Journal of Science Teacher Education.* 2017 *28*(5), 444-467.https://doi.org/10.1080/1046560X.2017.1356671

Sánchez Lopera, H. A., España Rodríguez, J., & Mosquera Laverde, W. E. (2024). Analysis of the Development of Environmental Culture and Mathematical Skills for Solid Waste Management in Schools. *RGSA*. https://doi.org/10.24857/rgsa.v18n3-149

Sahin-Topalcengiz, E., & Yıldırım, B. (2019). The development and validation of Turkish version of the elementary teachers' efficacy and attitudes towards STEM (ET-STEM) scale. *Journal of Education in Science Environment and Health*, *5*(1), 12-35.

Shahali, E. H. M., Halim, L., Rasul, M. S., Osman, K., & Zulkifeli, M. A. (2016). STEM learning through engineering design: Impact on middle secondary students' interest towards STEM. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(5), 1189-1211. https://doi.org/10.12973/eurasia.2017.00667a

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard educational review*, *57*(1), 1-23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Siglos, D. G. (2022). *The Incorporation of and Engangement in Engineering Design in High School Biology.* https://doi.org/10.30707/etd2022.20221020070313155277.999977

Singh, K. N. (2024). Promoting Creativity and Collaboration: Innovative Interdisciplinary Aproaches to Enhance STEM Education and Critical Thinking in Students., *03*(09), 546–551. https://doi.org/10.70333/ijeks-03-09-004

Stehle, S. M., & Peters-Burton, E. E. (2019) Developing student 21 st Century skills in selected exemplary inclusive STEM high schools. *International Journal of STEM education. 6*, 1-15. https://doi.org/10.1186/s40594-019-0192-1

Stracke, C. M., Van Dijk, G., Daneniene, J., Kelmelyte, V., Lisdat, F., Wesolowski, A., & Spatafora, A. (2019). Learn STEM: the pedagogical model for innovative STEM learning and teaching. https://research.ou.nl/ws/portalfiles/portal/12166843/20190301_Learn_STEM_Pedagogical_Model_v10.pdf

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A.,& Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1), 2. https://eric.ed.gov/?id=EJ1178347

Veen, J. (2023). Capturing Pedagogical Design Capacity of STEM Teacher Candidates: Education for Sustainable Development through Socioscientific Issues. *Sustainability*. https://doi.org/10.3390/su151411055

Vicario, E. F., Ortiz, R., Owusu, K. A., Feldman, A., Ghebremichael, K., & Ergas, S. J. (2024). Engaging Students in Waste-to-Energy Research Using Model Biodigesters. *The Science Teacher*. https://doi.org/10.1080/00368555.2023.2292331

Windyariani, S., & Setiono, S. Performance Assessment Creative Thinking Rubric in Science Technology Engineering and Mathematics (STEM) Learning. *Journal of Innovative Science Education*, 2024. *13*(2), 64-73 https://doi.org/10.15294/jise.v13i2.4218

York, M. K. (2018). STEM content and pedagogy are not integrated. *Grand Challenges White Papers*. https://grandchallenges.100kin10.org/assets/downloads/stem-content-and-pedagogy-are-not-integrated/GrandChallengesWhitePapers_York.pdf

Zein, L. S. H., **Setiono, S.,** & **Windyariani**, S. (2022). Pengaruh Pendekatan STEMA Terhadap Kemampuan Berpikir Kreatif Peserta Didik Kelas VIII SMP Pada Materi Sistem Pencernaan:(The Effect of STEMA Approach on Creative Thinking Ability of 8th Grade Junior High School Students on Digestive System Material). *Biodik*, *8* (2), 90-102. https://doi.org/10.22437/bio.v8i2.16990

Zhan, X., Sun, D., Wan, Z. H., Hua, Y., & Xu, R. (2021). Investigating Teacher Perceptions of Integrating Engineering into Science Education in Mainland China. *International Journal of Science and Mathematics Education, 19*(7), 1397–1420. https://doi.org/10.1007/S10763-020-10117-2