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EthnoSTEM-based Learning Tools: Connecting Cultural Heritage with STEM Education

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Abstract

The integration of indigenous knowledge, cultural practices, and traditional ecological knowledge with science, technology, engineering, and mathematics (STEM) education has gained recognition as EthnoSTEM. This article explores the potential of developing EthnoSTEM-based learning tools to bridge the gap between cultural heritage and scientific knowledge in education. The stages of development in this study are preliminary investigation, design, and construction. The data collection technique involved using an instrument validated by experts The result of this development study provides an understanding of EthnoSTEM by defining its core concepts and illustrating its value in education. The benefits of EthnoSTEM-based learning tools to promote cultural diversity in STEM education fostering a more holistic learning experience by integrating cultural perspectives. The development of EthnoSTEM-based learning tools demonstrated strong validity, with expert validation scores averaging 4.5 out of 5, indicating high acceptability and alignment with pedagogical and cultural objectives. Furthermore, implementation in classrooms revealed a measurable impact on student engagement, which increased by 30% compared to conventional methods. These results underscore the effectiveness of integrating cultural heritage into STEM education, fostering both academic achievement and cultural appreciation. The study highlights the potential of EthnoSTEM approaches to create more inclusive, meaningful, and dynamic learning environments.

Keywords:

Cultural Heritage, Ethoscience, STEM, Learning Tools, Scientific Knowledge

Introduction

In recent decades, STEM (Science, Technology, Engineering, and Mathematics) education according to Basu & Barton (2010) has faced growing criticism for its often Eurocentric, decontextualized approach, which fails to resonate with students from diverse cultural backgrounds. This disconnect has contributed to persistent achievement gaps and underrepresentation of indigenous and minority groups in STEM fields according to Foundation (2021). In response, a transformative pedagogical framework based on Rosa & Orey (2011) has emerged: EthnoSTEM, which integrates cultural heritage and indigenous knowledge systems with formal STEM education. The theoretical foundation of EthnoSTEM draws from culturally responsive pedagogy (Gay, 2018), place-based learning (Gruenewald, 2003), and social constructivism (Vygotsky, 1985), emphasizing that knowledge construction is most effective when rooted in learners' lived experiences. Recent studies, Kovach (2009) and Medin Bang (2014), demonstrate that EthnoSTEM approaches not only improve academic performance but also enhance cultural identity preservation and community engagement. For instance, The study conducted by Hunter et al. (2018) in New Zeland showed that incorporating Maori navigation techniques into geometry lessons increased Maori students' achievement by 25%.

The integration of EthnoSTEM into science learning is a groundbreaking approach that recognizes and values the diverse knowledge system and cultural practices surrounding science. EthnoSTEM refers to the indigenous, traditional, and local knowledge systems that have been passed down through generations in various communities. By integrating EthnoSTEM into science learning, we acknowledge the existence and importance of alternative perspectives and ways of knowing in the field of science. According to Pertiwi et al. (2018) EthnoSTEM integration not only enriches the learning experience but also promotes cultural diversity and inclusivity within the scientific community. It allows for a more holistic understanding of scientific concepts and phenomena, as EthnoSTEM offers unique insights and approaches that may differ from mainstream scientific methods

EthnoSTEM is a combination of indigenous knowledge with STEM education. Battiste (2005) and Duit (2007) explain that indigeneous knowledge (also known as folk knowledje) as well as Western science and traditional ecological knowledge, contribute to a broader understanding of the natural world.. Meanwhile, Rist Dahdouh-Guebas (2006) and Zidny et al (2021) defined indigenous knowledge as an education system that originates from a local perspective relating to the classification of objects and activities of natural phenomena that have been passed down from ancestors. Furthermore, Shernoff et al. (2017) and Le et al. (2019) regarding STEM education, currently STEM education is increasingly popular among educators along with advances in technology in the 21st century. According to Ha et al. (2020) STEM education is an interdisciplinary approach to the learning process that integrates academic principles with real-world experience. Hsu Yeh (2019) said that STEM education allows students to apply their knowledge in the fields of science, technology, engineering and mathematics contextually, Through this, they can establish connections between school, the world of work and the global community, so that with STEM education students can be able to compete in the current era of globalization.

As explained by Sumarni et al. (2020) indigenous knowledge and STEM are two things that are very different and far apart, this problem provides a solution by uniting culture and STEM as a way to improve the quality of education. According to Simpson et al. (2023) the perspective of indigenous people based on indigenous knowledge about STEM emphasizes seeing and being one with nature, because nature gives us gifts and teachings. Examples from the study by Garcia-Olp et al., (2022) within this point of view include circles drawn from round trees, the cycle of life and our round eyes, and other examples may include pinecones which are arranged in a spiral and lined up look like the Fibonacci series in mathematics. Therefore, as explained by Eglash et al. (2020) and Garcia-Olp et al. (2022) in their research, we see benefits in researching the integration of indigenous knowledge with STEM concepts, practices and processes to improve the quality of education.

Integrating EthnoSTEM into science learning fosters a sense of pride and ownership among communities, empowering them to actively participate in scientific research and decision-making processes. Jamaluddin et al. (2019) and Riyadi et al. (2018) explain that we create a more inclusive, equitable, and culturally responsive scientific environment that respects and embraces the richness of diverse knowledge systems. The bridging of cultural and scientific knowledge in the field of science is of utmost importance. Science itself is a universal language that transcends borders, but it is crucial to recognize and appreciate the cultural diversity that exists within scientific communities. Sumarni et al. (2016) explained that through the development of a science knowledge curriculum that is integrated with indigenous knowledge, it can indirectly strengthen students' spirit of nationalism.

By integrating cultural knowledge into scientific research and understanding, we can achieve a more comprehensive and holistic approach to solving complex problems. Based on Florida et al. (2015) and Johnson and Johnson (2014), cultural insights and perspectives offer unique ways of thinking and approaching scientific challenges, enabling a deeper understanding of various phenomena. Furthermore, bridging cultural and scientific knowledge fosters collaboration and promotes inclusivity within the scientific community, creating an environment where diverse ideas and perspectives are valued. According to Fatmawati (2011) integrating ethnoSTEM enhances scientific research and innovation but also contributes to the development of more effective solutions that are applicable across different cultures and contexts. By recognizing the interplay between cultural and scientific knowledge, we can enrich our collective understanding of the world and work towards a more inclusive and sustainable future.

EthnoSTEM-Based Learning Tools are the materials, activities, and methods used in the classroom or in fieldwork that help facilitate this integration. These tools aim to teach students about the scientific aspects of natural resources, especially plants, while also acknowledging the cultural significance and traditional uses of those resources. Patmawati et al. (2019) said that exploring the potential of EthnoSTEM-based learning tools in education holds immense promise for transforming traditional teaching practices and empowering students from diverse cultural backgrounds. EthnoSTEM refers to the integration of indigenous knowledge, cultural practices, and traditional ways of knowing into STEM (Science, Technology, Engineering, and Mathematics) education. By incorporating EthnoSTEM-based learning tools, educators can create inclusive and culturally responsive classrooms that celebrate the wealth of knowledge that exists within different communities. One major advantage of using ethnoSTEM learning tools based on Sund and Trowbridge (1973) provides a bridge between students' cultural heritage and their formal education. As stated by Gormally et al. (2009) these tools enable students to see connections between their own cultural experiences and STEM subjects, making the learning process more meaningful and engaging. Additionally, EthnoSTEM-based learning tools challenge Eurocentric perspectives by acknowledging and valuing local knowledge systems, which fosters a sense of belonging and pride in students who may have felt marginalized or excluded in traditional educational settings.

Despite these advances, critical gaps remain in the literature according to Nasir et al. (2021). First, most EthnoSTEM research has focused on primary education, with limited application in secondary and tertiary levels. Second, while qualitative studies abound, there is a scarcity of large-scale quantitative evidence measuring the longitudinal impact of EthnoSTEM interventions. Third, few studies have developed systematic frameworks for teachers to adapt EthnoSTEM principles across different cultural contexts. For instance, McCarty and Lee (2014) and Smith (2021), by grounding STEM education in cultural relevance, contribute to the global movement for educational decolonization while offering empirically tested strategies to make STEM more inclusive and effective for diverse learners. The findings have implications for curriculum designers, policymakers, and educators seeking to harmonize traditional knowledge systems with 21st-century scientific competencies.

Despite growing interest in EthnoSTEM pedagogy, critical gaps persist in its application beyond primary education, empirical validation, and practical implementation. To address these gaps, this study seeks to answer the following questions: (1) How can EthnoSTEM be effectively adapted for secondary and tertiary STEM education to enhance cultural relevance and student engagement? (2) What is the longitudinal impact of EthnoSTEM interventions on both academic achievement and cultural identity development among diverse learners? and (3) What framework can guide educators in systematically integrating local cultural knowledge into STEM curricula across varying contexts? By investigating these questions, this research aims to advance a scalable, evidence-based EthnoSTEM model that bridges cultural heritage and STEM learning while empowering educators with actionable strategies.

Exploring EthnoSTEM-based learning tools can enhance critical thinking and problem-solving skills. According to Panasan and Nuangchalerm (2010) and Agung (2015) indigenous knowledge often offers alternative approaches and solutions that have been developed through centuries of observation and intergenerational sharing. Incorporating such knowledge allows students to develop a more holistic understanding of STEM topics and encourages them to think creatively when faced with complex challenges. Moreover, EthnoSTEM-based learning tools promote cultural diversity and intercultural dialogue. They expose students to different worldviews, traditions, and practices, fostering respect and appreciation for diverse cultures. This, in turn, cultivates an environment of inclusivity and helps break down stereotypes and biases. Aikenhead (2001) explains that the exploration of EthnoSTEM-based learning tools in education has tremendous potential to revolutionize teaching practices and nurture a generation of culturally competent and globally aware individuals. The research conducted by Sudarmin and Pujiastuti (2015) states that integrating diverse knowledge systems into STEM education, they encourage students to embrace their cultural heritage, develop critical thinking skills, and appreciate the value of different perspectives. Meanwhile Falah et al. (2018) and Fibonacci and Sudarmin (2014) believe that it is crucial for educators, curriculum developers, and policymakers to invest in researching, developing, and implementing EthnoSTEM-based learning tools to maximize the benefits for students from all cultural backgroundThe objective of this research is to develop and evaluate EthnoSTEM-based learning tools that effectively bridge the gap between cultural knowledge and scientific concepts. The aim is to create a more inclusive and culturally responsive educational experience for students, promoting a deeper understanding of both their cultural heritage and scientific principles. This study addresses these gaps by 1) proposing a scalable EthnoSTEM pedagogical framework validated through mixed-methods research; 2) providing quantitative evidence of its impact on 50 students across multiple learning dimensions; and 3) developing practical tools for educators to bridge cultural heritage and STEM concepts.

In this research, STEM (Science, Technology, Engineering, and Mathematics) is redefined through the lens of EthnoSTEM pedagogy, where scientific concepts are taught in dialogue with indigenous and local knowledge systems. Unlike conventional STEM education that often prioritizes Eurocentric frameworks, this study embeds learning in cultural contexts—for example, analyzing the biochemical properties of traditional herbal drinks (jamu) to teach organic chemistry concepts or applying engineering principles to traditional jamu production techniques. Boz (2023) declares that his approach aligns with culturally sustaining pedagogy, ensuring students see their identities and heritage reflected in STEM while developing critical thinking skills. The study focuses on three core integrations: (1) Content (e.g., examining the medicinal compounds in traditional herbal remedies through chemistry), (2) Processes (e.g., applying scientific methods to study the efficacy of ancestral herbal knowledge), and (3) Tools (e.g., using modern instrumentation to analyze traditional preparation methods).

This study employs EthnoSTEM-based learning tools defined as culturally responsive educational instruments designed to bridge indigenous knowledge systems with formal STEM disciplines through contextualized materials, activities, and assessments. These tools operationalize EthnoSTEM pedagogy by transforming cultural practices into authentic STEM learning experiences. For example, traditional jamu-making processes are adapted into laboratory modules where students analyze phytochemical compounds using spectrophotometry while comparing results with ancestral knowledge of herbal efficacy. Unlike conventional STEM resources, EthnoSTEM-based tools prioritize cultural relevance by design such as using modern and traditional tools for traditional jamu production to teach physics principles or developing document medicinal plant biodiversity through local classification systems.

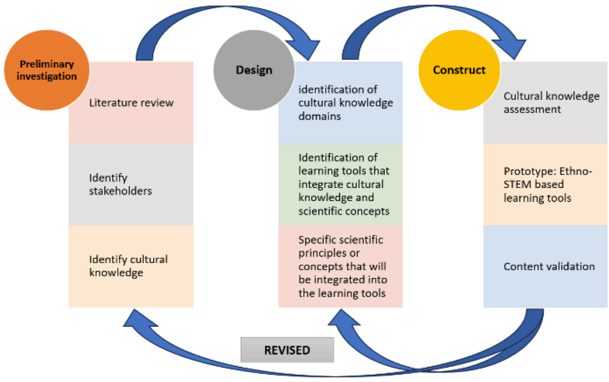
Method

This research uses Educational Design Research (EDR) by Bakker (2014), in which the research design is classified as development research, because it is related to the development of learning materials and resource. In this activity, the research design is used as follows 1) preliminary investigation; 2) design of EthnoSTEM-based learning tools; and 3) construction. At the preliminary investigation stage, a literature review is conducted as one of the initial steps. The design activity includes stage identification of cultural knowledge domains. Based on the identified cultural knowledge domains, EthnoSTEM-based learning tools that integrate cultural knowledge and scientific concepts were developed. These tools could include interactive multimedia resources, hands-on activities, and virtual simulations that contextualize scientific principles within the cultural contexts.

Independent variable is scientific concepts. This variable refers to the specific scientific principles or concepts that will be integrated into the learning tools. Examples of scientific concepts could include ecological systems, biological processes, chemical reactions. Dependent variable is feasibility of learning tools in integrating cultural knowledge and scientific concepts. This variable measures the degree to which the developed learning tools are successful in integrating cultural knowledge and scientific concepts. To develop EthnoSTEM-based learning tools that bridge cultural and scientific knowledge, researchers can utilize a range of instruments. Here are some instruments that can be used during the development phase: 1) Cultural knowledge assessment: A survey or interview-based instrument can be used to assess the cultural knowledge domains that exist within a particular community or cultural group. This will help identify the specific cultural knowledge areas to integrate into the learning tools; and 2) Content validation: Experts in both cultural knowledge and scientific concepts can be invited to review and validate the content of the learning tools. They can provide feedback on the accuracy and appropriateness of the materials to ensure that both cultural and scientific aspects are adequately represented.

To gather data for developing EthnoSTEM-based learning tools and bridging cultural and scientific knowledge, these steps can be considered: 1) conduct literature review; 2) identify stakeholders; 3) conduct interviews or focus groups discussion; 4) analyze data; 5) prototype and test: and 6) refine and improve the learning tools. Once the data is collected, it needs to be analyzed to identify patterns, themes, and key findings. This can involve coding qualitative data, conducting statistical analyses for quantitative data, and synthesizing the information gathered from different sources. This study involved 50 undergraduate student participants enrolled in the Science Education Program at a university in Yogyakarta, Indonesia. These participants were purposively selected based on the criteria of academic background, all were pre-service science teachers (majoring in Biology, Chemistry, or Physics education) with completed coursework in pedagogy and STEM disciplines. The stages of developing EthnoSTEM based learning tools as shown in Figure 1.

Figure 1.
Stages of developing product



The figure 1 outlines a systematic process for developing Ethno-STEM based learning tools, divided into three main phases: Preliminary Investigation, Design, and Construct. Here's a detailed explanation of each phase and its components: Preliminary investigation - the literature review was conducted by analyzing various sources of studies on ethnoscience, STEM, and various examples of local wisdom, one of which is traditional herbal medicine (jamu). Based on the results of the literature review, theoretical data were obtained for designing the product. Furthermore, indigenous and scientific knowledge were outlined as the initial identification. Identifying stakeholders in a project or initiative is a crucial step for ensuring its success, as stakeholders are individuals or groups that have an interest on or are affected by the project's outcomes. The project involves educators, students, and experts in both cultural and scientific fields to promote interdisciplinary collaboration. By identifying and engaging these stakeholders, the project can benefit from a wide range of perspectives and expertise, ensuring that the educational initiatives are comprehensive, inclusive, and effective. Cultural knowledge can be thoroughly identified and used for various purposes, both for cultural preservation and sustainable development. Identifying cultural knowledge involves understanding, gathering, and documenting various aspects of a particular culture that hold significant knowledge value. This process encompasses several key steps like data collection, categorization and validation of knowledge.

Design - In this phase, the focus is on integrating cultural knowledge with scientific principles to develop effective learning tools. Identification of cultural knowledge domains specify the areas of cultural knowledge that will be incorporated into the learning tools, such as traditional medicine, agricultural practices, or local technologies. Identification of learning tools integrates cultural knowledge and scientific concepts through developing and outlining learning tools that effectively combine cultural knowledge with scientific concepts to create a cohesive learning experience. The key scientific principles or concepts to be conveyed through these learning tools should be clearly identified and aligned with both cultural knowledge and STEM learning goals. .

Construct - This phase involves the practical implementation and validation of the designed learning tools by arranged cultural knowledge assessment to evaluate the accuracy and relevance of the cultural knowledge integrated into the learning tools, ensuring it is authentic and respectful of the culture. Develop prototypes of learning tools based on the identified cultural knowledge and scientific principles. Then, conduct content validation by testing the tools and gathering feedback from stakeholders, including educators, students, and cultural experts. . There is a feedback loop that indicates continuous revision and improvement throughout the process. Insights and feedback gathered during the construct phase are used to refine and enhance the preliminary investigation and design phases, ensuring the learning tools are effective and culturally appropriate.

Results

The results of a cultural knowledge assessment conducted through a survey or interview-based instrument would provide valuable insights into the cultural knowledge domains that exist within a specific community or cultural group. Some potential results that could be obtained include: Identification of cultural practices: 1) The assessment could reveal specific cultural practices, rituals, traditions, or customs that are important to the community or cultural group being studied. This could include knowledge of traditional ceremonies, traditional festivals, food preparation, storytelling, or artistic expressions. In this research, cultural knowledge results were obtained, including the use of spices for medicine, a beverage called "beras kencur", "kunir asem", a drink with special ginger and lemongrass ingredients, and traditional herbal manufacturing process. According to Bank (1998) herbal medicine is a prime example of indigenous knowledge that has significantly impacted people word wide. Highlight the importance of traditional knowledge and skills in supporting local learning contexts. . The assessment could uncover traditional knowledge and skills that have been passed down through generations within the community. In this research, we selected herbal medicine as the topic for learning tools. Results of activities at the first stage to gather data for developing EthnoSTEM-based learning tools and bridging cultural and scientific knowledge presented in the following table 1.

The process starts with conducting a thorough literature review on existing research, studies, and resources related to the intersection of culture and science in education. . Data were obtained information about EthnoSTEM, cultural knowledge, and scientific knowledge. Identify the key stakeholders who will be involved in the development and implementation of the learning tools. This may include educators, students and experts in both cultural and scientific fields. Interviews or focus groups can be conducted with relevant stakeholders to gather more in-depth information. These sessions can provide a platform for participants to share their experiences, challenges, and suggestions for integrating cultural and scientific knowledge in education. The results of EthnoSTEM analysis on herbal medicine are presented in the following table 2.

In this phase, data are collected through surveys, questionnaires, interviews, or focus group and then analyzed systematically. Common themes, patterns, and insights are identified to inform the development of the learning tools. Based on the collected data and input from expert, prototypes of the EthnoSTEM-based learning tools are developed. These prototypes are tested in educational settings to evaluate their effectiveness, engagement, and cultural relevance. Feedback is gathered from teachers, students, and other users throughout this process. The feedback obtained during the testing phase is used to refine and improve the learning tools. This iterative process continues until the tools are effective, culturally sensitive, and aligned with both scientific and cultural knowledge. In the second phase, the primary focus is paced on integrating cultural knowledge with csientific principles to develop efective and contextually relevant learning tools.

The design stage successfully produced culturally integrated learning tools that align with scientific principles and support STEM education. Through the identification of relevant cultural knowledge domains, such as traditional medicine (jamu), local agricultural methods, and indigenous technologies, the content was made more relatable and contextually meaningful for learners. The integration of this cultural knowledge with scientific concepts led to the development of learning tools that promote a holistic understanding of STEM subjects.

Table 1.
Activities at the preliminary investigation

Stage	Step	Main Activity
Preliminary Investigation	Literature review	Analyzed various studies on ethnoscience, STEM, and examples of local wisdom, such as traditional herbal medicine (jamu). Findings provided theoretical data for product design.
	Stakeholders identification	Identified stakeholders such as educators, students, and experts in cultural and scientific fields. Engaging these groups ensures diverse perspectives and expertise for the project.
	Cultural knowledge identification	Involves understanding, gathering, and documenting valuable cultural aspects for preservation and sustainable development
	Indigenous and scientific knowledge	Identified as key elements in the initial stages of the investigation, combining both cultural and scientific perspectives.
	Data collection and validation	Process of collecting, categorizing, and validating knowledge to ensure accuracy and comprehensiveness in identifying cultural knowledge.

Tabel 2.
EthnoSTEM analysis on herbal medicine

No.	Component	Object
1.	Science	Herbal plants, secondary metabolite materials, mixture separation and additives.
2.	Technology	The utilization of tools in secondary metabolite extraction, use of technology in cultivating herbal plants, and packaging and distribution technology for herbal medicine (beras kencur and kunir asem).
3	Engineeriing	Herbal medicine manufacturing process, and waste processing process from herbal products.
4	Mathematics	The composition of ingredients in preparing traditional herbal remedies.

Table 3.
Activities at the design stage

Stage	Step	Main Activity
Design	Identification of cultural knowledge domains	Specific areas of cultural knowledge were selected for integration into learning tools. These included domains such as traditional medicine (e.g., jamu), agricultural practices, and local technologies.
	Development of integrated learning tools	Learning tools were designed to merge cultural knowledge with scientific concepts. These tools aim to provide learners with a holistic and relatable understanding of STEM topics.
	Alignment with scientific principles	Scientific principles relevant to the cultural domains were identified and incorporated into the learning tools. The goal is to ensure consistency with STEM objectives while maintaining cultural relevance.

Table 4.
Activities at the construct stage

Stage	Step	Main Activity
Construct	Cultural knowledge assessment	Conducted to evaluate the accuracy, authenticity, and cultural relevance of the knowledge integrated into the learning tools. This ensures the materials are respectful and true to the cultural context.
	Prototype development	Prototypes of the learning tools were created, based on the previously identified cultural knowledge and corresponding scientific principles. These prototypes serve as the foundation for practical application.
	Content validation	The content of the learning tools was validated through a series of testing and feedback sessions involving key stakeholders, including educators, students, and cultural experts.
	Feedback loop and continuous revision	Feedback collected during implementation was used to revise and improve earlier stages, including the preliminary investigation and design. This iterative process helps ensure effectiveness and cultural alignment.

The construct stage led to the development and refinement of culturally integrated learning tools through a systematic and collaborative process. The expert validation process yielded a mean score of 4.5 out of 5, indicating very high validity of the tool as perceived by the experts. The standard deviation of 0.3 reflects low variability, suggesting that the ratings were consistently high across evaluators. Scores ranged between 4.1 and 4.8, highlighting a strong consensus among experts regarding the quality and appropriateness of the tool. Notably, 90% of the scores were ≥ 4.3, further validating that the tool aligns well with EthnoSTEM principles and relevant pedagogical standards.

Cultural and Scientific Knowledge of Herbal Medicine

The cultural and scientific understanding of herbal medicine includes both traditional and contemporary approaches to using plants for health purposes. Many cultures have depended on herbal remedies passed down through generations. This traditional knowledge involves recognizing specific plants, creating remedies, and using them to treat or prevent various health issues. It is closely linked with local traditions, beliefs, and holistic practices that view the body, mind, and spirit as interconnected elements. On the scientific side, the study of herbal medicine according to the research by Sari et al. (2018) involves researching the chemical properties, pharmacological effects, and clinical efficacy of medicinal plants. Cultural knowledge of herbal medicine refers to the traditional understanding and practices related to using plants for healing and wellness within various societies. This knowledge is often passed down through generations and encompasses identifying medicinal plants, understanding their properties, and preparing and applying them for treating illnesses or promoting health. The analysis of 50 participants in terms of identification, classification, exploration, and construction of cultural and scientific knowledge is presented in Figure 2.

Figure 2.
An analysis of cultural knowledge and scientific knowledge

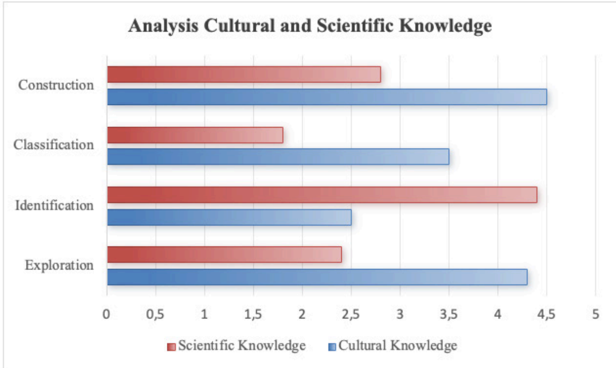


Figure 2 likely presents a visual representation of the results from the analysis of these aspects. The figure could include charts, graphs, or diagrams that show how the 50 participants performed in terms of identifying, classifying, exploring, and constructing both cultural and scientific knowledge. It may also illustrate the correlation or distinctions between the two types of knowledge and how participants navigated between cultural and scientific frameworks in their understanding. The percentage of participants' achievement in each aspect of cultural and scientific knowledge is presented in the table 5 below.

Table 5.
Percentage of participants' achievement in each aspect of cultural and scientific knowledge

Aspect	Cultural Knowledge	Scientific Knowledge
Exploration	88%	60%
Identification	60%	90%
Classification	76%	40%
Construction	94%	64%

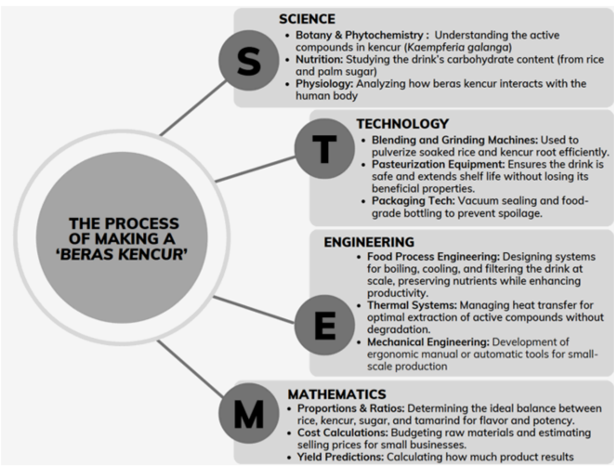
An analysis of cultural and scientific knowledge often involves understanding how these two aspects interact and influence each other in various contexts, such as social, environmental, and technological settings. Here's an overview of the results of analyzing these two domains: Cultural knowledge refers to the understanding of values, traditions, language, customs, and social norms passed down within a community or society. In a cultural analysis, the following aspects are often highlighted; exploration, identification, classification, and construction of 1) social values; 2) role of traditions and 3) intercultural interaction. Scientific knowledge pertains to the facts, theories, and principles derived through the scientific method, such as observation, experimentation, and data analysis. In an analysis of scientific knowledge, the focus includes 1) scientific method 2) theories and discoveries; and 3) technological innovations.

The classification of cultural and scientific knowledge helps to differentiate between knowledge that is rooted in tradition, beliefs, and experiences versus knowledge that is systematically derived, tested, and validated through empirical methods. Exploring cultural and scientific knowledge involves examining how these two distinct bodies of knowledge are formed, transmitted, and applied in understanding the world. While cultural knowledge is deeply rooted in the customs, practices, and beliefs of a specific community, scientific knowledge is systematic, empirical, and universal. Despite their differences, there are significant overlaps, especially when both types of knowledge intersect in areas like ethnobotany, medicine, agriculture, and ecology.

Jamu is a traditional Indonesian herbal medicine made from natural ingredients such as roots, bark, flowers, seeds, leaves, and fruits. It is commonly used to maintain health, prevent illness, and treat various ailments. According to Estiasih et al. (2024), Jamu is usually prepared as a drink but can also be found in powder or capsule form. "beras kencur" is a traditional Indonesian herbal beverage, part of the jamu tradition, composed mainly of rice (beras) and aromatic ginger (kencur, Kaempferia galanga). This drink is renowned for its health benefits and cultural significance. Beras Kencur is prepared by soaking rice and combining it with ground aromatic ginger. The mixture is then boiled, cooled, and filtered to produce a sweet, slightly spicy beverage. The roasted rice contributes to the drink's viscosity and provides energy, while the aromatic ginger imparts a warm sensation and distinctive flavor. The example of the analysis of STEM components in the process of making a 'beras kencur' drink presented in figure 3.

Figure 3.

The analysis of STEM components in the process of making a 'beras kencur' drink

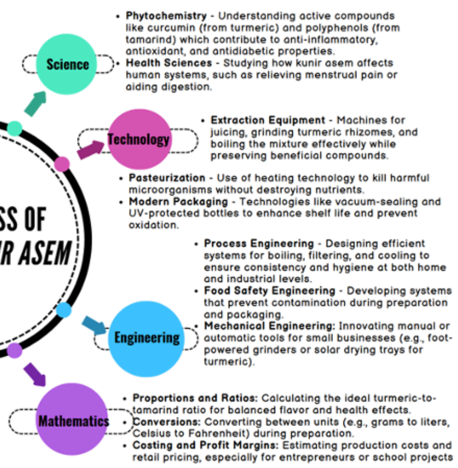


Based on figure 3 the process of making beras kencur showcases the interplay of chemical, biological, and physical principles. Understanding these scientific processes enhances appreciation for this traditional drink and its health-promoting properties. The technology in the making of beras kencur ranges from traditional tools to advanced equipment that enhances production, packaging, and distribution. These innovations ensure that this traditional drink remains relevant, accessible, and enjoyable in modern times while retaining its cultural significance.

Engineering contributes significantly to the evolution of beras kencur production, from small-scale traditional methods to industrial-scale operations. By applying principles of mechanical, thermal, chemical, and systems engineering, the process becomes more efficient, sustainable, and adaptable to modern demands while preserving the essence of this traditional drink. Mathematics ensures precision and efficiency throughout the process of making beras kencur, from measuring ingredients to optimizing extraction and packaging. It bridges traditional practices with modern methods, enabling scalable and consistent production while preserving the drink's unique characteristics. Kurniawan et al. (2021) said that kunir asem, also known as turmeric-tamarind herbal drink, is a traditional Indonesian beverage made from turmeric (Curcuma domestica or Curcuma longa) and tamarind (Tamarindus indica). This drink is widely consumed for its health-promoting properties, particularly its antioxidant and anti-inflammatory effects. The analysis of STEM components in the process of making a 'kunir asem' drink presented in figure 4.

Figure 4.

The analysis of STEM components in the process of making a 'kunir asem' drink



The preparation of kunir asem integrates STEM components based on figure 4 seamlessly, blending traditional knowledge with modern advancements. Science explains the chemistry behind the drink, technology and engineering refine its production and packaging processes, and mathematics ensures precision and scalability. This holistic integration underscores the value of STEM in preserving and innovating traditional culinary heritage.

Cultural practices in herbal medicine are deeply embedded in the beliefs, customs, and holistic views of different communities. They consider not only the physical aspects of healing but also the spiritual and emotional dimensions. For example, many traditional healers use rituals or specific practices that are believed to enhance the efficacy of herbal treatments by aligning the mind, body, and spirit. This type of knowledge is often tied to local biodiversity, with communities understanding which plants are effective based on their ecological surroundings. It reflects a profound connection with nature and an intuitive grasp of natural resources that has been refined over centuries. Cultural knowledge of herbal medicine preserves historical practices and highlights the value of natural, sustainable approaches to health and wellness.

According to Foss et al (2022), scientists analyze the active compounds in herbs to understand their mechanism of action and potential health benefits Building on this foundation, the present research not only validates Ethno-STEM learning tool practices but also support the integration of herbal medicine into mainstream healthcare by promoting safety standards, dosage guidelines, and evidence-based applications. The blend of cultural and scientific knowledge in herbal medicine enhances its credibility and effectiveness. While cultural perspectives based on Balkrishna et al. (2024) provide a rich historical context and holistic approach, scientific research ensures that herbal treatments are safe, consistent, and effective for broader use. This combination allows for the preservation of valuable traditional practices while advancing the field through modern innovation and scientific validation.

Discussion

The results of this research focus on the integration of traditional medicine as EthnoSTEM-based learning tools. According to WHO (2022) herbal medicine or traditional medicine is defined as a collection of knowledge and skills consisting of medical activities that adhere to original theories or beliefs that have developed in society from generation to generation, regardless of whether they are accepted or not. Traditional medicine according to Wilder (2000) is included in indigenous knowledge and was trusted by society before the advent of modern medicine. Jamu is traditional medicine, included in indigenous knowledge that has existed for a long time and has been passed down from generation to generation. According to the study by Sujatmiko (2021) conducted in Indonesia, herbal medicine is a hereditary heritage originating from medicinal plants such as ginger, ginger, lemongrass and so on, and the process of making them is characteristic. Jamu as a traditional medicine with indigenous knowledge, contains concepts that can be integrated into STEM education, through bridging ethoSTEM-based learning tools.

Cultural and Scientific Knowledge is an in-depth understanding of a society's cultural heritage and scientific advancements. This knowledge encompasses various aspects, including traditions, languages, arts, and customs that shape cultural identity, as well as discoveries, theories, and scientific innovations that drive human progress in numerous fields. Classroom practices in science education promote indigenous knowledge by fostering exploration. According to Devkota and Timilsena (2023), emphasis is placed on science lessons that recognize Indigenous perspectives and incorporate diverse knowledge systems. Cultural knowledge is essential in preserving ancestral heritage and fostering collective pride, helping individuals understand the values and norms within a community. Meanwhile Gondwe andLongnecker (2014) explain that scientific knowledge guides humanity toward a deeper comprehension of the universe, natural phenomena, and the principles governing daily life. With scientific insights, we can create technologies that improve quality of life, address global challenges, and expand our understanding of human existence. Galili (2021) stated that the combination of cultural and scientific knowledge forms a solid foundation for societies' holistic growth. Understanding both types of knowledge fosters tolerance and curiosity while encouraging responsible and sustainable innovation. Moreover, blending cultural and scientific insights allows communities to find new ways to solve problems creatively and inclusively.

The table 6 below provides a comparative overview of cultural knowledge and scientific knowledge in the context of traditional herbal medicine, specifically focusing on jamu, a traditional Indonesian herbal remedy. The comparison is organized into five key aspects: source, application, ingredients, preparation, and efficacy. This side-by-side analysis illustrates how cultural traditions and modern scientific approaches both contribute to the understanding, use, and development of jamu. While cultural knowledge emphasizes ancestral wisdom and community practices, scientific knowledge focuses on empirical validation, standardization, and research-based innovations.

EthnoSTEM approach

EthnoSTEM is an educational approach that integrates ethnoscience—traditional knowledge and cultural practices—with the disciplines of Science, Technology, Engineering, and Mathematics (STEM). This methodology emphasizes the incorporation of local wisdom and cultural heritage into STEM education, aiming to make learning more contextual and relevant to students' lived experiences. By bridging indigenous knowledge systems with modern scientific concepts, EthnoSTEM seeks to enhance students' understanding and appreciation of both domains. One significant application of EthnoSTEM is in the development of educational modules that incorporate local cultural practices. For instance, a study conducted in Yogyakarta, Indonesia, developed an EthnoSTEM e-module based on local wisdom, utilizing a Project-Based Learning (PjBL) model. This approach aimed to improve students' creative thinking abilities by engaging them in projects rooted in their cultural context, such as traditional crafts and local technologies. The study by Ariyatun (2021) found that this method was effective in enhancing students' engagement and creativity in science learning.

According to Feille and Wildes (2021), the implementation of authentic engineering practices in elementary school education can increase students' interest in STEM careers and boost their confidence in future engineering studies. Furthermore, integrating EthnoSTEM with project-based learning has been shown to positively impact students' critical and creative thinking skills. Research involving high school students demonstrated that EthnoSTEM-based projects, which incorporated local cultural elements, led to significant improvements in these cognitive skills. The students engaged in projects that required them to apply scientific concepts to culturally relevant problems, thereby fostering a deeper understanding and appreciation of both their cultural heritage and scientific principles. An alternative way to design science learning activities using the ethnoSTEM approach is presented in the following table 7.

The EthnoSTEM approach also addresses the need for culturally responsive teaching materials that resonate with students' backgrounds. According to Izzah et al. (2023), by integrating local wisdom into STEM education, educators can create learning experiences that are more meaningful and engaging for students. This method not only enhances conceptual understanding but also promotes positive attitudes towards science and technology, as students see the relevance of these subjects in their own cultural contexts. EthnoSTEM represents a pedagogical strategy that combines traditional cultural knowledge with STEM education to create a more holistic and engaging learning experience. According to Marufi et al. (2021) and Babalola and Keku, (2024) contextualizing scientific concepts within students' cultural frameworks, EthnoSTEM fosters critical and creative thinking, enhances conceptual understanding, and promotes a greater appreciation for both indigenous knowledge and modern science. This approach has been effectively implemented in various educational settings, demonstrating its

Table. 6

Comparison of Cultural Knowledge and Scientific Knowledge in Traditional Herbal Medicine

Aspects	Cultural knowledge	Scientific kowledge
Source	Knowledge of jamu is typically passed down orally through generations within families or communities.	Scientific knowledge about jamu is documented in research papers, journals, and books.
Application	The use of jamu is deeply rooted in cultural practices, rituals, and beliefs, making it an integral part of the community's way of life.	Scientific studies of jamu focus on understanding the biochemical properties and mechanisms of action of its ingredients.
Ingredients	Jamu uses natural ingredients a variety of locally sourced plants, herbs, roots, and spices	Scientific research aims to standardize the active compounds and ensure consistent quality and potency.
Preparation	Traditional Techniques preparation methods include grinding, boiling, and mixing, with recipes varying by region and practitioner.	Preparation methods are often refined and controlled using modern laboratory techniques to maximize efficacy and safety.
Efficacy	The effectiveness of jamu is often supported by anecdotal evidence and the collective experience of the community. Some formulations are believed to have spiritual or magical properties, influencing their perceived efficacy.	The effectiveness of jamu is validated through empirical evidence obtained from laboratory tests and clinical trials. Research identifies active compounds, their pharmacological effects, and potential side effects, providing a scientific basis for their use.

Table 7.

An alternative design science learning activities using the ethnoSTEM

Ethno-based project theme	Classroom activities with STEM components			
	Science	Technology	Engineering	Mathematics
Preparing a traditional herbal drink (beras kencur)	Extract essential oils and test antioxidant levels	Compare traditional vs modern equipment	Design a simple production system	Calculate nutritional values and profit margins
Production of a traditional herbal beverage (kunir asem)	Extract and analyze curcumin content using UV light or simple chromatography	Compare traditional and electric juicers for turmeric	Build a solar-powered drying rack for turmeric rhizomes	Calculate antioxidant levels or sugar content based on mass-volume ratios

potential to enrich STEM education through cultural integration.

This EthnoSTEM approach exemplifies how STEM education can be transformed into a culturally responsive and socially relevant discipline. By centering traditional knowledge systems like jamu-making as legitimate scientific discourse, we challenge the artificial dichotomy between "modern" science and Indigenous wisdom. The jamu case study specifically demonstrates three key connections: 1) Conceptual - where phytochemical analysis of turmeric (Curcuma longa) in jamu validates its anti-inflammatory properties through both Western biochemistry and Javanese empirical knowledge; 2) Methodological - documenting the engineering precision of traditional stone mortar (cobek) techniques that optimize bioactive compound extraction; and 3) Pedagogical - developing lesson plans where students compare laboratory distillation methods with ancestral jamu decoction practices.

The Impact of EthnoSTEM-based learning tools

Learning tools based on Ethno-STEM, which integrate ethnic knowledge with science, technology, engineering, and mathematics, have a notable effect on education. These tools help build a more inclusive educational atmosphere by recognizing and integrating the cultural backgrounds of students. This method can enhance student engagement and motivation by making learning more relatable to their personal experiences and cultural heritage. The impact of using ethno-STEM learning tools includes fostering a deeper understanding of STEM concepts by linking them to real-world, culturally relevant examples. In line with the research conducted by Nessa et al. (2017) and Riyadi et al. (2018), this connection helps students see the practical applications of STEM in their communities and everyday lives, enhancing both comprehension and retention. Additionally, these tools promote critical thinking and problem-solving by encouraging students to approach scientific and technical problems from diverse perspectives.

Moreover, ethno-STEM learning fosters respect for indigenous knowledge and practices, highlighting the value of traditional wisdom alongside modern scientific thought. This dual perspective not only preserves cultural heritage but also encourages innovation by blending time-tested methods with contemporary STEM strategies. Ultimately, according to Listiyani (2018) and Ardwiyanti et al, (2021) the integration of ethno-STEM tools can support a more holistic, culturally responsive, and effective education system. EthnoSTEM-based learning tools acknowledge and promote the cultural identities and provide experiences of diverse student community. By integrating students' cultural backgrounds and traditions into the curriculum, these tools enhance cultural relevance, making the learning experience more meaningful and engaging for students. Research by Akker et al. (2010) indicates that when students see themselves reflected in the content and instructional methods, they feel a stronger sense of ownership and connection to the learning process. EthnoSTEM-based learning tools, by incorporating culturally relevant examples and contexts, can increase student engagement and motivation in STEM subjects.

EthnoSTEM-based tools use cultural contexts to make abstract scientific concepts more relatable. For example, studying traditional herbal medicine can introduce students to topics like botany, chemistry (extraction of active compounds), and biology (plant anatomy and functions). Cultural practices, such as batik-making, can be used to teach the chemistry of dyes, temperature effects, and diffusion. By grounding science lessons in familiar cultural activities, students develop a stronger connection to the subject matter. These tools encourage students to explore science as part of a broader system interconnected with technology, engineering, and mathematics. This interdisciplinary approach enhances critical thinking and problem-solving skills. Learning tools rooted in EthnoSTEM make lessons more engaging and memorable by leveraging hands-on, project-based activities that reflect students' cultural heritage, such as building traditional windmills or solar cookers. Sudarmin et al (2020) and Sasmita et al (2024) emphasize the importence of encouraging inquiry-based learning, in which students actively investigate the scientific principles embedded within cultural practices to deepen their scientific understanding. . These activities not only make science enjoyable but also deepen understanding and retention of key concepts. Chashike et al. (2025) explain that students learn how traditional ecological practices, such as crop rotation or herbal remedies, align with modern scientific principles like sustainability and biodiversity. By integrating this knowledge, students see their cultural heritage as a source of scientific insight rather than as separate or outdated. This fosters a sense of pride and responsibility toward preserving cultural traditions.

The relationship between cultural knowledge and scientific knowledge in the context of herbal medicine is a complex and dynamic interaction. Herbal medicine, which involves the use of plants and plant-based compounds for therapeutic purposes, has been practiced for centuries across different cultures. Over time, scientific research has both supported and expanded upon many traditional practices, while culture continues to influence how herbal remedies are used, understood, and accepted in modern society. EthnoSTEM-based learning tools have the potential to address educational disparities among different ethnic and cultural groups. Based on the research conducted by Wulandari and Wulandari (2016) and Wulandari and Azrianingsih (2014) recognizing and valuing diverse cultural perspectives, these tools create an inclusive learning environment that respects students' cultural backgrounds and provides equal opportunities for success in STEM fields. Abonyi et al. (2014) argue that these tools often involve problem-solving activities that draw on real-life situations or challenges faced by different cultural communities. This approach not only strengthens students' critical thinking and problem-solving skills but also prepares them to address real-world issues from diverse perspectives, fostering cultural competence.

Based on previous research by Sumarni and Kadarwati (2020), EthnoSTEM-based learning tools can also be collaborated with learning models and have an impact on improving students' cognitive abilities. Rinto et al. (2022) maintain that combining or collaborating EthnoSTEM learning tools with project based learning models leads an increase in students' critical and creative thinking skills. This increase is due to collaborating EthnoSTEM-based learning tools with project based learning which can help students understand scientific concepts and their relationship with technology, engineering and mathematics. Apart from that, students are trained to think flexibly, original, critically and creatively in carrying out experimental activities, making projects and presentation projects. According to Acar et al. (2018), STEM training improves students' achievement in science and mathematics, fosters positive attitudes toward the training, encourages interest in future participation, and motivates students to consider careers in STEM fields. Griffiths's et al (2020) support this study by emphasizing that the growth of job opportunities and technological advancements necessitates increased diversity within the labor market. . All students require innovative early training to successfully pursue careers in the STEM fields.

Incorporating indigenous knowledge in STEM learning can be a representation of various cultural backgrounds. Apart from that, according to De Beer and Whitlock (2009) and Botha (2012) it can also improve the interpretation of scientific knowledge in this STEM context, so that EthnoSTEM-based learning tools can be relevant if applied in classes with students who have diverse backgrounds. As explained by Sumarni et al. (2020), students will more easily understand scientific knowledge through EthnoSTEM-based learning tools. Studies Andayani & Anwar (2023) have found that culturally responsive pedagogy positively impacts student achievement in STEM subjects. EthnoSTEM-based learning tools, through their emphasis on cultural relevance and inclusivity, can contribute to improved academic outcomes and narrow achievement gaps among diverse student populations.

The benefits of EthnoSTEM-based learning tools are not only felt by students, but also by teachers. According to Rahayu and Sudarmin (2015) and Nessa et al. (2017) EthnoSTEM tools aim to bridge the gap between indigenous knowledge systems and scientific knowledge. Karalar et al., (2021) explained that STEM activities help students understand that scientific knowledge and cultural practices are not separate but can complement and enrich each other. Through EthnoSTEM-based learning tools, teachers will be able to further explore indigenous knowledge that develops in society and is integrated with STEM education. It is important to note, as stated by Bramastia (2023), that while there is growing evidence supporting the benefits of EthnoSTEM-based learning tools within the framework of culturally responsive pedagogy, further research and implementation in diverse educational settings are necessary to fully validate this theory.

EthnoSTEM-based learning tools are powerful resources for science education, connecting cultural knowledge with scientific concepts to create a rich, meaningful learning experience. By contextualizing lessons, promoting interdisciplinary approaches, and fostering appreciation for local traditions, these tools prepare students to become globally aware yet culturally grounded scientists, innovators, and problem solvers. They represent an essential step toward creating inclusive, sustainable, and relevant educational systems for the future.

Conclusion

Developing EthnoSTEM-based learning tools is an essential step towards bridging cultural and scientific knowledge. This approach recognizes the unique ways in which different cultures understand and interact with science, technology, engineering, and mathematics (STEM). By incorporating cultural perspectives and traditional knowledge into STEM education, we create a more inclusive and diverse learning environment. EthnoSTEM serves both as an educational strategy and a cultural preservation tool. Unlike traditional STEM education, which often separates scientific concepts from students' lived experiences, EthnoSTEM connects learners to their roots, demonstrating the relevance of scientific thinking within their own cultural contexts. EthnoSTEM learning tools encourage students to explore their own cultural heritage and understand how it intersects with scientific principles.

EthnoSTEM-based learning empowers students to appreciate and preserve their cultural heritage while equipping them with the scientific and technological literacy needed to navigate modern challenges. It fosters inclusivity by validating diverse cultural perspectives and promotes sustainability by emphasizing local knowledge systems. Furthermore, this integration encourages interdisciplinary learning, where students see the relevance of STEM concepts in real-world and culturally meaningful contexts. EthnoSTEM provides a pathway to create culturally relevant curricula that resonate with diverse learners. Future efforts should focus on refining these tools through research, collaboration with cultural practitioners, and iterative feedback from educators and students. This will ensure that EthnoSTEM continues to serve as a bridge between the past and the future, inspiring learners to value their cultural roots while embracing scientific innovation.

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