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Ethnoscience-based physical science learning and its effects on students' critical thinking skills: A meta-analysis study

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ABSTRACT

This research aimed to ascertain the effects of ethnoscience-based instruction on students' critical thinking skills in learning physical science using a meta-analytic method. The data source was seven research articles obtained from databases and screened based on specific inclusion and exclusion criteria. The analysis was conducted through the organization of selected studies, extraction of the results, calculation of effect size using Cohen's d, discussion of results, and formulation of general findings. The findings of this study report that ethnoscience-based learning significantly affects students' critical thinking skills in physical science, with an overall effect size of 3.42. Therefore, ethnoscience-based instruction can be utilized by schools catering to indigenous learners to improve their science critical thinking skills and, at the same time, maintain and preserve their cultural identity.

Keywords: ethnoscience, critical thinking skills, meta-analysis, IP education, indigenous education, culture-based education, inclusive education

INTRODUCTION

One of the problems that indigenous peoples (IP) and advocates point about mainstream education is that its potential threat on the cultural identity of IP learners (Huffman, 2013). As the world advances and becomes a more interactive network, the need to upgrade the quality of education through globalizing competencies and 21st century skills heighten (Anagun, 2018; Larson & Miller, 2011; Organization of Economic Cooperation and Development [OECD], 2006). However, this strengthening of global standards leads to the loss of local knowledge and practices and decline of cultural authenticity and identity (Bishop et al., 2019; Burgess & Evans, 2017; Buxton, 2017; Vass, 2015). Some impacts of mainstream school learning include difficulty in learning; loss of respect for culture and heritage; low self-esteem, a sense of shame, and loss of indigenous identity; tendency to focus on individual's success at the expense of the community's; and community disunity (Episcopal Commission on Indigenous Peoples, 2008).

Culture has a strong influence on the learners' background knowledge (Baker & Taylor, 1995; Berry, 2005). In their formative years, they learn informally by interacting with the environment around them (Robinson, 1999; Taylor, 1999). The formation of a meaningful learning environment is determined by the cultural background brought by the teacher into the classroom (Berry, 2009; Ogunniyi et al., 1995). When learning science in schools mainly adopts conventional science learning from the west, science teaching will tend to separate learners' perspectives about the world around them (Cobern & Aikenhead, 1997). Various studies claim that learners with cultural backgrounds perceive science as too abstract since it is taught mainly with Western influences (Ayres, 2001). This poses a challenge on the main goal of science education, which is to make all learners scientifically literate (OECD PISA Framework, 2015). Another challenge that IP learners face is that some of them still experience direct and indirect academic discrimination even with the increased advocacy on inclusive education (Bonilla-Silva, 2006; Cole & Espinoza, 2008; Williams & Dempsey, 2014)–thus leading to various negative educational outcomes of these learners (Gibbs & Griffin, 2013; Greenhalgh et al., 2004; Hurtado et al., 2007).

To aid these issues, various IP educators, curriculum experts, and advocates design science lessons utilizing the principles of a culturally-relevant and context-based education (Alim & Paris, 2017; Aronson & Laughter, 2016; Ladson-Billings, 2014; Moll et al., 1992). Among these strategies, ethnoscience learning is linked with various positive impacts on the academic outcomes of IP learners (Amini et al., 2021; Azalia et al., 2020; Gunawan et al., 2019; Hastuti et al., 2019; Hikmawati et al., 2020; Kumalasari et al., 2019; Nurcahyani et al., 2021; Risdianto et al., 2021; Sarwi et al., 2021; Sudarmin et al., 2018, 2019). Ethnoscience is an interdisciplinary science that bridges culture with science learning (Lestari & Fajar, 2016). It deals with various scientific disciplines, which include ethnobiology (Isakndar, 2017), ethnochemistry (Ajayi & Achor, 2017), ethnophysics (Susilawati et al., 2018),

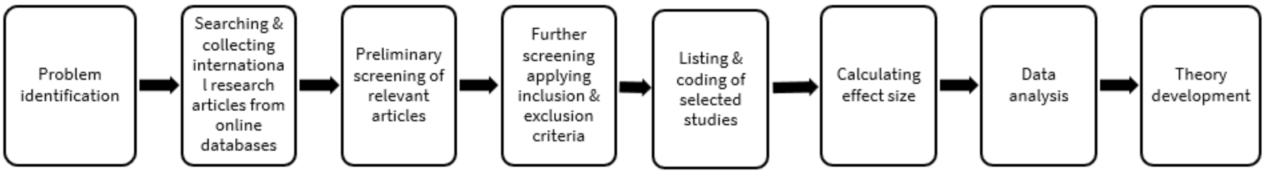

Figure 1. Flow chart (Idul, 2023)

ethnomathematics (Presmeg, 1999), ethnomedicine (Muleady-Mecham & Scheley, 2009), and native agricultural practices and food processing technologies. The major principle of ethnoscience is to make indigenous knowledge a basic and reinforced concept of culture and tradition (Nuroso & Sudarmin, 2018). Enculturation in science teaching can empower scientific thinking based on the learners' views of the environment, which directly surrounds them (Cobern & Aikenhead, 1997). Therefore, ethnoscience-based learning guides learners especially with cultural backgrounds to discover and build their own knowledge rooted with their traditions and communal practices (Fasasi, 2017). Anchored to the goals of science education, ethnoscience instruction also aims to develop the critical thinking and necessary science process skills of learners in order to relate the science concepts and theories they learned from school to their local context and daily lives (Sari et al., 2020).

According to Sudarmin et al. (2018), "critical thinking is an organized process that allows students to evaluate the evidence, assumptions, logic, and language that underlies others' statements." In Indonesia, one of many countries in Southeast Asia with rich population of IP, the critical thinking skills of learners are low (Saputri & Rinanto, 2018; Zubaidah et al., 2018). Saputra et al. (2019) reported that possible causes of this phenomenon can be contributed to students' difficulty in connecting science concepts and problems. Previous studies claim that ethnoscience-based learning can increase the students' critical thinking skills in various aspects through learning process (Gunawan et al., 2019; Nuroso et al., 2018; Risdianto et al., 2021; Sudarmin et al., 2018, 2019).

A meta-analytic study conducted by Nurcahyani et al. (2021) also supports the effectivity of ethnoscience learning on improving the science literacy of learners with cultural backgrounds. By examining and reviewing various international journals, results reveal that ethnoscience learning had a high influence on science learning with an average effect size of 0.84. Ethnoscience had a positive impact on science learning. Findings show that ethnoscience learning affected the critical thinking skills and academic competence of students in science since their school projects involves their daily life experiences in their immediate community. Additionally, it made the students more motivated because they find science learning more meaningful (Amini et al., 2021). Ethnoscience also led to the students' concept discovery and critically explain certain phenomena in their environment. However, the existing literature for meta-analytic study on ethnoscience learning is only focused on the general scientific literacy of students. Hence, this present study aims to review recent published research articles specifically exploring the critical thinking skills of students and how ethnoscience learning can affect these necessary skills. Moreover, this present meta-analysis is also targeted towards physical science, which covers concepts on integrated science, earth science, physics, and chemistry. Topics in physical science are abstract in nature, thus critical thinking skills are required to fully understand these concepts. In the current era of globalization, IP learners are challenged to maintain and preserve their local cultural values (Nurlina et al., 2020). By combining science concepts and authentic knowledge in the community (Gondwe & Longnecker, 2015), students have both the opportunities to maintain their cultural identity and enhance their critical thinking skills (Dewi et al., 2017). Thus, instead of assimilating knowledge from Western science perspective, IP educators enculturate science to the learners through integrating indigenous knowledge, systems, and practices. This leads to the question this meta-analytic research sought to answer:

Is ethnoscience-based learning effective in improving the critical thinking of students in physical science?

METHODOLOGY

Research Design

This study utilized a meta-analytic method by reviewing seven international journals identified using specific inclusion criteria to determine whether ethnoscience-based learning affects students' critical thinking skills. Meta-analysis is the quantitative synthesis of information extracted from various studies (Lau et al., 1997). By combining relevant evidence across studies, this method enables the integration of information from diverse literature and reach a more precise estimates of effect (Haidich, 2010; Ioannidis, 2010). For this study, a fixed-effect meta-analysis model is used. A fixed-effect model alternatively assumes that the average effect size in the population varies from one study to another, thus, the effect sizes are heterogeneous (Hedges, 1992; Hunter & Schmidt, 2000). Furthermore, a fixed-effect model can generate inferences that only extends to the studies included in the present study (Hedges & Vevea, 1998). Hence, the following assumptions were set for this research: effect sizes from the seven different studies included are heterogeneous; and the findings of this meta-analysis can only be used to generalize the results of the studies reviewed. In conducting this meta-analysis research, this study adapted the procedures by De Coster (2009) and Field and Gillett (2010). This procedure, as shown in **Figure 1**, includes the following:

(1) ensuring and pursuing the research topic to-be-summarized or identifying the main problem,

(2) doing a literature search from online databases,

(3) content validation using inclusion and exclusion criteria,

(4) listing and coding of selected studies,

(5) calculating the effect size using appropriate statistical measures,

(6) recognizing whether there is heterogeneity in the effect size,

(7) interpreting the results, and

(8) formulating generalizations.

Identification & Collection of Relevant Studies

Using Google Scholar as a main database in locating relevant articles, a total of 365 results were generated containing the terms "ethnoscience instruction in physics", "ethnoscience instruction in chemistry", or "effects of ethnoscience instruction on students' critical thinking skills" in the search titles. Out of the 365 papers, 41 papers were found to be relevant based on preliminary selection. These papers were stored in digital archive and have undergone a more thorough content validation applying the inclusion and exclusion criteria. From this screening, only seven research papers passed the criteria and were included in the present meta-analysis study.

Inclusion & Exclusion Criteria

The following were the inclusion criteria applied in screening and validating the journals reviewed:

(1) the study should focus on ethnoscience-based learning on physics, chemistry, or integrated science,

(2) the main dependent variable involves students' critical thinking skills,

(3) the year of publication should be from 2018 up to 2022,

(4) the studies may originate from any countries around the globe, however, studies conducted in countries highly populated with IP such as Asia, Africa and Central America are preferred,

(5) the research design of studies should be either experimental, quasi-experimental, or mixed methods experimental, and

(6) the control and treatment groups are from upper elementary or secondary schools.

Applying the inclusion criteria may yield to a number of relevant papers. Thus, to further screen the studies and obtain more pertinent papers, the following exclusion criteria were set:

(1) the paper shall be excluded if it did not report or it lacks effect size data such as sample sizes, mean, and standard deviation of both the control and treatment groups,

(2) if the full-text is not available or not open-access,

(3) if it accounted other variables aside from critical thinking skills such as process skills, science literacy, problem solving, academic performance, and the like,

(4) if the research design utilized is descriptive or correlational in nature, and

(5) if the main purpose of the study is only to design and develop ethnoscience learning materials.

Listing & Coding

After carefully reviewing the relevant papers for this meta-analysis, the following data were extracted from each paper and were placed in a datasheet:

(1) author/s and year of journal publication,

(2) title of the study,

(3) objectives of the study,

(4) variables involved,

(5) research design,

(6) subject, either physics, chemistry or integrated science,

(7) sample sizes from both control and experimental groups,

(8) effect size data including mean and standard deviation of quantitative effects from both control and experimental groups,

(9) effect size results, and

(10) effect size interpretation.

In the final tabular presentation, however, only the following data are reflected: author and year of publication, variable, research design, subject, effect size value, and interpretation.

Calculating Effect Size

This study utilized Cohen's d to assess the effect sizes of each of the reviewed journal. Cohen's d is an effect size tool used in measuring the difference between two group means, particularly in comparing control and treatment groups. The following is the formula used in obtaining Cohen's d:

$$d = \frac{\bar{x}_1 - \bar{x}_2}{s_{pooled}};\ s_{pooled} = \sqrt{\frac{(n_1-1)s^2 + (n_2-1)s^2}{n_1+n_2-2}}. \quad (1)$$

Table 1 presents effect size value and its corresponding interpretation based on the benchmarks suggested by Cohen (1998).

Table 1. Cohen's d interpretation

Effect size value	Interpretation
0.00≤ES<0.20	No effect
0.20≤ES<0.50	Small effect
0.50≤ES<0.80	Medium effect
0.80≤ES<1.30	Large effect
1.30≤ES	Very large effect

Table 2. List of studies with effect size data

Authors (year)	Variable	Research design	Subject	Respondents (n)		Effect size data				Effect size result (Cohen's d)	Interpretation
				Con	Exp	Con		Exp			
						Mean	SD	Mean	SD		
Rihayati et al. (2021)	CTS	QE	IS	26	42	67.04	6.52	79.21	6.59	1.85	Large
Risdianto et al. (2021)	CTS	QE	Physics	30	34	69.96	11.43	82.38	14.25	0.96	Large
Ramdani et al. (2018)	CTS	QE	IS	40	40	73.51	0.95	86.71	1.03	13.32	Large
Lia and Diliarosta (2020)	CTS	QE	IS	32	30	87.78	5.18	93.44	5.46	1.05	Large
Sudarmin et al. (2018)	CTS	QE	Chemistry	50	61	65.50	12.27	73.30	6.10	0.78	Approximately large
Azalia et al. (2020)	CTS	QE	Chemistry	33	33	51.21	4.97	78.64	4.97	5.52	Large
Hikmawati et al. (2021)	CTS	QE	IS	58	58	70.74	7.02	79.07	9.64	0.98	Large

Note. CTS: Critical thinking skills; QE: Quasi-experimental; IS: Integrated science; & SD: Standard deviation;

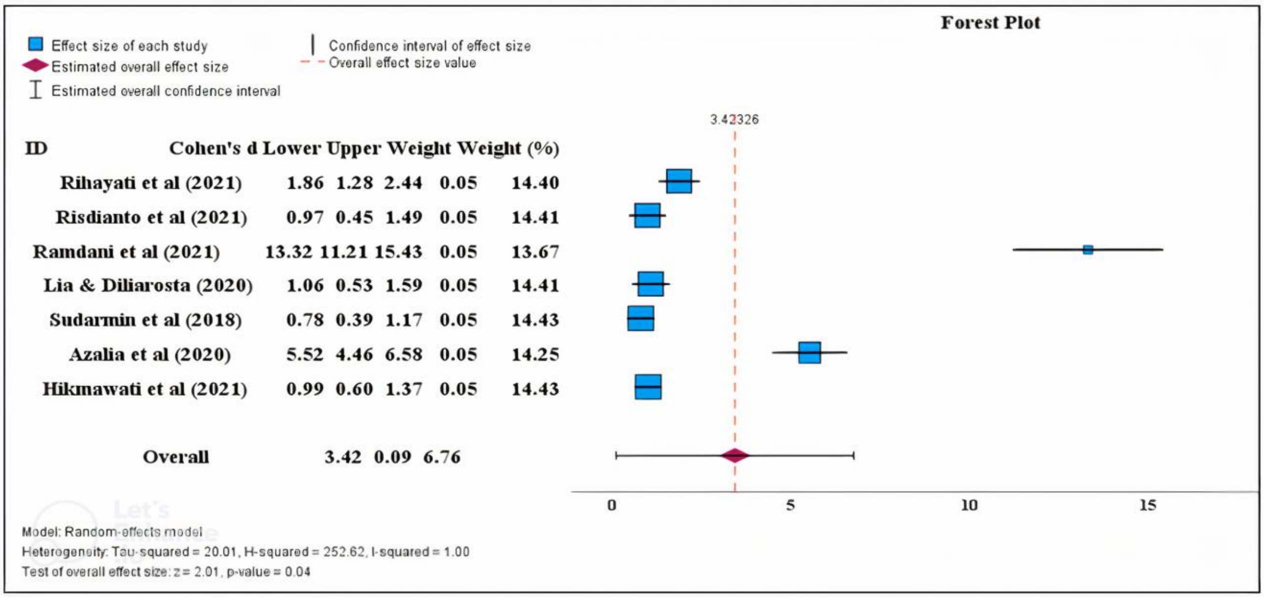

Figure 2. Forest plot of ethnoscience-based studies (Idul, 2023)

RESULTS AND DISCUSSION

In this study, a total of seven studies listed in **Table 2** were thoroughly reviewed in terms of the effects of ethnoscience-based instruction on the critical thinking skills of students in learning physical science. Of these seven studies, two are focused on chemistry, one on physics, and four on integrated science. These studies were published between 2018 and 2021. As shown in **Figure 2**, results show that only Sudarmin et al. (2018) reports a medium effect size, while the rest of studies show either large or very large effect sizes. The overall effect size is 3.42–this means that ethnoscience-based instruction according to the selected studies has statistically large significant effect on the critical thinking of students in learning physical science.

Findings of the study reveal that the three studies, which reported the highest effect sizes are Azalia et al. (2020), Ramdani et al. (2021), and Rihayati et al. (2021). In the context of Ramdani et al. (2021), ethnoscience learning was implemented along with the 5E learning cycle to improve the critical thinking skills of indigenous Indonesian learners. Through engagement, exploration, explanation, elaboration, and evaluation (Jack, 2007), the learners were able to enhance their critical thinking skills by associating their learned science concepts to their cultural traditions. In this study, students were tasked to discuss and apply motion systems in everyday life based on the traditional practices they observe in their community. It also reported that the utilization of natural science materials embedded with local wisdom present learning materials more attractive and informative (Ramdani et al., 2021). This strengthens the claim of Khusniati (2017) and Sudarmin et al. (2019) that learning science in schools will be much easier to comprehend if educators pay more attention on the culture of students–of what they directly experience in their surrounding environment. Integrating local wisdom, customs, and practices, into mainstream education is appropriate for the 21st century science learning since it encourages a multicultural approach in the teaching-learning process (Gunstone, 2014).

Additionally, in the study of Azalia et al. (2020), ethnoscience learning was embedded with the utilization of STEM e-book application on chemistry, tagged as “ethno-STEM e-book”, to promote critical thinking. Ethno-STEM integrated teaching materials focused on the topic of chemical equilibrium are linked with ethnoscience elements so that learners learn easier from their local habits, norms, systems, and practices. This is consonance with the premise Sunarsih et al. (2020) that learning materials and resources adapted to culture or certain ethnicity can aid students to have a deeper understanding of their distinctive culture. The study concluded that the application of ethnics-integrated STEM chemical equilibrium e-book contributed a higher percentage on the positive educational outcomes of native learners particularly on their critical thinking (Azalia et al., 2020).

It also further implied that the use of local wisdom-based modules can improve not only critical thinking, but scientific literacy in general (Setiawan et al., 2017). Another element that also contributed to the improvement of the learners’ critical thinking was the hands-on nature of the activities included in the learning material utilized in the study. However, Azalia et al. (2020) also revealed that the integrated ethno-STEM e-book had its limitations during the implementation. The following are the lack of quality of the material presented since this area of science education is still developing; some questions and homework need to be further revised; and some students are not yet fully-accustomed to using learning materials that are associated with the systems and practices of local communities. Ramdani et al. (2021) also reported some inconsistencies from learners exposed to ethnoscience learning. It was observed that some students are highly dependent on the teaching material and only develops strategy as stated on the materials provided. If they are given with a problem that requires them to formulate new techniques, some of them encounter difficulties.

Rihayati et al. (2021) integrated ethnoscience through the discovery learning model and context-based education implemented on the immediate communal setting of the learners. The results of the study are in lined with Nurcahyo et al. (2018) that discovery learning with scientific approaches probes students to actively solve problems and eventually develop their critical thinking skills. It is also in consonance with Martaida et al. (2017), which emphasized that critical thinking skills of students exposed to discovery learning are better compared to learners exposed to conventional instruction. Individually looking through the rest of the studies included in this present meta-analytic research on how ethnoscience was integrated in physical science learning: Lia and Diliarosta (2020) also utilized the discovery learning model; Hikmawati et al. (2021) used the 6E learning model; Risdianto et al. (2021) taught through direct instruction model; and Sudarmin et al. (2018) introduced video learning. Thus, it can be implied from the research included in this meta-analysis that ethnoscience-based learning is usually integrated with other learning models to strengthen its implementation.

Ethnoscience serves as a foundation and an anchorage in learning science and culture. With this, a huge challenge is put on the implementers of the curriculum, IP teachers as they are tasked to immerse themselves on the culture and traditions of their learners and seek ways on how to intertwine local and scientific knowledge. Teachers who want to practice ethnoscience are required to learn and master local wisdom–knowledge that originates from beliefs and were passed down to the community’s ancestors (Nurcahyani et al., 2021). Science teaching materials must have accurate and contextual problems in order to facilitate science learning and foster students’ critical thinking skills (Kumalasari et al.,2019). Sample applications of ethnoscience-based learning was laid-out by Hikmawati et al. (2021) and it includes: telling folktales and local legends as a way to engage students into learning; asking their initial ideas and beliefs about the ethnoscience material without judgment; urging learners to investigate about their local customs, beliefs, and knowledge, and link it with science concepts; students sharing their investigations to the class; explain the cultural context of their investigations; they can also display or exhibit some of their works or products; and some may also draw or act out their practices. The role of the teacher is to facilitate the flow of learning, ask questions, and clarify the topics studied integrated with local wisdom.

From the findings of this meta-analysis and based on existing literature, it can be concluded that ethnoscience affects students’ scientific literacy and more specifically, their critical thinking skills. One of the factors that can be attributed to this improvement is that students’ find it easier to learn since ethnoscience connects education in the classroom with their daily lives. It also motivates them to actively participate in the learning process (Nurcahyani et al., 2021). The implementation of ethnoscience is highly dependent on the environment, where the students live. Environmental learning also plays a pivotal role in supporting students’ knowledge about ethnoscience (Ichsan & Rahmayanti, 2020). Ethnoscience is also essential in developing and empowering indigenous learners in preserving local culture, appreciating local culture, and introducing local culture to others (Hikmawati et al., 2021). Through these, students with cultural background may be able to surpass the threat of cultural identity loss and be able to move along with the ever-changing world.

CONCLUSIONS & RECOMMENDATIONS

Based on the findings reported by the seven international research articles included in this meta-analysis, this study concludes that ethnoscience contributes largely on the improvement of critical thinking skills of students with cultural backgrounds in learning physical science. It can also be implied that ethnoscience is implemented along with various learning models, and thus, educators have the task to design ethnoscience-based teaching and learning materials that best cater the needs of their learners. The results of this data may serve as a baseline data in encouraging more teachers, particularly IP educators, to explore ethnoscience and other related pedagogies in order to realize the goal of 21st century science learning, which is to make every learner scientifically literate. Even with the threats of globalization to local culture, science educators are encouraged not to counteract with the mainstream education, but to maximize the utilization of local resources and empower the acculturation of local wisdom on top of what’s already being taught in schools. Since most of the studies included in this study were conducted in Indonesia, the findings of these study may also serve as a foundation for neighboring Southeast Asian countries, where indigenous learners are present.

Since the results and generalizations of this study are only limited based on the studies that were included, this research recommends that further searching using various scholarly databases should be done. Future studies may expand the variable included in the research, may find for more international studies conducted outside Asia, and may explore research designs such as mixed-methods experimental research design to obtain more supplementary and comprehensive data. This study also recommends locating more studies focused on some specialized and less explored branches of science or mathematics to widen the scope of ethnoscience learning.

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Ethical statement: The authors stated that all the protocols and guidelines in conducting a meta-analytic study were properly followed. This study has undergone thorough review from the university ethics committee and approved by University of Science and Technology of Southern Philippines on January 2023. This study does not involve human subjects. All the data gathered from this study were kept confidential and were utilized for this research only.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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