The Inclusion of Indigenous Knowledge in Science and Chemistry Education to Promote Education for Sustainable Development
(The Case of Indigenous Knowledge of the Baduy Community in Indonesia)

DISSERTATION

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By

Robby Zidny

Faculty of Biology and Chemistry
University of Bremen

Supervisor and 1st Examiner:
Prof. Dr. Ingo Eilks FRSC

2nd Examiner:
Prof. Dr. Jesper Sjöström

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OVERVIEW

This dissertation is a cumulative doctoral work. It consists of six main chapters outlining five journal articles and a book chapter that discuss a literature review and four studies. The dissertation studies focus on the inclusion of indigenous knowledge (IK) in science and chemistry education to promote education for sustainable development (ESD).

The first chapter analyses the general literature background and research framework of the study. This chapter presents an analytical literature review discussed in "A Multi-Perspective Reflection on How Indigenous Knowledge and Related Ideas Can Improve Science Education for Sustainability" (Zidny et al., 2020). It encompasses the theoretical framework, didactic model, educational research framework, and the educational values of the inclusion of IK in science and chemistry education.

The second chapter outlines the research background of the Indonesian science curriculum and the current state of implementation of ESD in Indonesia. The significance of indigenous communities for this study is also presented with a special focus on the Baduy community in the Banten province, Java Island, Indonesia. The profile of the Baduy community is discussed in the book chapter "Indigenous Knowledge as a Socio-Cultural Context of Science to Promote Transformative Education for Sustainable Development: Insights into a Case Study on The Baduy Community (Indonesia)" (Zidny & Eilks, 2018)

The third chapter presents four major studies that are part of research-based development of didactic teaching-learning-designs on the inclusion of IK and perspectives into science and chemistry education. The first study in this chapter (section 3.1) attempts to map out and explore indigenous, science-related knowledge from the Baduy community. From the findings, an educational analysis was conducted to identify contexts and content for science learning as well as for integrating indigenous science (ISc) into socioscientific issues-based education. This study is part of the book chapter by Zidny and Eilks (2018) and a paper entitled "Exploring Indigenous Science to Identify Contents and Contexts for Science Learning to Promote Education for Sustainable Development" (Zidny et al., 2021).

The second study in chapter 3 (section 3.2) focuses on implementing a first teaching intervention on the integration of IK and Western modern science (WMSc) in chemistry education. The teaching intervention adopted model 3 of the ESD-based pedagogical approaches suggested by Burmeister et al. (2012) focusing on the controversial sustainability issue of pesticides use. The lesson was implemented in two groups on different educational levels, encompassing upper secondary school and university chemistry student teachers. The lesson's main activities start from the controversial issues of pesticides use to encourage learners to think critically, express their arguments, and
solve chemistry problems in classroom task activities. Feedback from the learners about the lesson and the learning design was collected. This study is described in "Integrating perspectives from indigenous knowledge and Western science in secondary and higher chemistry learning to contribute to sustainability education" (Zidny & Eilks, 2020).

The analysis and evaluation of the students’ activities is discussed in the third study in chapter 3 (section 3.3). This study attempted to explore the initial level of students’ arguments and their ability to link the context with chemistry concepts. Based on the findings, information from the analysis was used to evaluate and improve the learning design. This study is described in "A case study on students’ application of chemical concepts and use of arguments in teaching on the sustainability-oriented chemistry issue of pesticides use under the inclusion of different scientific worldviews" (Zidny et al., 2021, under review a).

The final study in chapter 3 (section 3.4) focuses on a second teaching intervention on the inclusion of ISc as a starting point to promote green and sustainable chemistry education. The teaching intervention adopted models 1 and 2 of ESD-based approaches suggested by Burmeister et al. (2012), namely adopting green chemistry lab practices and content. The lesson was implemented in an environmental chemistry course (elective course) with second-year undergraduate student teachers in Indonesia. This study is described in "Learning about phytochemical aspects of botanical pesticides adapted from ethnoscience as a contribution to green and sustainable chemistry education" (Zidny & Eilks, under review b).

Chapter 5 summarizes all the studies in the research project and outlines the implication of the studies. In chapter 6, the published works of the thesis are presented.
ZUSAMMENFASSUNG


Die zweite Studie in Kapitel 3 (Abschnitt 3.2) konzentrierte sich auf die Implementierung einer ersten Intervention zur Integration von indigenem Wissen mit einer westlich-modernen Wissenschaftsperspektive in den Chemieunterricht. Die Unterrichtsintervention basiert auf dem Modell 3 der BnE-basierten pädagogischen

Die Analyse und Bewertung der Aufgaben der SchülerInnen wird in der dritten Studie in Kapitel 3 (Abschnitt 3.3) erörtert. In dieser Studie wurde das anfängliche Niveau der Argumentationsfähigkeit der SchülerInnen und ihre Fähigkeit untersucht, den Kontext mit den chemischen Konzepten zu verknüpfen, die in der Intervention implementiert wurden. Basierend auf diesem Ergebnis wurden die Informationen aus der Analyse verwendet, um die Entwicklung des Lerndesigns zu bewerten und zu verbessern. Diese Studie ist Teil des Artikels mit dem Titel „A case study on students' application of chemical concepts and use of arguments in teaching on the sustainability-oriented chemistry issue of pesticides use under the inclusion of different scientific worldviews“ (Zidny et al., 2021, in Begutachtung a).

Die abschließende Studie in Kapitel 3 (Abschnitt 3.4) ist eine Fallstudie einer zweiten Lehrintervention zur Einbeziehung von indigemem Wissen als Ausgangspunkt für eine BnE. Die Unterrichtsintervention basiert auf den Modellen 1 und 2 nach Burmeister et al. (2012), in denen Prinzipien der grünen Chemie für die Laborpraxis und als Inhalte im Chemieunterricht übernommen werden. Die Lektion wurde in einem Umweltchemiekurs (Wahlkurs) mit Lehramtsstudierenden im zweiten Studienjahr in Indonesien durchgeführt. Diese Studie ist bechrieben in „Learning about phytochemical aspects of botanical pesticides adapted from ethnoscience as a contribution to green and sustainable chemistry education“ (Zidny & Eilks, in Begutachtung b).

Kapitel 5 fasst alle Studien im Promotionsprojekt zusammen und skizziert Implikationen der Studien. In Kapitel 6 werden die Publikationsarbeiten des Promotionsprojekts dargestellt.
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1. The framework of the studies

This section presents the introduction and framework of the thesis that has been discussed in the analytical literature review "A Multi-Perspective Reflection on How Indigenous Knowledge and Related Ideas Can Improve Science Education for Sustainability" (Zidny et al., 2020).

1.1. Introduction

A main challenge in science learning which is commonly experienced by students is the perception that their lessons are not very relevant to their life and future (Stuckey et al., 2013). The lack of connections of science teaching to the everyday life of the students and society seems to be the main factor for the missing perception of relevance in science learning (Childs et al., 2015; Hofstein et al., 2011). Science teaching requires different ways to reform the curriculum and pedagogy to foster the relevance of science education (Eilks & Hofstein, 2015). Learning of science should rely on the real-life phenomenon and societal situations, which introduce conceptual learning to encourage the students to appreciate the relevance of science learning (Greeno, 1998). Science education as a relevant part of education, in general, should play an essential role in preparing students to be able to think critically and independently towards the issue of the impact the development of science and technology has on society (Holbrook & Rannikmae, 2007; Stuckey et al., 2013).

1.2. Raising the relevance in science learning through education for sustainable development (ESD)

Effective evidence-based curriculum development in science education is required for attaining more relevant and effective teaching and learning as well as for innovating the curriculum (Hugerat et al., 2015). Thus, it is important to introduce new topics and learning designs that continuously emerge in science education and to reform teacher education programs. One of the related fields is sustainability thinking and action. The official pedagogical approach related to the topic is Education for Sustainable Development (ESD) (Burmeister et al., 2012). The implementation of ESD in science education is proposed to contribute to the domains of relevant science learning (personal, societal and vocational relevance) (Stuckey et al., 2013).

The implementation of ESD-based approaches in science education is mostly restricted to Western modern scientific (WMSc) worldviews on the history of science and often overlooks cultural and philosophical aspects (e.g., Ideland, 2018; Khaddoor et al., 2017; Zidny et al., 2020). The contexts for science learning taught in one region of the world might not necessarily be meaningful to another with different cultural backgrounds and socio-economic environments (Gilbert, 2006; Holbrook, 2005). Contexts and issues introduced
by ESD should consider the cultural, geographical conditions and the level of development of each country or community (Wiyarsi & Çalik, 2019). Therefore, offering local cultural and philosophical perspectives may influence science teaching and learning, especially related to the discussion of sustainability in science education. In this case, science learning might become more relevant if it is connected with the cultural background, perspectives, values, and worldviews that exist in the corresponding country. This might concern countries with various indigenous communities, like Indonesia. In this thesis, a reorientation or extension of ESD is suggested by integrating the indigenous knowledge (IK) perspectives into science curricula. This is suggested to provide a chance for educators to better incorporate intercultural, interdisciplinary and multi-perspective worldviews and systems thinking into science curricula. Moreover, it might also foster education for responsible citizenship and incorporating philosophical-cultural values (Eilks et al., 2013; Simonneaux, 2014; Sjöström et al., 2016; Zidny et al., 2020).

1.3 The inclusion of indigenous knowledge (IK) in science education

In countries with diverse indigenous communities, such as in Asia, the way of knowing about nature was developed by various cultural influences, which are different from the Western modern perspective. The influence initially came from ancestors orally, and formed science-related knowledge or indigenous science (ISc). Other scholars have interpreted ISc under various terms, such as traditional (native) knowledge (Stephens, 2000), ethnoscience (Fasasi, 2017), or traditional ecological knowledge (Snively & Williams, 2016). ISc and perspectives on nature in science differ at various levels among human societies around the world. ISc consists of local wisdom, which is generally based on a sacred respect of nature, as a form of responsibility and indigenous peoples’ relationship toward nature (Knudtson & Suzuki, 1993). Accordingly, learning ISc may encourage students to recognize the close relationship between humans and nature in the culture of their local environment.

Based on an analytical literature review (Zidny et al., 2020), some educational benefits can be suggested by integrating ISc into science learning. The first is to motivate students to study science across cultures, as suggested by science organizations, such as IUPAC (Mahaffy, 2006). Another value is to make the learning context more relevant, especially for students in countries with indigenous communities (Zidny et al., 2020). The introduction of ISc in science curricula can help students to engage with the knowledge represented by their cultural environment and foster their knowledge perception and attitude towards science (Botha, 2012; Fasasi, 2017). Accordingly, students in culturally diverse classrooms can find science learning more meaningful and relevant (Zidny et al., 2020; Zidny & Eilks, 2018). The other essential benefit is to offer cross-disciplinary science learning in order to
innovate education for sustainable development and systems thinking. As a result, learning can enhance student understanding and awareness that different disciplines, including ISc and Western modern science (WMSc), should be involved in decision-making to address sustainability issues (Koutalidi & Scoullos, 2016; Matlin et al., 2016; Zidny & Eilks, 2020).

1.4 Educational research framework to integrate indigenous science (ISc) into Science Education

Based on the analytical literature review, a new educational research framework on how to incorporate ISc and WMSc in science curricula was developed (Figure 1) (Zidny et al., 2020). The research framework was adapted from the Model of Educational Reconstruction (MER) (Duit et al., 2005). According to the model, educational research-based development is suggested to make a connection between (1) the analysis of science content structure, (2) research on the design of teaching and learning, and (3) the development and evaluation of the learning design. This framework suggests educational reconstruction by integrating multi-perspective views from ISc with WMSc to make the instruction suitable to the students’ perspectives, skills, and needs. The analysis of social demands in the framework also provokes the integration of sustainability, local wisdom, and socio-cultural values as a complex representation of ISc. The issue related to sustainability is suggested to be integrated into the curriculum to offer an essential context for science learning by drawing on ISc.

Figure 1. The educational research framework to integrate ISc in science education
1.5 Research objectives

a. To map out the ISc of the Baduy tribe in Indonesia to inform science education to enhance the relevance in science learning and promote ESD and intercultural learning.

b. To analyze and categorize ISc related to science contexts and concepts in Indonesian science curricula and to analyze related sustainability values that can be learned from these contexts.

c. To develop research-based innovations for chemistry learning incorporating indigenous science and chemistry scientific knowledge for Indonesian education and to evaluate the effects of the learning designs.
2. Research background

2.1 Indonesian science curriculum

The educational systems in Indonesia, from early childhood to higher education, is regulated by the Ministry of Education and Culture. The curricula for upper secondary education are centralized in the form of the Indonesian national educational curriculum. The current curriculum that has been implemented in upper secondary education is the national curriculum of 2013. It consists of national educational standards, a basic framework and curriculum structure, a syllabus, and curriculum implementation guidelines (Somantrie et al., 2017). At the higher education level, the curriculum is developed by higher education institutions independently concerning a National Higher Education Standard (Junaidi, 2020). The development of the curriculum in higher education institutions refers to the learning outcomes formulated within the framework of Indonesian national qualifications. These learning outcomes are usually developed by study programs and scientific organizations in their fields.

2.2 The current implementation of ESD in Indonesia

Since the declaration of the Decade of Education for Sustainable Development (DESD) 2005-2014 by UNESCO, the Indonesian ministry of education and culture started some programs to encourage ESD implementation. However, the application of ESD in the curriculum in Indonesia is not yet fully optimal. According to the UNESCO report in 2011 (UNESCO, 2011), the ESD concept was only implicitly implemented into the educational system in Indonesia, e.g., through institutional programs related to ESD, such as green schools and green campuses. ESD has not been integrated thoroughly in the curriculum and in classroom teaching and learning practices. This may be due to the missing of explicit rules issued by the government and policymakers in education regarding ESD. In addition, reasons were also related to teachers and prospective teachers not being sufficiently equipped with knowledge and concepts to integrate concepts in their teaching and learning designs.

2.3 Indigenous knowledge in Indonesia: a case study of the Baduy community

Indonesia is a country with a diverse socio-cultural environment. There are various tribes, languages, religions, beliefs and customs. According to the Indonesian Central Statistics Agency (BPS), 1131 tribes are recorded as occupying the Indonesian ethnicity demographic (BPS, 2013). The Baduy tribe is one of the traditional community in Indonesia. They live in the forest area and still conserve their cultural integrity. The Baduy society is located in the Kendeng Mountains on Java Island. It is around 120 km from Jakarta, the
capital city of Indonesia. The Baduy people still maintain their local cultural wisdom related to the interconnectedness between nature and humans and the knowledge about sustainability and conservation of ecosystems in their environment.

The Baduy community consists of two groups of indigenous peoples, namely the inner Baduy and the outer Baduy. The inner Baduy group applies very strict rules regarding the application of cultural customs and protects their area from being influenced by outside cultures. The outer Baduy has a role as a buffer to protect the inner Baduy from the external world influence. The Baduy people are really concerned about conserving their natural environment because it has a role in their lives in terms of biodiversity resources, agriculture, food security, and livelihood (Zidny & Elks, 2018). The concept of sustainability values and local wisdom from the indigenous knowledge in the Baduy community indeed an interesting context that can be addressed in science learning to make it more relevant to students in the corresponding society. It also could lead to intercultural understanding in science education globally. In this study, the context of indigenous knowledge in the Baduy community was reconstructed and integrated as a pedagogical approach to enhance relevance in science learning and promote ESD.
3. Short description of the studies implementation:

Research-based development of didactic teaching and learning designs on the inclusion of indigenous knowledge and perspectives in science and chemistry education

3.1 Exploration of indigenous science (ISc) related to the content, contexts, and sustainability issues in science and chemistry learning

This section introduces the study of the exploration of ISc of the Baduy community. The study was discussed in the book chapter entitled "Indigenous Knowledge as a Socio-Cultural Context Of Science to Promote Transformative Education for Sustainable Development: Insights into a Case Study on The Baduy Community (Indonesia)" and in the paper entitled "Exploring Indigenous Science to Identify Contents and Contexts for Science Learning to Promote Education for Sustainable Development" (Zidny & Eilks, 2018; Zidny et al., 2021).

3.1.1 Focus and Method

The study explored the ISc and socio-cultural context of the Baduy community in Indonesia. The study involved a qualitative research design using ethnographic methods (Creswell, 2012). For collecting research data, several techniques used include a literature review, interviews, observations, documentation, focus group discussion, and triangulation of the data (Zidny & Eilks, 2018). Based on the ethnographic study data, further analysis was conducted using qualitative content analysis to identify content and contexts for science learning. The ethnographic study data was compared with the existing scientific literature related to ISc in the Baduy community. The analysis involved two stages encompassed (1) thematic analysis to categorize the example topics from ISc for science learning and (2) analysis on the interpretation of ISc into socioscientific issues-based science education (Zidny et al., 2021) (Figure 2).
3.1.2 Result and conclusion

Based on the analysis, six themes related to the socio-cultural context of science in the Baduy community were identified (Table 1) (Zidny et al., 2021).

<table>
<thead>
<tr>
<th>Themes</th>
<th>ISc of the Baduy community</th>
<th>Science background</th>
<th>Related science content</th>
<th>Suggested Educational Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>The Baduy community uses plants as biopesticides to control pests in their rice plantations: Noni fruit (Morinda citrifolia L.), Momordica charantia, Achasma walang, Bridelia monoica. 160 phytochemical compounds in Noni fruit have been explored for possible benefits, such as anti-viral, anti-fungal, anti-bacterial, or anti-nematode function (Senthilkumar, et al., 2016).</td>
<td>Chemistry: organic compounds, pesticides, phytochemistry, chemical analysis</td>
<td>Higher Education and Upper secondary school</td>
<td></td>
</tr>
<tr>
<td>Medicine</td>
<td>The outer Baduy community uses some medicinal plants to treat different diseases. For example, Orthosiphon aristatus, a species in the family of lamiaceae is used (Ichwandi &amp; Shinohara, 2007). Phytochemicals in Orthosiphon aristatus have been isolated, which have anti-diabetic, anti-inflammatory, antioxidant, hepatoprotective, analgesic and nephroprotective activity. These include terpenes, organic acids and flavonoids (Singh, et al., 2015).</td>
<td>Chemistry: phytochemistry, chemical analysis</td>
<td>Higher education and upper secondary school</td>
<td></td>
</tr>
<tr>
<td>Natural dyes</td>
<td>Craftsmen in Baduy society use natural dyes from plants for their distinctive clothing (Batik Baduy) such as indigo from the leaf of indigofera tinctoria. Indigo is formed in damaged leaves by oxidation of hydrolysis products of various precursors like indican (indoxyl-β-D-glucoside) or isatan B (indoxyl/okeogluconate) to indoxyl (Maugard, et al., 2001). The process is affected by the activity of decomposing bacterial enzymes.</td>
<td>Chemistry: chemistry of dyes, chemical reactions, chemical extraction</td>
<td>Junior high and upper secondary school</td>
<td></td>
</tr>
<tr>
<td>Household cleaning materials</td>
<td>Lime (Citrus aurantium), soap nuts (Sapindus rarak), Pteris vitatta and Mischocyrtus fuscescens are used for body cleaning products. The pericarps of soap nuts (Sapindus rarak) contain saponins, high-molecular-weight glycosides consisting of a sugar moiety linked to an aglycone (Hamburger, et al., ). Saponins have detergent or surfactant properties, because they contain both water-soluble and fat-soluble components.</td>
<td>Chemistry: chemistry of detergents, chemical reactions, surface tension</td>
<td>Junior high and upper secondary school</td>
<td></td>
</tr>
</tbody>
</table>
The Baduy people have no access to electricity and fossil fuels like kerosene for lighting. They extract the oil from the fruits of picung (*Pangium edule*) and make it into oil for lamps.

*Pangium edule* contains methyl esters that can be considered a future biodiesel source. This biodiesel produces cloud, pour and cold filter plugging points of −6, −4 and −8 °C, respectively. This shows the viability of using this biodiesel in cold countries (Atabani, et al., 2015).

Biodiesel produces cloud, pour and cold filter plugging points of −6, −4 and −8 °C, respectively. This shows the viability of using this biodiesel in cold countries (Atabani, et al., 2015).

Further, potential topics of ISc for SSI-based education were analyzed from the content and contexts presented in Table 2. The analysis was conducted based on socio-constructivist pedagogies (Juntunen & Aksela, 2014a), the five criteria for selecting socioscientific issues for socio-critical learning (Marks & Eilks, 2009) and topical issues in ESD (Burmeister et al., 2012). Table 2 shows the result of the analysis that encompasses potential topics that can be learned to promote ESD in science education (Zidny et al., 2021).

**Table 2. The potential topics for education from ISc of Baduy Community**

<table>
<thead>
<tr>
<th>Themes</th>
<th>Potential Topic</th>
<th>Sustainability aspect to be learned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>Bio-rational control of pest insects using indigenous materials vs. synthetic pesticides</td>
<td>Learning about risk-benefit analysis between synthetic and green pesticides</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Green chemistry approaches to isolate and explore eco-benign pesticides</td>
</tr>
<tr>
<td>Medicine</td>
<td>Investing in research on traditional medicinal plants as starting points for chemical drug development</td>
<td>Comparison of risks and benefits regarding modern Western and traditional medicine</td>
</tr>
<tr>
<td>Natural dye</td>
<td>Natural dyes from local plants: chemistry applications and sustainability assessment</td>
<td>Risks of chemical textile dyes and eco-friendly alternatives from ISc</td>
</tr>
<tr>
<td>Household cleaning materials</td>
<td>Using plant-based biodegradable compounds from ISc as household chemical</td>
<td>Addressing the issues of water pollution and considering alternative biodegradable household chemicals from ISc</td>
</tr>
<tr>
<td>Renewable energy</td>
<td>Oil lamp from ISc (<em>Pangium edule Reinw</em>): A non-edible oil feedstock for biodiesel production</td>
<td>Issues associated with fossil fuels use and renewable energy sources from plants</td>
</tr>
<tr>
<td>Astronomy</td>
<td>The role of ethnoastronomy in the determine rice planting and harvest times as a response to climate change</td>
<td>Introducing the issue of climate change effects to the agricultural season and reflectively adapting land use to mitigate harmful effects by comparing ISc and modern Western science.</td>
</tr>
</tbody>
</table>

From the study and analysis, it can be concluded that the indigenous knowledge of the Baduy community consists of the application of science (indigenous science) in the sociocultural context (Zidny et al., 2021). The contexts offer a different perspective on science education on how a way of knowing is used to achieve sustainability. It is also promoting a
cross-disciplinary aspect of sustainability and provides a broader view to better understand the non-Western generation of scientific knowledge. The context of science learning from the Baduy community can be used as a fruitful topic in science curricula. It can facilitate the learners to perceive science as more relevant, personal and meaningful because it is close to real-life experiences in the corresponding society. The inclusion of ISc in the science curriculum also gives a chance to discuss how two different ways of understanding (Western modern science and ISc) adjoining to address sustainability issues.

### 3.2 Teaching intervention 1: Chemistry learning about controversial sustainability issues of pesticide based on indigenous science (ISc) and Western modern science (WMSc) perspective (adaptation of Model 3 ESD-type pedagogy)

This section introduced the first teaching intervention on the inclusion of ISc and WMSc perspectives in chemistry learning using the controversial sustainability issue of pesticides use. The study is discussed in the paper entitled "Integrating perspectives from indigenous knowledge and Western science in secondary and higher chemistry learning to contribute to sustainability education" (Zidny & Eilks, 2020).

#### 3.2.1 Focus and Method

The study was conducted using a teaching intervention (Table 3) that introduces the sustainability issue of pesticides use based on ISc and WMSc perspectives (Zidny & Eilks, 2020). Two groups of university (N=73) and upper secondary school (N=40) students participated in the study. The post-intervention questionnaires consist of ten Likert-scale items, and an open-ended question. It was administered at the end of the teaching unit. The data in the study were analyzed using descriptive statistics and text analysis.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Tools and Tasks</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The students explore their a priori knowledge about pesticides and green pesticides.</td>
<td>Worksheet 1</td>
<td>15'</td>
</tr>
<tr>
<td>• The students watch a video about global issues regarding the risks of conventional pesticides in the environment. Then they express their arguments in writing and through a discussion.</td>
<td>Video from TEDx : &quot;Do we really need pesticides?&quot;</td>
<td>45'</td>
</tr>
<tr>
<td>• The learners consider an alternative approach borrowed from IS, based on an article. Then they review and discuss the arguments.</td>
<td>Worksheet 2</td>
<td>45'</td>
</tr>
<tr>
<td>• The participants apply chemistry concepts to answer questions about the topic.</td>
<td>Article and video about pesticides from the Baduy community</td>
<td>30'</td>
</tr>
<tr>
<td>• The students describe their own perceptions of the topic and the incorporation of alternative views taken from IS.</td>
<td>Worksheet 3</td>
<td>15'</td>
</tr>
<tr>
<td></td>
<td>Worksheet 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Questionnaire</td>
<td></td>
</tr>
</tbody>
</table>
3.2.2 Results and conclusion

Based on the data analysis of Likert scale questionnaires, the feedback toward the lesson from the undergraduate student teachers and upper secondary school students can be seen in Figures 3 and 4 (Zidny & Eilks, 2020).

Figure 3. Undergraduate student teacher's feedback toward the lesson

Figure 4. Upper secondary school student's feedback toward the lesson

According to the students’ responses, both groups of students showed positive feedback regarding their experience in terms of motivation and interest in the topic and the relevance of the lesson to the chemistry curriculum. The lesson also supports the students’
view on different cultures and offers them insight into the inclusion of ISc and Western modern science to address sustainability issues and promote intercultural learning.

Further analysis was conducted to the students’ feedback on the open-ended questionnaire. The questionnaire focused on the students’ perspectives on all learning process experiences. Based on text analysis, the student feedback was represented through word cloud visualization and sentiment scores (Figures 5 and 6) (Zidny & Eilks, 2020).

![Word cloud visualization based on the learning experience of (a) university student and (b) upper secondary school students](image)

Figure 5. Word cloud visualization based on the learning experience of (a) university student and (b) upper secondary school students

![Sentiment analysis score of (a) university students and (b) upper secondary school students.](image)

Figure 6. Sentiment analysis score of (a) university students and (b) upper secondary school students.

According to the word cloud visualization, there were many positive words and phrases that were provided by both groups of students to the lesson. The most mentioned words included "environmental care, interesting lesson, open insight, interesting topic". The sentiment analysis result supports the students’ positive attitude toward the lesson, indicated by the positive average scores of sentiment analysis in both university student teachers and upper secondary school students. Nevertheless, a small number of secondary school students still had difficulties recognizing the connection between the chemistry learning context with the related concepts, as illustrated by words "lack of concept" and "not fully understand".
In conclusion, both groups of students perceived the lesson as relevant and interesting. The lesson can open insights for the learners that chemistry learning should consider different disciplines and science worldviews (including ISc and WMSc) to find the solution to sustainability issues.

3.3 Investigation of initial student's ideas related to their argumentation and the application of the chemical concept in the first teaching intervention

This section describes the study on the investigation of the students’ use of argumentation and applying chemical concepts in the teaching intervention. The study is discussed in the paper entitled "A case study on students' application of chemical concepts and use of arguments in teaching on the sustainability-oriented chemistry issue of pesticides use under inclusion of different scientific worldviews" (Zidny et al., 2021, under review a).

3.3.1 Focus and Method

The study intended to explore learners' initial ideas related to the application of chemical content knowledge and argumentation based on classroom worksheet task in the first teaching intervention. The analysis was conducted based on the students’ responses on three worksheets based in Table 4 (Zidny et al., 2021, under review a).

Table 4. Categorization of argumentation and application of chemical concepts in the study

<table>
<thead>
<tr>
<th>No</th>
<th>Worksheet Questionnaire</th>
<th>Category of answer</th>
</tr>
</thead>
</table>
| Q1 | Student's argumentation on the issue of potential risks of pesticides use | Students’ arguments was categorized as:  
  - socio-economic  
  - ethical  
  - ecological  
  - scientific  
  The categorization was adopted from (Liu et al., 2011) |
| Q2 | Student's argumentation on the multiple perspectives of scientific worldviews from WMSc and ISc | |
| Q3 | Applying chemistry concepts in a related context | The student’s response was categorized as:  
  - C1: Student answered the task by connecting a chemistry concept to the context  
  - C2: Student answered the task using an inappropriate chemistry concept as explanation or has misconceptions for the context  
  - C3 : Student answered the task by repeating the question  
  - C4 : Student was unable to answer the question / no response  
  The categorization was modified from (Akkuzu & Uyulgan, 2016; Broman & Parchmann, 2014) |
3.3.2 Results and conclusion

- The application of chemistry concepts based on the student feedback to the problem-solving task (Q3)

The student feedback distribution to the problem-solving task (Q3) is shown in Table 5 (Zidny et al., 2021, under review a).

Table 5. The percentage distribution of the student answer

<table>
<thead>
<tr>
<th>Problem Solving Chemistry (Q3)</th>
<th>Undergraduate student’s response in each category (%)</th>
<th>Secondary school student’s response in each category (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>1a</td>
<td>80,8</td>
<td>6,9</td>
</tr>
<tr>
<td>1b</td>
<td>66,6</td>
<td>0</td>
</tr>
<tr>
<td>2a</td>
<td>75,3</td>
<td>0</td>
</tr>
<tr>
<td>2b</td>
<td>67,5</td>
<td>0</td>
</tr>
<tr>
<td>2c</td>
<td>26,0</td>
<td>0</td>
</tr>
<tr>
<td>2d</td>
<td>28,8</td>
<td>14</td>
</tr>
</tbody>
</table>

The results indicate that university student teachers used more chemistry concepts to solve problem-solving tasks than upper secondary school students (Column C1). Further analysis was conducted to identify the common concepts and misconception that were found in the student responses. The results are shown in Tables 6 and 7 (Zidny et al., 2021, under review a).

Table 6. Common concepts used in student responses to the problem-solving questions (Q3)

<table>
<thead>
<tr>
<th>Number</th>
<th>Topic in problem-solving</th>
<th>Content area</th>
<th>Example of concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (a)</td>
<td>The social issue of pesticides (a case study on DDT) in the environment</td>
<td>Structure of matter, Chemical bonding, Organic chemistry</td>
<td>Stability of chemical structure, benzene, aromatic compound, electron delocalization, bonding energy, structure resonance</td>
</tr>
<tr>
<td>1 (b)</td>
<td>The issue of pesticides that endanger human health</td>
<td>Structure of matter, Chemical bonding, Organic chemistry</td>
<td>Solubility, polarity, hydrophobic molecule, like dissolve like, Benzene, functional groups</td>
</tr>
<tr>
<td>2 (a,b,c,d)</td>
<td>How students explain chemical phenomena from IS from a scientist's point of view</td>
<td>Structure of matter, Chemical bonding, Organic chemistry, Chemical reaction, Chemical analysis</td>
<td>Functional groups, carbohydrates, fermentation reaction, polarity, like dissolve like principle, chemical reagent, extraction</td>
</tr>
</tbody>
</table>

Table 7. Student quotes with misconceptions acquired from worksheets

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Misconception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability of chemical structure, Hydrophobicity, Benzene</td>
<td>Benzene is hydrophobic. There is no water in the environment, so it is difficult to react.</td>
</tr>
<tr>
<td>Stability of chemical structure, Carbon chain length, boiling point, reaction energy</td>
<td>DDT is difficult to decompose because it has a large number of carbon atoms on the chain, which makes its boiling point higher, and requires more energy.</td>
</tr>
<tr>
<td>Solubility, polarity, Halogen (Cl) groups</td>
<td>DDT accumulates in fat due to the polarity of CCl₃ groups.</td>
</tr>
<tr>
<td>Solubility, carbon-chain length, boiling point,</td>
<td>DDT structure has many C atoms, causing the boiling point to be higher and making it difficult to dissolve in water.</td>
</tr>
</tbody>
</table>
### Misconceptions of upper secondary school students

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Misconception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability of chemical structure, halogen group, electron configuration</td>
<td>DDT is difficult to degrade because it has halogen group compounds that have a full electron configuration</td>
</tr>
<tr>
<td>Stability of chemical structure, Benzene, boiling point, evaporation</td>
<td>DDT compounds contain benzene, which is difficult to decompose because it is difficult to evaporate due to its high boiling point</td>
</tr>
<tr>
<td>Solubility, lone pair electron, polarity, solvent</td>
<td>Compounds that have a lone electron like Cl can dissolve in a polar solvent.</td>
</tr>
<tr>
<td>Polarity, electronegativity, CCl3 group</td>
<td>DDT is very polar because it has a very electronegative CCl3 group.</td>
</tr>
</tbody>
</table>

The findings indicate both groups of student consist of students who can link the context to the problem-solving task with chemistry content and concepts such as organic chemistry, the structure of matter, chemical bonding and analytical chemistry. This shows that these contents and concepts exist for students to understand the chemical problem-solving question. In terms of applying the chemical concepts, the university students were able to elaborate a more constructive explanation and make better interrelationship between concepts. The upper secondary school students tended to use factual knowledge to answer the problem-solving task. Some misconceptions were also identified among both groups. These misconceptions mainly were related to the concepts of solubility, polarity, molecular structure stability and chemical and physical properties of organic compounds.

- **Argumentation of the students based on the worksheet tasks (Q1 and Q2)**

  The result of students’ argumentation is presented in Figures 7 and 8 (Zidny & Eilks, under review a). In general, both groups of learners expressed more arguments in the second argumentation task (initiated by multi perspective scientific worldview) rather than in the first argumentation task. This means that the discussion that brings together WMSc and ISc provides an approach to address the sustainability issue with a positive impact on students’ argumentation in all categories. The most promising aspect of the argumentation tasks was that the intervention improved the level of ethical argumentation, since it is not regular for students to express ethical consideration in SSI-based learning (Juntunen & Aksela, 2014b).

![Figure 7. Upper secondary school students’ arguments](image)
3.4 Teaching intervention 2: Learning ethnochemistry as a starting point to develop green and sustainable chemistry principles to the practice of science education lab work (adaptation of Models 1 and 2 ESD-type pedagogy)

This section introduces the study on a second teaching intervention on the inclusion of ISc (Ethnosicence) and WMSc in chemistry learning. The teaching intervention adapted learning Models 1 and 2 of ESD in chemistry by integrating green and sustainable chemistry principles and green laboratory work. The study is discussed in the paper entitled "Learning about phytochemical aspects of botanical pesticides adapted from ethnoscience as a contribution to green and sustainable chemistry education" (Zidny & Eilks, under review b).

3.4.1 Focus and Method

The study focused on a teaching intervention integrating across-discipline chemistry learning with ethnoscience in the lesson topic of "Ethnochemistry in the lab". The description of the learning activities in the lesson plan is represented in Figure 9 (Zidny & Eilks, under review b). The lesson was part of an environmental chemistry course (elective course) with a total of 41 participants from second-year undergraduate chemistry teacher education. This lesson facilitates the student to learn about phytochemical compounds and the process that adapted the indigenous culture's botanical pesticides use. The learning intervention used ethnoscience as a starting point for the learners to develop green chemistry lab activities. To support the green lab activities, a simple experiment of microwave-assisted extraction (MAE) using an unmodified kitchen microwave was introduced in the lesson and compared to the other conventional methods. During the lesson, the learners performed a green chemistry lab evaluation by comparing MAE with conventional methods (Soxhlet and steam distillation) using green metric star evaluation (adopted from Duarte et al., 2015). A Likert-scale questionnaire about the students'
experience toward the lesson was administered to the students after the teaching intervention.

3.4.2 Results and conclusion
The results of the feedback from the university student teachers toward the lesson were very positive (Figure 10) (Zidny & Eilks, under review b). Most of the student perceived the lesson as facilitating and motivating them to learn chemistry ideas from the ethnoscience of indigenous culture. It also provided them with a new insight into the generation of scientific technology inspired by other disciplines such as indigenous cultural knowledge.

![Figure 9. The description of the learning activities in the lesson plan.](image)

![Figure 10. The student's feedback on the post-intervention questionnaire (N=41).](image)
In terms of green and sustainable chemistry learning, the students gained more experiences in implementing green chemistry principles in the chemistry lab and in assessment. The participants developed skills to assess and compare extraction techniques' advantages and disadvantages based on the green metric star (Zidny & Eilks, under review b).
4. Summary

Indigenous knowledge can provide valuable educational values in offering rich contexts for relevant to science learning in any given society (Zidny et al., 2020, 2021). It also reflects the view on nature in the generation of scientific knowledge and offers more holistic perspectives to promote sustainability and intercultural learning (Aikenhead & Michell, 2011; Jones Brayboy & Maughan, 2009; Kim & Dionne, 2014; Zidny et al., 2020). Research on the inclusion of indigenous knowledge in science and chemistry education is suggested to provide evidence-based curriculum development to foster relevance in science learning and promote ESD.

The studies in this dissertation suggest a new educational research framework and didactic model which is suggested to integrate different knowledge systems and multi perspectives on ISc and WMSc (Zidny et al., 2020; Zidny & Eilks, 2020). The framework and didactic model can be used to reconstruct the context of indigenous knowledge to better current science and chemistry education curricula. For the purpose of the implementation of learning designs in class, the pedagogical approach and model of ESD-based type curricula is suggested to link ISc with the discussion of the relevant SSIs in science and chemistry education as well as related topics in the discussion of green and sustainable chemistry (Burmeister et al., 2012; Zidny et al., 2020). This approach can provide the learners insight into how across-disciplinary and intercultural learning from ISc and WMSc can help develop solutions to global sustainability issues.

Research-based development of didactic models and learning designs was conducted to justify evidence-based curriculum development on the inclusion of the ISc and perspectives in science and chemistry education. The project was initiated by exploring relevant contexts and content for science learning from the ISc in the Baduy community, Indonesia. The findings indicate a lot of aspects of ISc might be identified and categorized with a focus on science learning, including agriculture, medicine, renewable energy, household cleaning materials, natural dyes, and astronomy (Zidny et al., 2021). Based on this finding, an educational analysis was carried out to identify potential topics and sustainability aspects that can be integrated to a socio-constructivist ESD pedagogy (Juntunen & Aksela, 2014a). The study also provides a new way for science educators and practitioners on how to incorporate and reconstruct the valuable knowledge, local wisdom, and culture of indigenous peoples into the formal science curriculum.

The topic of agriculture from indigenous science in Indonesia was chosen for the implementation of learning designs in upper secondary and higher institution. One teaching intervention was conducted by taking the role of multi-perspectives from ISc and WMSc to address the sustainability issue of pesticides use in agriculture (Zidny & Eilks, 2020). The
lesson connects the issue with chemistry content from organic and general chemistry. The learning activities provided the learners with a chance to express their arguments about the issues and apply chemistry concepts related to the issue and context. The findings of this study indicate that both groups of students perceive the lessons as relevant and interesting for them. It also broadens their insight into how chemistry learning has a complex interaction with the environment and society to find solutions to sustainability issues. Nevertheless, in term of the connection between chemistry learning of content with the context needs further improvement for the upper secondary schooling level.

Further analysis was conducted to the student's activity tasks in the teaching intervention by investigating initial ideas related to their argumentation and application of chemical concepts about the learning context (Zidny et al., 2021, under review a). The results indicate that both groups of learners showed positive improvement in all argument categories (socio-economical, ethical, environmental and technological) after a multi-perspective of ISc and Western modern science was provided in the discussion about sustainability issues in class. The most promising aspect was that the lesson can enhance the level of ethical argumentation of the learners, which is uncommon in SSI-based learning (Juntunen & Aksela, 2014b). In term of the chemistry concepts application in the problem-solving questions, the university students showed a better ability to provide more comprehensive explanations and to make interrelationship between concepts. The upper secondary student tended to more use factual knowledge in their explanation. The reflection from this study offers a new insight that the human element in chemistry education in term of socio-cultural and philosophical values plays significant roles to make a better connection between chemistry learning and real-life phenomenon.

The second teaching intervention was conducted by adapting Models 1 and 2 of ESD pedagogical approaches to improve the development of lessons and offering alternative learning designs. The lesson was more focused on investigating ethnochemistry from the indigenous community, which was connected to the contents of green chemistry principles and the practice of green chemistry lab work (Zidny & Eilks, under review b). The feedback from the second-year undergraduate chemistry student teachers toward the lesson was very positive. The case provides a new perspective for them that other disciplines such as ethnochemistry can contribute to advances in the generation of scientific knowledge, especially related to offering valuable green and sustainable resources. The lesson also facilitated them to learn the direct implementation of green chemistry principles on laboratory work and assessment.

The studies in this dissertation are limited and need much more evidence and research for further development on the inclusion of ISc in formal science education. Further studies are necessary to be carried out in other countries where indigenous knowledge exists to
seek similarities or differences of research findings, and to provide alternative viewpoints to any topics of interest. The study in this dissertation has provided innovation and prior valuable insights into more specified studies. All in all, the research on the integration of indigenous knowledge in science education is essential. It provides new perspectives on how this pedagogical approach is valuable to enhance science learning’s relevance and to promote education for sustainable development.
5. References


Fasasi, R. A. (2017). Effects of ethnoscience instruction, school location, and parental


Zidny, R., & Eilks, I. (2020). Integrating perspectives from indigenous knowledge and Western science in secondary and higher chemistry learning to contribute to sustainability education. *Sustainable Chemistry and Pharmacy, 16*, 100229.


Zidny, R., & Eilks, I. (under review b). Learning about phytochemical aspects of botanical pesticides adapted from ethnoscience as a contribution to green and sustainable chemistry education.
6. Publications

All publications related to this dissertation:


Zidny, R., & Eilks, I. (2020). Integrating perspectives from indigenous knowledge and Western science in secondary and higher chemistry learning to contribute to sustainability education. Sustainable Chemistry and Pharmacy, 16, 100229.


Zidny, R., & Eilks, I. (under review b). Learning about phytochemical aspects of botanical pesticides adapted from ethnosience as a contribution to green and sustainable chemistry education.

Other publication which support this dissertation:

Declaration of contribution of the candidate to a multi-author article/manuscript
which is included as a chapter in the submitted doctoral thesis

Book Chapter:
Contribution of the candidate in % of the total work load (up to 100% for each of the following categories):

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**Papers article 5:**
Zidny, R., & Eilks, I. (under review b). Learning about phytochemical aspects of botanical pesticides adapted from ethnoscience as a contribution to green and sustainable chemistry education.

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APPENDIX
Indigenous Knowledge as a Socio-Cultural Context of Science to Promote Transformative Education for Sustainable Development: Insights into a Case Study on The Baduy Community (Indonesia)

Robby Zidny
Ingo Eilks

Published in
Indigenous knowledge as a socio-cultural context of science to promote transformative education for sustainable development: A case study on the Baduy community (Indonesia)
Indigenous Knowledge as a Socio-Cultural Context Of Science to Promote Transformative Education for Sustainable Development: Insights into a Case Study on The Baduy Community (Indonesia)

Robby Zidny*,** and Ingo Eilks*

*University of Bremen, Germany, and *University of Sultan Ageng Tirtayasa, Indonesia

Science education must strive to design new curricula that represent a balanced perspective by exposing students to multiple ways of understanding science. The socio-cultural context of viewing science from indigenous perspectives might provide insights into different views on environmental ethics and might enrich understanding of how to solve the increasingly complex problems of the 21st century. An ethnographic study on indigenous knowledge in the Baduy community in Indonesia shows that it can promote our understanding of trans-disciplinary aspects of sustainability which propose a different way of knowing. In their agricultural system, the Baduy community applies principles and concepts of science in a sustainable way which can be understood as ethnochemistry, ethnobotany, ethnomathematics, and ethnoastronomy. Indigenous knowledge has potential to provide learners with a broader view of the world and to understand scientific knowledge by more holistic learning which might make learners able to understand better the role of any social and cultural context in the generation of scientific knowledge.

Introduction

Gilbert (2006) described “context” as a situation that gives meaning to words, phrases and sentences. He emphasized that a context provides a “coherent structural meaning” for a new idea that can be situated within a broader framework (p. 960). The example of the context should be considered important to the lives of communities within the society in place. Science learning starting from a context can become relevant education if it is connected to environmental education and ESD (Eilks & Hofstein, 2014). Recent research trends in science education (Bermudez, Battistón, García Capocasa, & De Longhi, 2017; Hamlin, 2013; Kim, Asghar, & Jordan, 2017) use the socio-cultural context of science from indigenous knowledge to promote environmental education, sustainability, socio-ecological issues, and biodiversity. Indigenous knowledge is the local knowledge held by indigenous peoples or local knowledge unique to a particular culture or society (Warren et al., 1993). This knowledge also has other different names such as “Ethnoscience” (including ethnochemistry, ethnophysics, ethnobiology, ethnomedicine, and ethnoagriculture)
(Abonyi, Njoku, & Adibe, 2014), traditional ecological knowledge (TEK) (Snively & Corsiglia, 2000) and indigenous science (Ogawa, 1995).

Over the times, curricula in science education changed significantly (Eilks et al., 2013). The dominant curriculum approach in the late 1990s to early 2000 focused context-based science education to create meaningful learning for students (King & Ritchie, 2012). It was, however, also suggested that contexts for science learning developed in one country might not be meaningful in another one with a different culture and society (Gilbert, 2006; Holbrook, 2008). Nevertheless, most contexts in science curricula even in non-Western countries are regularly restricted to a Western view on the history of science and a Western view on its technologically ramifications, and thus often neglect any non-Western cultural components (e.g., Khaddoor, Al-Amoush, & Eilks, 2017).

In the view of science education, the relevance of any context suggested for learning must be concerned with the various natural and environmental phenomena described by science in the certain socio-cultural environment in place. In the means of situated cognition, science education to be accepted as meaningful by students in a certain community must be based on their socio-cultural identity. In many countries of the world, e.g. in Asia, the way of knowing about nature was developed by diverse cultural influences, a lot of them can be considered as being non-Western. The influence was inherited from ancestors orally and forms the community’s indigenous knowledge. This knowledge allows insight and guidance to a different kind of environmental ethics. It might help developing understanding how to solve the increasingly complex problems of the 21st century (Snively & Williams, 2016).

The socio-cultural aspects of science from indigenous knowledge can be used as a context for realizing science learning which encourages teachers and students to gain enhanced respect for local culture as well as to provides ways of teaching and learning locally relevant knowledge and skills (De Beer & Whitlock, 2009; UNESCO, 2002). This effort can improve the relevance of science learning and also promote education for sustainability that takes value from local wisdom of indigenous people and strengthen adjoining it with Western views on science. An indigenous culture and the culture of Western science might complement each other in students’ everyday world experiences. In Indonesia, for instance, the Baduy tribe is a traditional community located near a forest area and still maintains ancestral culture. The Baduy are very dependent on the forest that plays an essential role in terms of food security, livelihood, agriculture, and biodiversity resources. One of the Baduy people's central behaviour is related to nature in terms of environmental protection and conservation. Suparmini, Setyawati, Sriadi, Sumunar, & Dyah Respati Suryo (2013) indicated that the Baduy people's behaviour in terms of environmental protection and conservation includes knowledge about: (a) agriculture, (b) the knowledge system, (c) technology, and (d) conservation practices. The socio-cultural context of science behind an indigenous way of knowing certainly can be very interesting to be associated with learning in the classroom to create science learning directly meaningful to daily life and society along a regional example, but also to lead to intercultural learning.
Focus and method

This study aimed to investigate the science-related indigenous knowledge of the Baduy tribe in Indonesia related to their socio-cultural context. The Baduy society is part of a group of indigenous communities formed by a Sundanese tribal group. Their region is geographically located in the Kendeng Mountains in the Indonesian Banten province, 120 km from Jakarta. The Baduy people have cultivated among their community a great wisdom related to the interconnectedness of all living things with the earth and the cosmos, as well as a thorough knowledge about the conservation and sustainability of ecosystems. The Baduy community is divided into two sub-groups: the Baduy dalam (inner Baduy) who maintain strict adherence to the religious prescriptions and inhabit the inner areas and the Baduy luar (outer Baduy) who have a role as a buffer between the inner Baduy and the external world. The study employed qualitative research designs specifically using ethnographic techniques (Creswell, 2012). Research data collection techniques included observations, interviews, documentation, focus group discussion, literature review, and triangulation of data.

Findings and discussion

The study revealed that the Baduy community applies trans-disciplinary indigenous science (ethnochemistry, ethnobotany, ethnomathematics, ethnoastronomy) in a sustainable way to fulfil their needs, especially in terms of agriculture. They apply principles of sustainable chemistry by avoiding the use of synthetic pesticides. As an alternative, they replace it with the use of bio-pesticides extracted from several plants available in the environment such as the Noni fruit (*Morinda citrifolia* L), *Momordica charantia*, *Achasma walang*, *Bridelia monoica*. The bio-pesticide is produced by simple extraction methods. Today, it is known that the Noni fruit contains 160 phytochemical compounds which have benefits such as anti-viral, anti-fungal, anti-bacterial, and anti-nematode behaviour (Senthilkumar et al., 2016).

Furthermore, there is a prohibition on the use synthetic fertilizers in Baduy swidden farming. The Baduy (particularly Outer Baduy) operate several other ways to fertilize their soil. One of which is the introduction of *Paraserianthes (Albizia) falcatoria* (Iskandar & Ellen, 2000). The *Paraserianthes (Albizia) falcatoria* tree is fast growing, nitrogen-fixing, and thus improving soil fertility through nitrogen fixation (Reijntjes et al., 1992). The Baduy society also has a sustainable way to keep the harvested rice in order to be stored for a long period of time (up to 50 years). The Baduy keep it in a special storage called “Leuit”. It is a building design that prevents rats from destroying rice crops without killing them. By applying this knowledge, the Baduy built a paddy storage system that has a wooden circle on the legs that makes the rats difficult to climb. Mathematically, with the angular position and specific cross-sectional area of the wooden circle, it is made very slippery caused by the coefficient of friction is zero (Arisetyawan, Suryadi, Herman, & Rahmat, 2014).

The Baduy rice farming cycle is fixed annually with reference to an agricultural calendar. It is affected by the various environmental perturbations, such as climate
change. As the result, the Baduy have culturally adapted their traditional calendar based on carefully observed natural phenomena and changes of various indicators, such as the annual cycle of appearance and disappearance of the configuration of the belt of Orion and the Pleiades, the flowering time of certain kind of plants, and animal behaviour (Iskandar & Iskandar, 2016). The appearance of Orion and the Pleiades constellation are used as a benchmark for adjustment agricultural issues of the calendar in the Baduy society. The Pleiades usually appear two weeks before the Orion when the sun is in the northern hemisphere. According to the Baduy people, that time is when the land is “cold”. This is an early sign for the planting season.

The Baduy community has an agricultural system that is very concerned with environmental conservation. The application of indigenous science in the Baduy is based on mutually agreed principles and norms to maintain the sustainability of life in the community for both present and future generations. Their local knowledge systems contribute to understanding, mitigating and adapting to climate change, environmental degradation, and biodiversity loss (UNESCO, 2002).

The lesson learned from the life of the Baduy community is how their science is used adjoining with the socio-cultural context (beliefs, norm, culture, spirituals, taboos, law, etc.) to realize sustainable development (ecologically, economically, and societally). The field study reveals that the Baduy cosmological beliefs, norms and culture from their ancestors lead them how to protect nature. They believe that land, forests, and other natural resources have a spirit, so they must protect their homeland. Moreover, they also will not let anything harm the ecosystem and the sacred forest where they live. In their agricultural system (upland rice planting), nine kinds of traditional rituals have been predominantly undertaken in the management of the swidden farming system. The Baduy understand that the existence of their community not only depends on the sustainability of the natural resources but also on the integrity of their culture. Taboos are imposed in a social and cultural context to protect norms, beliefs, culture and behaviour from outside influences. The Baduy have a unique traditional governance, which still exists to regulate their customs. In order to enforce the customary law and control violating taboos, self-control mechanism; social control and punishments are imposed (Ichwandi & Shinohara, 2007). Moreover, their agricultural practices are guided by cultural traditions which use organic farming and fallow-regimes system that allow fields to regenerate.

**Conclusion**

The indigenous knowledge of the Baduy is one example of the application of science (indigenous science) in socio-cultural contexts. This knowledge has a rich context which contributes to the relationship of environmental, socio-cultural and spiritual understandings. The context could be addressed in science learning in order to foster education for sustainability in the curriculum. The integration of indigenous knowledge in the science curriculum provides chances for dialogue and consolidation of two
knowledge system (Western and indigenous knowledge) in dealing with the merging of worldviews concerning sustainability science issues.

There exists a general agreement on the need to reform scientific expertise by developing new ways of understanding knowledge to cope with the challenges of sustainability issues (Sjöström, Eilks, & Zuin, 2016). Trans-disciplinary aspects of sustainability become more and more acknowledged as a transformational stream of sustainability science (Tejedor, Segalàs, & Rosas-Casals, 2018). Indigenous science could provide one view on these trans-disciplinary aspects of sustainability, which proposes different perspectives in the way of knowing. It has potential to provide learners with a broader view on the world to better understand the non-Western generation of scientific knowledge for more holistic learning which has potential to make learners able to understand the role of the various social and cultural contexts in the world for the production of scientific knowledge (Aikenhead & Michell, 2011; Kim & Dionne, 2014).

The lesson learned from the life of the Baduy community is how their science is used adjoining it with their socio-cultural context (beliefs, norm, culture, law, taboos) to realize sustainability. This context can provide a new perspective for science education to promote better understand the way of knowing in science, different ways of contextualizing knowledge in science, promoting intercultural learning, and to achieve sustainability.

**Acknowledgement**

We are grateful for the support afforded to the project by Islamic Development Bank and Indonesian Ministry of Research, Technology and Higher Education.

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A Multi-Perspective Reflection on How Indigenous Knowledge and Related Ideas Can Improve Science Education for Sustainability

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A Multi-Perspective Reflection on How Indigenous Knowledge and Related Ideas Can Improve Science Education for Sustainability

Robby Zidny 1,2 • Jesper Sjöström 3 • Ingo Eilks 4

Abstract
Indigenous knowledge provides specific views of the world held by various indigenous peoples. It offers different views on nature and science that generally differ from traditional Western science. Furthermore, it introduces different perspectives on nature and the human in nature. Coming basically from a Western perspective on nature and science, the paper analyzes the literature in science education focusing on research and practices of integrating indigenous knowledge with science education. The paper suggests Didaktik models and frameworks for how to elaborate on and design science education for sustainability that takes indigenous knowledge and related non-Western and alternative Western ideas into consideration. To do so, indigenous knowledge is contextualized with regards to related terms (e.g., ethnoscience), and with Eastern perspectives (e.g., Buddhism), and alternative Western thinking (e.g., post-human Bildung). This critical review provides justification for a stronger reflection about how to include views, aspects, and practices from indigenous communities into science teaching and learning. It also suggests that indigenous knowledge offers rich and authentic contexts for science learning. At the same time, it provides chances to reflect views on nature and science in contemporary (Western) science education for contributing to the development of more balanced and holistic worldviews, intercultural understanding, and sustainability.

1 Introduction

One of the main problems in science education—is the perception of students that a lot of their secondary science lessons are neither interesting, engaging, nor relevant (Anderhag et al. 2016;
Potvin and Hasni 2014; Stuckey et al. 2013). This is in line with Holbrook (2005) who discussed that learning of science is perceived not to be relevant in the view of students and thus becomes unpopular to them. A main factor for the missing perception of relevance is suggested in a lack of connections of the teaching of science to the everyday life of students and society (Childs et al. 2015; Hofstein et al. 2011). To raise the relevance of science education as part of relevant education, science education should accept a more thorough role in preparing students to become critical citizens (e.g., Sjöström and Eilks 2018). The role of science education is to prepare students to think responsibly, critically, and creatively in responding to societal issues caused by the impact of science and technology on life and society (e.g., Holbrook and Rannikmäe 2007; Hofstein et al. 2011; Sjöström 2013; Stuckey et al. 2013).

To improve the relevance of science education, science teaching requires new ways in the curriculum and pedagogy beyond the mere learning of science theories and facts (Eilks and Hofstein 2015). Science learning should be based on everyday life and societal situations that frame conceptual learning to enable students to appreciate the meaningfulness of science (e.g., Greeno 1998; Østergaard 2017). For acquiring more relevant science teaching and learning—as well as for innovating the curriculum—theory-driven and evidence-based curriculum development for science education and corresponding teacher education are needed (Hugerat et al. 2015). Accordingly, it is important to implement new topics and pedagogies in science teaching and to change teacher education programs. One source for such new topics is sustainability thinking and action, and a corresponding related educational paradigm is called Education for Sustainable Development (ESD) (Burmeister et al. 2012). ESD in connection with science education has been suggested to have potential to contribute to all three domains of relevant science teaching (personal, societal, and vocational relevance) (Eilks and Hofstein 2014). It is relevant for individual action, e.g., in cases involving consumption of resources, participation in societal debates about issues of sustainable development, or careers related to sustainability in science and technology (Sjöström et al. 2015).

However, it should be mentioned that the ESD movement has been criticized for a too instrumental view on the relationship between science, technology, and society. The possibilities of environmental technology for solving environmental problems are emphasized, whereas the need for other societal and behavioral changes is not so much mentioned. Such a view is called ecological modernization (e.g., Læssøe 2010; Kopnina 2014). Education for sustainability (EfS) is a more critical alternative to a narrow-focused ESD (e.g., Simonneaux and Simonneaux 2012; Birdsall 2013). According to Albe (2013), it requires the individual to take the political dimension of environmental issues and their intrinsic power relationships into consideration. The aim is to empower the individual for acting responsibly in terms of sustainability, which was also identified by Stuckey et al. (2013) as an essential justification in their model of relevant science education. Yet another related and critically oriented alternative to mainstream ESD is called ecojustice education (Mueller 2009). In this paper, we use the term science education for sustainability describing science education driven by critical and alternative Western views on the transformation to a sustainable world.

According to Savelyeva (2017), the dominant Western sustainability discourse is based on an anthropocentric conception, where nature needs to be managed within the three pillars of sustainability: ecological, economic, and societal sustainability. Such a view on the human-nature relationship is oriented towards producing a sustainable person. However, as will be explained more in detail below, alternative Western—and less anthropocentric—sustainability discourses have been suggested, such as self-reflective subjectivity (Straume 2015),
transformative sustainability learning (Barrett et al. 2017), a virtue ethics approach (Jordan and Kristjánsson 2017), and eco-reflexive Bildung (Sjöström et al. 2016; Sjöström 2018).

Science is practised based on natural and environmental resources in any given cultural and socio-economic context. However, the picture of science represented in many textbooks all over the world often neglects its cultural component or restricts it to a Western view on the history of science (e.g., Forawi 2015; Khaddour et al. 2017; Ideland 2018). Indigenous views on nature and indigenous knowledge in science at different levels vary among societies and cultures across the globe. The wisdom of indigenous knowledge is often based on sacred respect of nature, due to indigenous peoples’ relationships and responsibilities towards nature (Knudtson and Suzuki 1992). Thus, learning about indigenous knowledge may help students recognize this intimate connection between humans and nature in the foreground of culture from their regional environment or beyond.

Recently, Sjöström (2018) discussed science education driven by different worldviews. Especially he discussed how science teachers’ identities are related to their worldviews, cultural values, and educational philosophies, and all these are influenced by the individual’s perspectives towards it. Different educational approaches in science education and corresponding eco(logy) views were commented on by Sjöström in relation to the transformation of educational practice. The focus was especially pointed on the similarities between Asian neo-Confucianism and alternative-Western North-European reflexive Bildung (see further below).

Indigenous cultures and the culture of (alternative) Western modern science might complement each other in students’ everyday world experiences. The introduction of indigenous knowledge in the classroom will represent different cultural backgrounds and might help improve the interpretation of this knowledge (Botha 2012), so that it makes science more relevant to students in culturally diverse classrooms (de Beer and Whitlock 2009). In addition, the incorporation of indigenous knowledge into school curricula might help to enable students to gain positive experiences and develop corresponding attitudes towards science. It might help students to maintain the values of their local cultural wisdom (Kasanda et al. 2005; de Beer and Whitlock 2009; Ng’asike 2011; Perin 2011).

Some research used indigenous knowledge to contextualize science curricula by a cultural context (Chandra 2014; Hamlin 2013; Kimmerer 2012; Sumida Huaman 2016; van Lopik 2012). Indigenous knowledge offers rich contexts which have the potential to contribute understanding the relationship of environmental, sociocultural, and spiritual understandings of life and nature. This approach could be appropriate to accommodate sociocultural demand in science education curricula as well as to raise students’ perception of the relevance of science learning. Aikenhead (2001) found, however, that possible conflicts may arise when students have the problem of taking information from one knowledge system and placing it into another. There is a number of barriers enabling indigenous knowledge to co-exist in the science curriculum and in the minds of learners and teachers. Barriers are related to limitations of time and corresponding learning materials, prescribed curricula, the selection of appropriate pedagogies, and teachers’ doubts in conveying topics containing spiritual aspects in science (Snively and Williams 2016). Teachers have to be aware that it is especially tricky to handle indigenous spiritual views with sufficient care and respect.

Coming from a Western view on nature and science, this analysis attempts to examine the potential role of indigenous knowledge to enhance the relevance of science education with a certain view on education for sustainability. Our view is that the sciences, as well as many other subject areas, have important roles in education for sustainability (Sjöström et al. 2015; Sjöström et al. 2016). The paper suggests Didaktik models (in the following called “didactic
models”) (e.g., Jank and Meyer 1991; Blankertz 1975; Meyer 2012; Arnold 2012) and frameworks for how to elaborate on and design EfS that takes indigenous knowledge and related non-Western and alternative Western ideas into consideration. Didaktik can be seen as the professional science for teachers and has a long history in Germany, central Europe, and Scandinavia (e.g., Seel 1999; Schneuwly 2011; Ingerman and Wickman 2015).

A theoretical framework, which contributes multiple reference disciplines of science education (Duit 2007), is proposed for adopting indigenous knowledge in science learning. This approach encompasses the interdisciplinary nature of relevant science education to carry out science education research and development. It could provide guidance for research-based curriculum development to construct an indigenous knowledge framework for raising the relevance of science education and students’ perception thereof.

2 Indigenous Knowledge and Related Concepts in the Science Education Literature

The search method in this paper used several scientific literature databases, namely Web of Science, ERIC, Science Direct, and Google Scholar. Several keywords were used to find literature related to the following three main points: (1) a conceptual framework of indigenous knowledge, which includes the definition and concept of indigenous knowledge, the perspective of indigenous knowledge and Western modern science, indigenous knowledge in science education, and the role of indigenous knowledge to promote sustainable development; (2) the relevance of science learning through indigenous knowledge, which encompasses the relevance of science learning in general and indigenous knowledge as a context that supports the relevance of science learning; and (3) research designs and pedagogical approaches to integrate indigenous knowledge in learning and education for sustainability education in science education.

The term indigenous knowledge is broadly defined as the local knowledge held by indigenous peoples or local knowledge unique to a particular culture or society (Warren et al. 1993). The search for the term “indigenous knowledge” in the databases located articles pertaining to a number of different terms. Other notions of indigenous knowledge include indigenous science, traditional ecological knowledge, traditional knowledge, ethnoscience, native science, traditional wisdom, Maori science, and Yupiaq science. The search for the term indigenous knowledge in the Web of Science produced as much as 8436 hits (retrieved on 2018-01-29), including 577 educational research articles either combined with science education or combined with other related topics (plant sciences, environmental sciences, anthropology, environmental studies, and others). From the 577 educational articles, 446 are peer-reviewed research papers, and only a few articles discuss specific conceptual frameworks of indigenous knowledge. The search in ERIC showed 2404 results for the search term “indigenous knowledge” (retrieved on 2018-01-29). From this database, many review papers and research journal papers were found which are specifically discussing the concept of indigenous knowledge. Some research papers also focus on the relationship between indigenous knowledge and sustainable development. Similar results were also found in Science Direct and Google Scholar that mostly contain empirical and theoretical articles on indigenous knowledge. Of the many terms related to indigenous knowledge, the terminology of indigenous science, ethnoscience, and traditional ecological knowledge were the most frequently used in the literature related to science education, so the search then focused these three terms. Because
of the abundance of available articles, potential articles were screened based on the relevant titles. As a result, 22 articles were selected which are directly focusing conceptual frameworks of indigenous knowledge. To complement the perspective with Western modern science and alternative Western thinking, some literature on the philosophy of science education were added by further literature searches.

The literature search for the relevance of science learning was done by using the keyword “relevant science education.” It generated 5363 articles (retrieved on 2018-01-29) in ERIC (consisting of 3178 journal articles, reports articles, book chapter, and others). A more specific search was done combining “relevant science education” with “indigenous knowledge” that brought up articles relating to the sociocultural contexts of science and socio-scientific issues. Further analysis focused on raising the relevance of science learning by indigenous knowledge in terms of promoting environmental protection and sustainable development. Thirty relevant articles were identified including some of the same articles as in the previous literature search.

Further analysis of previously obtained articles was aimed to complement the literature on the topic of research designs and pedagogical approaches to integrate indigenous knowledge in science learning. The search was done with the keyword “pedagogical approach for integrating indigenous knowledge.” This search generated 70 hits in ERIC and 942 results in Science Direct (retrieved on 2018-01-29). A screening for empirical research in anthropological and psychological paradigms, designing instructional approaches to introducing indigenous knowledge into science classrooms and using indigenous science to contextualize science learning by a sociocultural context, identified 14 articles. Further analysis of the articles from this search identified the need for more design research in science education for the integration of indigenous knowledge. One strategy identified in the literature is the Model of Educational Reconstruction (Duit et al. 2005). Search results using the keywords “Model of Educational Reconstruction” produced 88,816 hits in ERIC (retrieved on 2018-01-29). Screening related titles with science education identified seven articles. A search on the development of learning designs accommodated to the relevance of science learning for sustainable development, as well as to promote sustainable development, was added. The search for the keyword “ESD in Science Education” generated 148,499 articles on the ERIC database (retrieved on 2018-01-29). Some articles based on topics related to sustainability and referring to context- and/or socio-scientific issue–based science education were identified this way (Table 1).

3 Indigenous Knowledge, Western Modern Science, and Alternative Western Thinking

3.1 Concepts to Characterize Indigenous Knowledge

Based on an analysis of terms, there are differences in the use of terms Indigenous (with capital I) and indigenous (with lowercase i). According to Wilson (2008), Indigenous (with capital I) refers to original inhabitants or first peoples in unique cultures who have experiences of European imperialism and colonialism. Indigenous peoples have a long history of live experience with their land and the legacy from the ancestor, and their future generations (Wilson 2008; Kim 2018). Meanwhile, the term indigenous (with lowercase i) refers to “things that have developed ‘home-grown’ in specific places” (Wilson 2008, p. 15). In this paper, it is suggested to follow Kim’s (2018) point of view to use the term “indigenous” (with lowercase i) to positioning oneself as an indigenous to one’s homeland. The first author is indigenous to
Indonesia, which is a country that has many traditional tribes and indigenous societies. These societies affect the culture of people living near indigenous environments but not living indigenous lifestyles. Even though the first author considers himself not to belong to an indigenous community, he spent his childhood in a rural environment, and he felt the experience of indigenous knowledge in his daily life as well as he was influenced by the culture of modern society. The first author is also able to speak an indigenous language (second language) used by one of the Indonesian indigenous peoples (Baduy Tribe) and interacted with them in a study focusing the Baduy’s science-related knowledge (Zidny and Eilks 2018). This study is part of a project to educationally reconstruct indigenous knowledge in science education in Indonesia in order to enhance the relevance of science learning as well

<table>
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<tr>
<th>Keywords/topic</th>
<th>Sources and number of hits (2018-01-29)</th>
<th>Identified articles and book chapter</th>
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</table>
as to promote education for sustainability. Meanwhile, the other authors are coming from central and northern European backgrounds with experience to Eurocentric cultures. In line with Kim (2018), all authors position themselves as an “ally” to indigenous people and still maintaining their personal cultural and integrity. In this regard, Kovach (2009) encouraged non-indigenous knowledge academics to incorporate a decolonizing agenda to support indigenous scholarship. The term “decolonization” is defined as a process to acknowledge the values of indigenous knowledge and wisdom (Afonso 2013) and bring together both indigenous and non-indigenous people to learn and respect indigenous knowledge (Kim 2018).

In the last few decades, studies on the knowledge of indigenous cultures involved various disciplines both from the natural and from the social sciences. There is no universal definition available about this kind of knowledge and many terms are used to describe what indigenous people know (Berkes 1993). Some scholars define indigenous knowledge by several terms and their respective perceptions. Snively and Williams (2016) argue that this distinction describes a way to distinguish heterogeneous cultural groups’ ways of knowing about nature. Many terms to describe indigenous knowledge have been used in the literature in science education (Table 2).

Ogawa (1995) proposed to understand science education in a “multiscience” perspective in order to foster “multicultural science education” contributing to the field of science education. The idea of a multiscience perspective acknowledges the existence of numerous types of science at play in science classrooms. Ogawa defined science in a multiscience perspective encompassing three categories: personal science (referring to science at the individual level), indigenous science (referring to science at the cultural or society level), and Western modern science (referring to a collective rational perceiving reality shared and authorized by the scientific community). In a more recent publication, Aikenhead and Ogawa (2007) proposed a new definition about science. They proposed a concept of science which explores three cultural ways of understanding nature. It changes the key terms to become more authentic to better represent each culture’s collective, yet heterogeneous, worldview, metaphysics, epistemology, and values. They also suggested dividing the ways of understanding nature into the following three categories:

1) An indigenous way (referring to indigenous nations in North America)

Indigenous ways of living in nature are more authentic. This view is used to describe indigenous knowledge, which encompasses indigenous ways of knowing. Ways of living in

**Table 2** Alternative terms to describe indigenous knowledge

<table>
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<tr>
<th>Alternative terms</th>
<th>Literature</th>
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<tr>
<td>Indigenous science</td>
<td>Aikenhead and Ogawa 2007; Ogawa 1995; Snively and Corsiglia 2000</td>
</tr>
<tr>
<td>Ethnoscience</td>
<td>Sturtevant 1964; Hardesty 1977; Abonyi 2002</td>
</tr>
<tr>
<td>Native science</td>
<td>Cajete 2000</td>
</tr>
<tr>
<td>Traditional wisdom</td>
<td>George 1999</td>
</tr>
<tr>
<td>Aboriginal science</td>
<td>Aikenhead 2006</td>
</tr>
<tr>
<td>Traditional (native) knowledge</td>
<td>ICSU 2002; Stephens 2000</td>
</tr>
<tr>
<td>Yupiaq science</td>
<td>Kawagley 1995</td>
</tr>
<tr>
<td>Maori science</td>
<td>McKinley 1996</td>
</tr>
</tbody>
</table>
nature are action-oriented, which must be experienced in the context of living in a particular place in nature, in the pursuit of wisdom, and in the context of multiple relationships. One example of this kind of knowledge is the Yupiaq way of understanding nature, which has the focus of surviving the extreme condition in the tundra (Kawagley et al. 1998).

2) A neo-indigenous way (bringing up distinctive ways of Asian nations of knowing nature)

A neo-indigenous way of knowing is based in far more heterogeneous indigenous cultures, which are influenced by the traditions of Islamic and Japanese cultures. The term “indigenous science” is used by Japanese literature in the context of a multiple-science perspective. Indigenous science is a collective rational perceiving reality experienced by particular culture-dependent societies (Ogawa 1995).

3) Euro-American (Western modern) scientific way

Eurocentric sciences represent a way of knowing about nature and it was modified to fit Eurocentric worldviews, meta-physics, epistemologies, and value systems. This also includes knowledge appropriated over the ages from many other cultures (e.g., Islam, India, and China).

3.2 Defining Indigenous Science and Related Terms

From the same perspective, Snively and Corsiglia (2000) defined indigenous science as science obtained from the long-resident oral community and the knowledge which has been explored and recorded by biological scientists. They interpreted indigenous science as Traditional Ecological Knowledge (TEK). The concept of TEK is used by various scientists in the fields of biology, botany, ecology, geology, medicine, climatology, and other fields related to human activity on the environment guided by traditional wisdom (Andrews 1988; Berkes 1988, 1993; Berkes and Mackenzie 1978, Inglis 1993; Warren 1997; Williams and Baines 1993). Even so, Snively and Corsiglia (2000) stated that the definition of TEK is not accepted universally because of the ambiguity in the meaning of traditional and ecological knowledge. Other scholars prefer the term “indigenous knowledge” to avoid the debate about tradition and give emphasis on indigenous people (Berkes 1993). In addition, Snively and Corsiglia (2000) argued that TEK does not represent the whole of indigenous knowledge because it also contributes to some aspects of Western modern science. Therefore, TEK is the product of both Western modern science and indigenous knowledge (Kim et al. 2017).

Snively and Williams (2016) distinguished the scope of indigenous knowledge, indigenous science, traditional ecological knowledge, and Western science as follows:

- **Indigenous knowledge (IK):** The local knowledge held by indigenous peoples or local knowledge unique to a particular culture or society (Warren et al. 1993). IK is a broad category that includes indigenous science.
- **Indigenous science (IS):** IS is the science-related knowledge of indigenous cultures.
- **Traditional ecological knowledge (TEK):** TEK refers to the land-related, place-based knowledge of long-resident, usually oral indigenous peoples, and as noted, consider it a subset of the broader categories of IK and IS. TEK is not about ecological relationships exclusively, but about many fields of science in its general sense including agriculture, astronomy, medicine, geology, architecture, navigation, and so on.
Western science (WS): WS represents Western or Eurocentric science in the means of modern Western science knowledge. Here, Western science knowledge is understood as mainstream Western modern science, i.e., acknowledging that also in modern Western societies’ alternative worldviews and views on science and nature exist (Korver-Glenn et al. 2015). Such views are here called “alternative Western thinking.”

To understand the relationship between indigenous knowledge, indigenous science, and TEK, Kim and Dionne (2014) suggest the “cup of water” analogy (Fig. 1). This analogy illustrates science as a cup or container, and knowledge as water that fills the cup. The shape of the water will adjust to the shape of the cup that holds it. Science is described as a collection of knowledge and methods that shape the perception of knowledge (Kim and Dionne 2014). Thus, knowledge will be perceived differently according to the form of science that reflects cultural traditions and the perspective of those who adhere to it. Western or European knowledge is shaped by Western modern science (WMS) who adhere to the culture and perspective of Western or European societies (Aikenhead 1996; Kim and Dionne 2014). Indigenous knowledge is formed by indigenous science which adheres to the culture and perspective of indigenous society, while TEK is part of the indigenous knowledge which is guided by indigenous science methods that are in parallel with WMS in terms of presenting solutions to ecological problems. Thus, TEK does not represent the whole indigenous knowledge system and has some similarities and differences with WMS (Kim and Dionne 2014).

The term of IK in science education is also known as “ethnoscience.” Ethnoscience was first introduced by anthropologists in an ethnography approach that refers to a system of knowledge and cognition built to classify and interpret objects, activities, and events in a particular culture (Sturtevant 1964; Hardesty 1977). According to Snively and Corsiglia (2000), also IS is sometimes referred to as ethnoscience, which consists of the knowledge of indigenous expansionists (e.g., the Aztec, Mayan, or Mongolian empires) as well as the long-term residents of origin knowledge (i.e., the Inuit, the Aboriginal people of Africa, the Americas, Asia, Australia, Micronesia, and New Zealand). Abonyi (1999) emphasizes that the indigenous own thinking and relation to life is a fundamental focus of ethnoscience to realize their vision of the world. He also notes that ethnoscience may have potentially the same

![Fig. 1 Relationship between indigenous knowledge (IK), indigenous science (IS), and traditional ecological knowledge (TEK) (adapted from Kim and Dionne 2014)](image-url)
branches as Western modern science because it is concerned with natural objects and events. Accordingly, the dimensions of ethnoscience would include a number of disciplines, namely ethnochemistry, ethnophysics, ethnobiology, ethnomedicine, and ethnoagriculture (Abonyi et al. 2014). Ethnoscience might have the same characteristics as TEK because it has been categorized into various disciplines of WMS-based scientific knowledge. Table 3 summarizes all the terminology, definitions, and acronyms related to indigenous knowledge in this paper.

All in all, this analysis is not intended to make contention about the different definitions of indigenous knowledge. Despite there are some different perspectives of scholars to define knowledge systems, we support the view of Snively and Williams (2016) that this distinction simply serves as a way to distinguish between highly heterogeneous groups and their ways of knowing nature.

### 3.3 Perspectives of Indigenous Knowledge

There is some literature in science education which has identified various characteristics and opposing views between Western modern science and indigenous knowledge. Nakashima and Roué (2002) identified that indigenous knowledge is often spiritual and does not make

<table>
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<tr>
<th>No.</th>
<th>Terminology and acronym</th>
<th>Definition</th>
<th>References</th>
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<tbody>
<tr>
<td>1.</td>
<td>Indigenous (with capital I)</td>
<td>Refers to original inhabitants or first peoples in unique cultures who have experiences of European imperialism and colonialism</td>
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</tr>
<tr>
<td>3.</td>
<td>Indigenous knowledge (IK)</td>
<td>The local knowledge held by indigenous peoples or local knowledge unique to a particular culture or society</td>
<td>(Warren et al. 1993)</td>
</tr>
<tr>
<td>4.</td>
<td>Indigenous science (IS)</td>
<td>The science-related knowledge of indigenous cultures. This science shaped indigenous knowledge based on the culture and perspective of indigenous society.</td>
<td>(Snively and Williams 2016); (Kim and Dionne 2014)</td>
</tr>
<tr>
<td>5.</td>
<td>Traditional ecological knowledge (TEK)</td>
<td>TEK is part of the indigenous knowledge which is guided by indigenous science methods that are in parallel with WMS in terms of presenting solutions to ecological problems.</td>
<td>(Kim and Dionne 2014)</td>
</tr>
<tr>
<td>6.</td>
<td>Ethnoscience</td>
<td>Refers to a system of knowledge and cognition built to classify and interpret objects, activities, and events in a particular culture. Ethnoscience has been categorized into various disciplines of WMS-based scientific knowledge, namely ethnochemistry, ethnophysics, ethnobiology, ethnomedicine, and ethnoagriculture.</td>
<td>(Sturtevant 1964; Hardesty 1977); (Abonyi et al. 2014)</td>
</tr>
<tr>
<td>7.</td>
<td>Western science (WS)/Western modern science (WMS)/alternative Western thinking</td>
<td>Western science knowledge is understood as mainstream modern Western science, acknowledging that also in modern Western societies, alternative worldviews and views on science and nature exist. This we call “alternative Western thinking.”</td>
<td>(Korver-Glenn et al. 2015)</td>
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distinctions between empirical and sacred knowledge in contrast to Western modern science, which is mainly positivist and materialist. They also emphasized that Western modern science generally tries to use controllable experimental environments on their subject of study, while on the contrary indigenous knowledge depends on its context and particular local cultural conditions. In addition, indigenous knowledge adopts a more holistic approach, whereas on the opposite, Western modern science often tries to separate observations into different disciplines (Iaccarino 2003).

The perspective of Western contemporary culture and philosophy encourages us an interesting idea about the different forms of knowledge. Feyerabend (1987) acknowledged that any form of knowledge makes sense only within its own cultural context, and doubted people’s contention that the absolute truth criteria are only being determined by Western modern science. This is in line with Bateson (1979) who pointed out that the actual representation of knowledge depends on the observer’s view. Therefore, every culture has its way of viewing the world so they may have developed unique strategies for doing science (Murfin 1994). The theory of multicultural education in science also proposed the same ideas which recognize science as a cultural enterprise. Aikenhead (1996, p.8) stated that “science itself is a subculture of Western or Euro-American culture, and so Western science can be thought of as ‘subculture science’”. It is based on the worldview presuppositions that nature and the universe are ordered, uniform, and comprehensible. However, Hansson (2014) has shown that many upper secondary students view scientific laws as only valid locally and that they differentiate between their own views and the views they associate with Western science. This indicates that also many Western people have a “personal science” (Ogawa 1995) way of thinking.

At the same time, it is widely known that there is a different perspective between Western modern science and indigenous knowledge in the context of strategies to create and transmit knowledge (Mazzocchi 2006). Eijck and Roth (2007) pointed out that both domains of knowledge are incommensurable and cannot be reduced to each other, because they are based on different processes of knowledge construction. Therefore, it is difficult to analyze one form of knowledge using the criteria of another tradition. Despite there are many distinctions on both sides, Stephens (2000) discovered the common ground between indigenous knowledge and Western modern science (Table 4), even though there are some suggestions to improve the content (e.g., Aikenhead and Ogawa 2007). Stephens (2000) emphasized that correlating one with another would be validated local knowledge as a pathway to science learning, and demonstrated that the exploration of multiple knowledge systems could enrich both perspectives to create thoughtful dialog.

3.4 Indigenous Knowledge and Alternative Western Thinking

Ideologically mainstream Western science can be described with labels such as positivism, objectivism, reductionism, rationalism, and modernism (e.g., Sjöström 2007). Many of these characteristics can be explained by the body-mind dualism that has been promulgated in Western civilization all since René Descartes (e.g., Bernstein 1983). It is called a Cartesian view and also includes the view that human beings are seen as separate from nature and with rights to exploit the Earth and its resources. In contrast to Western dualisms and modernism, most Eastern philosophies are more holistic and system-oriented (e.g., Hwang 2013). For example, Neo-Confucianism has been suggested as an alternative to the dominant Western sustainability discourse (Savelyeva 2017). Humans are positioned in harmony with cosmos and such a view can be called cosmoanthropic: “everything in the universe, including humans,
shares life and deserves greatest respect […] cosmos is not an object, physical reality, or a mechanical entity; cosmos is a dynamic and ever-changing interpretive reality, which reflects human understanding, sense-making and interpretation of the universe” (Savelyeva 2017, pp. 511–512).

Another more recent Korean philosophy, highly influenced by Neo-Confucianism, but also based on, e.g., Taoism and Buddhism, is called Donghak (=Eastern learning). Moon (2017) describes that in Donghak the interconnection and equal relations between God, human, nature, and cosmos go beyond the anthropocentric understanding of any human-nature relations. Similarly, Wang (2016) has discussed Taoism and Buddhism in relation to the concepts of self-realization and the ecological self-according to ecosophy, the eco-living philosophy developed by the Norwegian philosopher Arne Naess. It is strongly influenced by Buddhist traditions and can be explained as a lifestyle that incorporates ecological harmony and ecological wisdom.

Recently, De Angelis (2018)—in the context of sustainability—compared Buddhist/Eastern spiritual perspectives and indigenous-community learning with alternative Western thinking such as transformative learning theory (Sterling 2011) and Dewey’s experience-thinking (see further below). De Angelis (2018) proposes that they all—to a higher or lower degree—share the notions of inner experience, oneness of reality, and moral sustainable values. Other similarities are awareness of context and a holistic orientation. She writes: “human beings

### Table 4
Stephens’s (2000) similarities and differences between indigenous knowledge and Western modern science

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<th>Western modern science</th>
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<td>• Holistic</td>
<td>• Universe is unified</td>
<td>• Part to whole</td>
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<td></td>
<td>• Communication of procedures, evidence and theory</td>
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are seen as strictly interconnected and co-existing with nature and their self-development is conceived in harmonious terms with it” (p. 184). Values, feelings, and emotions are seen as significantly contributing to various transformative processes. Furthermore, she emphasizes that her intention is to give “a voice to ‘other’ ways of perceiving the relationship between humans and the environment” (p. 189).

As indicated with the examples above, many of the ideas that are characteristic of Eastern philosophies and indigenous knowledge (according to Table 4) can also be found in some alternative Western thinking. Examples include holistic thinking, an integrated worldview, and respect for all living things. Below, we more in detail describe the following three interrelated philosophical directions of alternative Western thinking: (a) a post-human version of the European notion of Bildung, (b) phenomenology and embodied knowledge, and (c) network-thinking, respectively:

(a) Post-human Bildung: In Central and Northern Europe, there is a philosophical and educational tradition called Bildung (Sjöström et al. 2017). It was in its modern educational meaning coined in Germany in the late eighteenth century and then spread to Scandinavia. However, the real origins of the concept can be traced back to the Middle Age, when it had theological and spiritual connotations (Horbach 2016; Reichenbach 2016). Meister Eckhart (1260–1328) introduced the term as early as in the late thirteenth century when he translated the Bible from Latin into German. He used it as a term for transcending “natural existence and reach real humanity” (Horbach 2016, p. 8). Then it took roughly five hundred years until the term started to be used in educational contexts, meaning self-formation. The rooting of Bildung in Romanticism was later intertwined with contemporary ideas of Enlightenment (Reichenbach 2014). It became also connected to morality and virtue, or in one word to humanity (Reichenbach 2016).

Generally, the following five historical elements of Bildung can be identified:

- Biological-organic growth process (self-knowledge is a prerequisite for humanism)
- Religious elements (transparency for a spiritual world in contrast to only materialism)
- Connection to ancient cultures
- Enlightenment thoughts (forming informed and useful democratic citizens)
- Socio-political dimension (emancipation)

The two main elements of Bildung are autonomous self-formation and reflective and responsible societal (inter)actions. Most versions of Bildung are highly influenced by Western modernism (Sjöström 2018), although alternatives, which in a way connect to the roots of the concept, have developed during the last two decades. Rucker and Gerónimo (2017) have theoretically connected the concept to the complexity and some scholars have started to discuss it from postmodern, post-human, and sustainability perspectives, where both relations and responsibility are emphasized (e.g., Taylor 2017; Sjöström 2018; Rowson 2019). Taylor (2017) asked if a post-humanist Bildung is possible and she seems to think so:

A posthuman Bildung is a lifelong task of realizing one’s responsibility within an ecology of world relations, it occurs outside as well as inside formal education, in virtual as well as ‘real’ places. [...] It is a matter of spirituality and materiality which means that it is not an ‘inner process’ but an educative practice oriented to making a material difference in the world. [...] It is education as an ethico-onto-epistemological quest for (better ways of) knowing-in-becoming. (pp. 432–433)
With many similarities to the Eastern thoughts of co-living, and just like “ecosophy” in a Western context, two of us have discussed what we call eco-reflexive Bildung (Sjöström et al. 2016). It adds an eco-dimension to critical-reflexive Bildung and has similarities to the cosmoanthropic view described above as well as to Donghak. These ideas have in common the view of life and society as interdependent and an inseparable whole.

(b) Phenomenology and embodied knowledge: The discussion about Bildung connects to the second alternative Western idea, which is life-world phenomenology and connected embodied experiences (Bengtsson 2013). These ideas are based on philosophical thinking originating from the philosophers Merleau-Ponty, Heidegger, and Husserl. Bengtsson (2013) describes this understanding by the view that the life of the individual and the world is interdependent and that the lived body is a subject of experiencing, acting, understanding, and being in the world. John Dewey had similar thoughts about the experience (Retter 2012) and Brickhouse (2001) has emphasized the importance of an embodied science education, which overcomes the body-mind dualism.

Related to this, some science education scholars have emphasized the role of wonder, esthetic experience, romantic understanding, and environmental awareness in science education (e.g., Dahlin et al. 2009; Hadzigeorgiou and Schulz 2014; Østergaard 2017). Hadzigeorgiou and Schulz (2014) focused on the following six ideas: (1) the emotional sensitivity towards nature, (2) the centrality of sense experience, (3) the importance of holistic experiences, (4) the importance of the notions of mystery and wonder, (5) the power of science to transform people’s outlook on the natural world, and (6) the importance of the relationship between science and philosophy. These six ideas are related to “relations between self, others and nature” and to Dewey’s esthetic (phenomenological existence) and reflective (pragmatic existence) experience (Quay 2013). It can also be described by “being-in-the-world” and “a total, relational whole” (p. 148).

Dahlin et al. (2009) have argued for a phenomenological perspective on science and science education and they discussed how it can foster students’ rooting (see also Østergaard et al. 2008). By phenomenology, they emphasized that all human experiences are important and that “subject and object must be seen as belonging together, as two aspects of one (non-dualistic) whole” (Dahlin et al. 2009, p. 186). Furthermore, they are critical to cognitionism and technisation and instead emphasize the rich complexity of nature and lived experience. In contrast to both constructivism and sociocultural learning, they describe phenomenology to be more open to esthetic, ethical, and moral dimensions of science. These views have similarities to Eastern philosophies and indigenous knowledge.

(c) Network-thinking: The third alternative and related Western idea is network-thinking by, e.g., the French sociologist Michael Callon (born 1945) and the French philosopher Bruno Latour (born 1947). A conflict between modernism and postmodernism in science education has been identified by Blades (2008). This tension is related to the tension between views in traditional science education versus more progressive views in the area of environmental education (Dillon 2014). In an article about emancipation in science education, Zembylas (2006) discussed the philosophy of meta-reality by Roy Bhaskar. He claimed that Bhaskar’s ideas offer an interesting alternative to modernist and post-modernist accounts. Bhaskar viewed everything as connected—humans, nonhumans, and “things.” These thoughts are similar to some thinking of actor-network theory developed
by, e.g., Callon and Latour. In Latour’s networks, knowledge and power are not separable and he claims that it is not possible to stay outside a field of competing networks for giving an objective description of the state of affairs. Latour (2004) introduced the concept matters of concern to refer to the highly complex, uncertain, and risky state of affairs in which human and non-human entities are intimately entangled.

Network-oriented science education focuses on interactive relational production of knowledge. Colucci-Gray and Camino (2014) write about “science of relationships” and “epistemic and reflexive knowledge” (see also Colucci-Gray et al. 2013). More recently, the same authors suggested activities that aim at developing reflexivity about the individual’s position in the global, ecological web. They related it to the thinking of Gandhi and emphasized ideas such as non-duality and interdependency, and relational ways of knowing (Colucci-Gray and Camino 2016). Except for cognitive and social development, they also emphasized emotional and spiritual development. On the question what should be the narratives of science education, they answered non-human relationships, interactions between science, values and learning, embodied experiences, and interdisciplinarity. In addition to Gandhi’s philosophy they also refer to ecosophy and different Eastern traditions.

Brayboy and Maughan (2009) have pointed out that the objective for most culturally relevant science learning is not to put indigenous knowledge and Western modern science in opposition to one another, but instead to extend knowledge systems and find value and new perspectives for teaching and learning from both. This is aligned with the perspective of two-eyed seeing as a means to build bridges and “to help these cultures find ways to live in mutual respect of each other’s strengths and ways” (Hatcher et al. 2009, p. 146): “Through two-eyed seeing students may learn to see from one eye with the strengths of indigenous ways of knowing and from the other eye with the strengths of Western ways of knowing.” McKeon (2012) used the perspective of “two-eyed seeing” for weaving the knowledge from the views of non-indigenous environmental educators to enrich environmental education by indigenous understandings. The indigenous understandings are communicated through oral tradition to teach about the interconnectedness of nature and the concepts of transformation, holism, caring, and responsibility. The core ideas in environmental education (systems theory, ecological literacy, bio-philia, and place-based education) can obtain advantage from and connect to foundational values of indigenous education (McKeon 2012).

4 Indigenous Knowledge in Science Education

4.1 Conceptual Frameworks of Indigenous Knowledge in Science Education

Studies in constructivism opened up the science educators to understand science not only as a body of knowledge but also as a way of thinking. Indigenous science is the knowledge which reflects the indigenous way of thinking about the physical world (Abonyi et al. 2014). Thus, constructivism provides the opportunity for indigenous science to adjoin with Western modern scientific views. The perspective of constructivism suggests that knowledge is not a kind of thinking that can be copied between individuals, but rather has to be reconstructed by each learner (Taber 2014). According to Taber (2013), human learning is interpretive (a sense-making process to produce a perception of the world), incremental (integrating the existing knowledge and understanding which enable learners to make sense), and iterative (reinforces
the existing interpretation). Accordingly, once learners have developed a particular understanding, then they will interpret new information according to this way of thinking and tend to learn it in a way that reinforces the existing interpretation. The indigenous ways of thinking can provide corresponding learners with a broader (more holistic) view of the world to understand science and nature beyond a non-Western perspective (Kim and Dionne 2014). The integration of indigenous knowledge in science education provides a holistic learning framework of the study, which make learners with an indigenous background able to understand the role of their societal and cultural context in the production of scientific knowledge (Aikenhead and Michell 2011). It has potential to facilitate learners to make own sense of their world and reinforces their existing interpretation of natural phenomena.

Cobern (1996) suggested that learning is the active process of constructing a conceptual framework based on the interpretation of learners’ prior knowledge, rather than the process of transmission which only make learners memorize knowledge. The interpretation is affected by the personal and culturally embedded background of knowledge of the learners that make learning processes meaningful. This view suggests building a conceptualization of scientific knowledge in which it is reasonable to expect culture-specific understandings of science (Cobern 1996). Accordingly, in the perspective of any learners, indigenous science can serve as a base for the construction of reality by linking culture to advance scientific knowledge (Abonyi et al. 2014). Moreover, incorporating indigenous knowledge in science education for all may help to reflect the different intellectual traditions of various cultures adjoined with scientific knowledge to solve relevant problems in the context of its ecological, societal, and economic ramifications.

McKinley and Stewart (2012) point out four major themes of research and development associated with integrating indigenous knowledge into science education. These are (a) equity of learning outcomes for students from non-Western backgrounds, (b) contributions of indigenous knowledge to the knowledge base of Western modern science, (c) environmental concerns over sustainability, and (d) inclusion of the nature, philosophy, and limits of science. For instance, Lowan-Trudeau (2012) developed a model based on métissage (the metis methodologies) to incorporate Western and indigenous knowledge and philosophy into ecological identities and pedagogical praxis. Métissage offers the diversity of views and experiences about nature which is required for the development of environmental education research for future generations. Environmental education researchers from all cultural backgrounds are encouraged to acknowledge and engage with indigenous knowledge, philosophies, and methodologies (Lowan-Trudeau 2012).

The integration of indigenous knowledge in education should recognize indigenous frameworks and methodologies to give more attention to their history, politics, cultural beliefs, and philosophical views as well as to balance the Western perspective (Smith 1999, 2002). For instance, some Maori scholars have used their frameworks and methodologies to incorporate indigenous knowledge in education. Smith (1999) suggested Kaupapa Maori as a research approach to reconstruct and recognize indigenous knowledge of Maori people rather than using mainstream research that is too Western paradigm-oriented. The term of Kaupapa Maori describes the Maori worldview that incorporates their thinking and understanding about practice and philosophy living (Smith 1997; Pihama and Cram 2002). Based on the framework and key principles of Kaupapa Maori, Maori’s scholars developed oral traditions and narrative inquiry approaches to express their experiences. Ware, Breheny, and Forster (2018) developed a Māori approach called Kaupapa Kōrero to collect, introduce, and understand Māori experiences and also interrelatedness and influence of their societal expectations,
indigeneity, and culture. In school education, Lee (2002) suggested the *akonga Maori* framework to view Maori secondary teachers’ experiences in relation to teacher education in ways that are culturally responsive and culturally relevant to Maori students. This framework offers education providers to be more involved with Maori students in preparing them for their work in secondary schools.

In the literature, the integration of indigenous knowledge with science education has been widely distilled and packaged based on the different genres and cultures of Western modern science disciplines in the form of TEK (Afonso Nhalevilo 2013; Bermudez et al. 2017; Chandra 2014; Chinn 2009; Funk et al. 2015; Hamlin 2013; Kim and Dionne 2014; Kimmerer 2012; Sumida Huaman 2016; van Lopik 2012; Nadasdy 1999; Simpson 1999). Based on the suggested polygon framework of TEK (Houde 2007; Kim et al. 2017), it is suggested that TEK pedagogy should respect five dimensions as in the didactic model in Fig. 2.

Using the polygon framework of TEK, Kim et al. (2017) explored current pedagogical conceptualizations of knowledge systems in science education and criticized the implication of TEK (Table 5).

Reflecting on the conceptualization of the TEK polygon in science education, it is suggested that TEK should be interpreted as the product of both Western modern science and indigenous knowledge because it has distilled indigenous knowledge into Western modern science framework. The two knowledge systems should complement each other, should work together, and should be acknowledged in their respective entities. It is also suggested to take certain aspects into account when incorporating indigenous knowledge in science education:

- An educational approach to indigenous knowledge should give more attention to socioculture, history, and current politics of a place in addition to ecological and environmental aspects (Smith 2002; Ruitenberg 2005; Kim et al. 2017). This approach gives the student opportunities to learn science more authentically beyond their physical environments. From local environments, learners have a wealth of information regarding
the diverse rural sociocultural and ecological connections. Avery and Hains (2017) suggest that the diverse knowledge of rural children, which is inherited by elders’ wisdom, must be respected in order to solve the complex problems in the new age of the Anthropocene. The knowledge should be cultivated to enrich science education pedagogies and practices which can be learned from individual and unique rural contexts. Moreover, supporting and valuing students’ knowledge in urban science education is also a necessity. Science education should recognize urban students’ ways of communicating and participating in order to support the effective teaching of science to students with different cultural backgrounds in urban science classrooms (Edmin Emdin 2011).

Table 5 Conceptualization of TEK in science education

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</table>
| 1   | Place-based teaching approach                   | - Science education sorely focuses on the advantages of learning about the natural environment through a place-based approach (Kim et al. 2017).  
- TEK tend to adopt a Western compartmentalized “space” conception which is not reflecting indigenous perspectives (Kim et al. 2017; Smith 2002). |
| 2   | Environmental education for sustainability      | - TEK distilled the spiritual aspect of IK and might recognize it as a myth (Garrouette 1999; Kim et al. 2017).  
- The cultural appropriation in promoting TEK tend to focus on the differences between TEK and WMS and to meet the needs of Western environmental problems (Carter 2008). |
| 3   | Fostering multiculturalism in science education | - Science education should not view TEK and WMS as being incommensurate (Kim et al. 2017).  
- Some implications of TEK in science curricula highly emphasize the cultural aspect, rather than the scientific values for students (Kim et al. 2017).  
- Indigenous knowledge is often represented as a comparison of other cultures in science curricula and tends to assume it as primitive knowledge (Kim and Dione 2014). |
| 4   | Culturally relevant curricula for indigenous students | - There is a hesitation that TEK can help revitalize cultural identities for indigenous students because it is grounded in a Western framework (Kim et al. 2017). |
| 5   | TEK cosmology                                   | - Scholars have tended to perceive TEK as a different and separate system than WMS, thus creating a divide between the knowledge systems (Houde 2007).  
- Spiritual aspects that concern interconnectedness of nature are missing because it is distilled in the packaging process under the empiricist philosophy of science (McGregor 2006; Kim et al. 2017). |
The pedagogy of multiculturalism of indigenous knowledge in science education must attempt to acknowledge the multiple perspective ways of knowing the differences and similarities of as well as relations of different types of knowledge systems (Ogawa 1995; Aikenhead 1996; Mueller and Tippins 2010; Kim and Dionne 2014). Kapyrka and Dockstator (2012) suggest an educational approach to encourage teachers and students to promote respective cultural understandings and collaborative solutions between indigenous and Western worldviews.

Indigenous cosmological grounding must be involved to help revitalize cultural identities for indigenous students (McGregor 2004; Kimmerer 2012). For instance, Sutherland and Swayze (2012) used the indigenous framework of Ininiwisk n tamowin (the knowledge of the people in how we understand the Earth) as a model for science and math programs in indigenous settings. This framework was applied to a culturally relevant environmental education program, as a process of lifelong learning, and to give a broad understanding of interconnected relationships with nature, living and non-living entities in the environment and beyond (Sutherland and Swayne 2012).

Science education should recognize the significant wisdom values of indigenous knowledge that encompass spirituals, philosophical, worldviews, and stories of indigenous communities (Kawagley et al. 1998; Kawagley and Barnhardt 1998; McGregor 2004). All these aspects are necessary as a reflection on multiple perspective ways of knowing (Snively 1995) and as appreciation on the interconnected relationships of human and nature as well as to maintain the values of local cultural wisdom (Kasanda et al. 2005; de Beer and Whitlock 2009; Ng’asike 2011; Perin 2011).

Collaborative work with indigenous experts is needed to understand nature from an indigenous perspective (Garroutte 1999; Kim and Dionne 2014). The knowledge holders and communities must be involved to avoid diminishing or misrepresenting knowledge (Kim et al. 2017).

4.2 The Potential Role of Indigenous Knowledge for Transformative Education

According to the goal of twenty-first century education, Bell (2016) suggested that conventional teaching models must shift to a transformative style of education in order for humankind to learn how to live more sustainably. This implication could accommodate student transformative experiences in which they use ideas from the science classroom to see and experience the world differently in their everyday lives (Pugh et al. 2017). The involvement of transformative education with sustainable science has the potential to play an integral role in this paradigmatic shift, which requires the wider legitimation of our ecology as a highly interconnected system of life (Williams 2013). The students can use their ideas and beliefs in another way of knowing nature, which contributes to a better understanding of social, cultural, economic, political, and natural aspects of local environments. Indigenous science could provide a potential topic in pedagogical approaches for transformative education towards a sustainable future.

There exists a general agreement on the need to reform scientific expertise by developing new ways of understanding knowledge to cope with challenging sustainability issues (Sjöström et al. 2016). Transdisciplinary aspects of sustainability became acknowledged as a transformational stream of sustainability science (Tejedor et al. 2018). Indigenous science can provide one of these transdisciplinary aspects of sustainability, which proposes a different way
of knowing. It has potential to provide learners with a different view of the world to understand scientific knowledge and more holistic learning, which learners make able to understand the role of the social and cultural context in the production of scientific knowledge (Aikenhead and Michell 2011; Kim and Dionne 2014).

By integrating multiple ways of knowing into science classrooms, students can learn the value of traditional ways of knowing. They can learn to utilize a conceptual eco-reflexive perspective and to acknowledge that learning and understanding are part of a complex system that includes experience, culture, and context, as well as mainstream science that is taught in class (Mack et al. 2012). This process can facilitate transformative experiences which encompass three characteristics: (1) motivated use (application of learning in “free-choice” contexts), (2) expansion of perception (seeing objects, events, or issues through the lens of the content), and (3) experiential value (valuing content for how it enriches everyday experience) (Pugh et al. 2017). The transformation of science education for learners is not merely a set of strategies related to changing learners’ behavior, changing the curriculum or pedagogy, changing definitions of science, or changing governance. Transformation of (science) education will also need to occur in the wider context to respect both indigenous and non-indigenous knowledge (Snively and Williams 2016).

4.3 The Role of Indigenous Knowledge in Science Education for Sustainability

Despite indigenous knowledge has been passed down from generation to generation over the centuries, its existence has been neglected and tended to be largely omitted from science curricula (Kibirige and van Rooyen 2006), as many other aspects of society and culture are (Hofstein et al. 2011). With the growing consideration of several problems facing the world, such as hunger, poverty, diseases, and environmental degradation, issues due to the weakness of Western modern science to overcome it has opened the insight and interest of the global community to take into account more thoroughly indigenous knowledge as a solution (Senanayake 2006; Odora Hoppers 2004). For instance, scientists have identified indigenous peoples’ practices to survive their life in nature: indigenous soil taxonomies; soil fertility; agronomic practices (terracing), such as contour banding, fallowing, organic fertilizer application, crop-rotation, and multi-cropping; conservation of soil and water; and anti-desertification practices (Atteh 1989; Lalonde 1993). Practices of indigenous pest control systems gained new interest for wide use in tropical countries. An ancient known mention of a poisonous plant having bio-pesticide activities is *Azadirachta indica*. This plant contains compounds which have been established as a pivotal insecticidal ingredient (Chaudhary et al. 2017).

The acknowledgement of the knowledge and practices of indigenous people to promote sustainable development has increased around the globe. For instance, UNESCO created the *Local and Indigenous Knowledge System* (LINKS) (UNESCO 2002). This program has a goal to explore the ways that indigenous and local knowledge systems contribute to understanding, mitigating and adapting to climate change, environmental degradation, and biodiversity loss. In addition, as part of its education for a sustainable future project, UNESCO launched the *Teaching and Learning for Sustainable Future: A Multimedia Teacher Education Program* (UNESCO 2002). It provides professional development for student teachers, teachers, curriculum developers, education policymakers, and authors of educational materials. This program also encourages teachers and students to gain enhanced respect for local cultures, their wisdom and ethics, and suggests ways of teaching and learning locally relevant knowledge and skills.
The integration of an indigenous perspective in science education has been widely applied by scholars in some regions, including Africa, Australia, Asia, and America. Ogunniyi and Hewson (2008) analyzed a teacher training course in South Africa to improve the ability of teachers to integrate indigenous knowledge into their science classrooms. Ogunniyi and Ogawa (2008) addressed the challenges in the development and implementation of indigenous science curricula in Africa and Japan. In Canada, Bridging the Gap (BTG) program provides inner-city students from Winnipeg in Manitoba with culturally relevant, science-based environmental education. This program content brings together environmental education and local indigenous knowledge and pedagogies (Sutherland and Swayze 2012). Reintegration of indigenous knowledge into education has also been carried out for a long time in Alaska. This process was initiated by the AKRSI (Alaska Rural Systemic Initiative) program that reconstructs indigenous knowledge of Alaska people and develops pedagogical practices by incorporating indigenous ways of knowing into formal education (Barnhardt et al. 2000). This process aims to connect learning processes inside classroom and experience outside school so that it can broaden and deepen the students understanding as well as encouraging them to learn about traditional culture and values (Barnhardt 2007). Moreover, in Indonesia, there is a bold attempt to reconstruct ethnoscience to promote the values of nature conservation and develop critical self-reflection on own cultural backgrounds (Parmin et al. 2017; Rahmawati et al. 2017; Widiyatmoko et al. 2015). In higher education, Australian undergraduate programs implemented indigenous studies in their curricula. The results suggest that the program can promote the greater capacity for students’ skills in critical reflections (Bullen & Roberts 2019).

Furthermore, the integration of indigenous knowledge is also involved in science teacher’s professional development programs. Sylva et al. (2010) conducted a study to transform science teacher professional development to facilitate teachers to make the content related to the environment and agriculture science fields more relevant to Hawaiian students’ lives and backgrounds. Chinn (2014) suggested that scientific inquiry learning associated with indigenous knowledge and sustainability practices supports the development of ecological attention of teachers. In addition, long-term professional development providing situated learning through cross-cultural immersion and interdisciplinary instruction also supports teachers to develop cross-cultural knowledge and literacy (Chinn 2006).

The application of indigenous knowledge to promote education for sustainability in various parts of the world is recognized. Teachers and students participating in sustainability and environmental education programs, as well as science education programs, should be considered potential beneficiaries of published research on indigenous science.

5 Raising the Relevance of Science Learning Through Indigenous Knowledge

5.1 The Relevance of Science Learning

The term relevance in science learning has many different meanings that can be viewed from different perspectives. Relevance can be defined as students’ interest in learning (Ramsden 1998; Childs 2006; Holbrook 2005), usefulness or student’s needs (Keller 1983; Simon and Amos 2011), or aspects of the application of science and technology to raise welfare and
sustainability in social, economic, environmental, and political issues (De Haan 2006; Hofstein and Kesner 2006; Knammiller 1984). Stuckey et al. (2013) attempted to formulate a comprehensive understanding of relevance in science education and suggested a model of relevance by linking different dimensions of the relevance of science education. The model encompasses three main dimensions:

1) Individual relevance, with an emphasis on students’ interests and the development of individual intellectual skills
2) Societal relevance, by facilitating the student’s competence to engage responsibly in the present and future society
3) Vocational relevance, by providing vocational orientation and preparation for career development

Stuckey et al. (2013) suggested curriculum development to move dynamically to accommodate the relevance of science learning in its different dimensions and aspects (Eilks and Hofstein 2015). Current curricula in many countries are suggested to overcome a preference for learning based on scientific principles and facts that have been done in the “Golden Age” of the science curriculum in the 1950s and 1960s (Bybee 1997). At that time, the curriculum was designed using a discipline-based structured approach to provide effective learning about the concepts, theories, and facts of science (Eilks et al. 2013). The curriculum of science at that time is today considered irrelevant for most learners as it only accommodates the emphasis in the selection and preparation of a minority of students to become scientists and engineers (De Boer 2000; Stuckey et al. 2013).

Over time, science curriculum development has undergone significant changes (Eilks et al. 2013). The curriculum development in late 1990 to early 2000 was done by suggesting context-based science education and creating meaningful learning for students in many countries (e.g., King and Ritchie 2012). The contexts used were considered relevant from the perspective of Western modern science. However, in the viewpoint of global science, relevance must be concerned with the natural and environmental phenomena described by science in various contexts and cultural forms. Different views on science should be accepted by students with respect to different environments based on cultural identity, time, and society. One of the problems experienced by students in science education in developing countries is the feeling that learning science is like recognizing foreign cultures (Maddock 1981) and this is also experienced by students in industrialized countries (Aikenhead 1996; Costa 1995). The phenomenon occurs due to the fundamental differences between Western modern science and the knowledge systems of many non-Western cultures (Aikenhead 1997; Jegede 1995). The same issue is also expressed by Kibirige and van Rooyen (2006) suggesting that students with indigenous backgrounds may experience a conflict between Western modern science, that they learn in school, with their indigenous knowledge. As already described above, a similar conflict can also be expected for many students with a Western background, when their “personal science view” differ from the views of mainstream Western science (Ogawa 1995; Hansson 2014). Surely this is a challenge for researchers and educators who want to reach the goal of relevant science education for all students by bridging the difference between student’s experiences in their cultural context and the world of Western science.
5.2 Indigenous Knowledge as a Socio-scientific and Cultural Context to Accommodate Relevance in Science Education

In order to realize relevant science education in a contemporary view, it is necessary to consider socio-scientific and cultural contexts in science education (Stuckey et al. 2013; Sjöström et al. 2017; Sjöström 2018). As Ogawa (1995) emphasizes, every culture has its own science called “indigenous science.” Thus, every student must become aware of his individual, personal “indigenous” knowledge to construct his knowledge of Western science. The focus of learning cannot be restricted to provide the student scientifically acceptable information, but should be to help students understand the concepts and explore the differences and similarities between their ideas, beliefs, values, and experiences with modern science concepts (Snively and Corsiglia 2000). The same view is also affirmed by Abonyi (1999) who stated that current instructional approaches in science education, which often do not take into consideration prior cultural beliefs, will lack in a contribution to students’ interest in science. In consequence, it might negatively influence students’ understanding and attitudes towards science learning (Alshammari et al. 2015).

The introduction of indigenous knowledge in the classroom can represent different cultural backgrounds of the learners and might improve their interpretation of knowledge (Botha 2012). It might have the potential to make science learning more relevant to students in culturally diverse classrooms (de Beer and Whitlock 2009). Related to this, Hayes et al. (2015) stated that societal culture has a major impact on the functioning of schools and the complexity of factors which affects the way schools teach science. The incorporation of indigenous knowledge into school curricula has the potential to enable students to gain further experiences and develop corresponding attitudes towards science. In the same time, it might help indigenous students to maintain the values of their local cultural wisdom (Kasanda et al. 2005; de Beer and Whitlock 2009; Ng’asike 2011; Perin 2011). Another goal of integrating indigenous knowledge in classroom learning is to reduce the notion that learning science is “strange” from the students’ own point of views by providing insights that views on science and nature can be different from culture to culture (Mashoko 2014). Knowledge can be seen as a dynamic process within the context of sociocultural and ecological relations. Accordingly, knowledge is not sourced only from the teachers but can be found in the experience of the students living, which is a prominent feature of the rural experiential environment (Avery and Hains 2017). Kawagley et al. (1998) contended that although indigenous ways of knowing are different from the Western way of thinking, their knowledge is scientific and relevant to the current situation because it is obtained from the results of long-term environmental observations combined with experiments in a natural setting. Indigenous science for science learning is relevant for students because they can learn traditional knowledge and skills that are still relevant to today’s life, as well as to find values and apply new insights to their practice which is essential for their survival (Kawagley et al. 1998; Barnhardt and Kawagley 2008).

Students bring ideas and beliefs based on their previous experiences in the classroom. The differences in cultural backgrounds cause them interpret the concept of science differently from a common scientific view. Accordingly, the exploration of multicultural science learning is required that brings students’ prior knowledge into the classroom. In many cases, the cultural aspect of the multicultural science context is important because it plays a role in providing valuable scientific knowledge and is also a pedagogical bridge linked mainly to multicultural students of science (Atwater and Riley 1993; Hodson 1993; Stanley and Brickhouse 1994). The relevant approach to this goal is by developing culturally sensitive...
curricula and teaching methods that integrate indigenous knowledge—and the variety of different cultural views—into the science curriculum (Aikenhead and Jegede 1999).

Zimmerman and Weible (2017) developed science learning curricula based on the socio-cultural conceptualization of learning with specific consideration of place to understand how students’ rural experiences intersect with school-based learning. They suggested that education which focuses only on scientific concepts is not enough to support young people to become representative of their community. The learners need support in methods of presenting evidence and arguments, which can be facilitated in science classroom to convince key stakeholders in their rural community. This is important to make science learning meaningful and can lead to the development of various kinds of environmental meanings as learning outcomes.

Snively and Williams (2016) suggest that science educators must strive to design new curricula that represent a balanced perspective. Furthermore, they should expose students to multiple ways of understanding science. Indigenous perspectives have the potential to give insight and guidance to the kind of environmental ethics and deep understanding that we must gain as we attempt to solve the increasingly complex problems of the twenty-first century. For instance, the empirical study of the integration of indigenous perspective in science education has become a model of science education in Canada, with sustainability at its core (Fig. 3) (Murray 2015). Sustainability sciences should provide a balanced approach to how society

![Three dimensions of science education with the sustainability sciences as the foundation, as described in this didactic model by (Murray 2015)](image-url)
alters the physical environment and how the state of the environment shapes society (Snively and Williams 2016).

Murray (2015) emphasized in a magazine article that the focus of sustainability sciences is not merely on environmental science. It should also recognize science outside of environmental, citizenship, and cultural contexts. Therefore, it is important to make strong connections among the pure sciences, sustainability issues, socio-scientific issues, and the relevance of the curriculum (Murray 2015; Stuckey et al. 2013). According to Fig. 3, sustainability sciences can integrate multiple perspectives on science worldviews and accommodate the three dimensions of the relevance of science education (individual, societal, and vocational relevance). In this case, indigenous science can be a source for socio-scientific and cultural issues which promote the relevance of science education. Accordingly, new pedagogical approaches should address indigenous science in order to enhance the relevance of science learning as well as to promote sustainable development.

As can be seen in Fig. 3, Murray (2015) uses the term *Vision III* for multiple perspectives on scientific worldviews and indigenous systems of knowing, complementing Western traditions. This is included in our previous use of the term, although our *Vision III* of scientific literacy and science education is even broader in scope (Sjöström and Eilks 2018). Our view is inspired by an eco-reflexive understanding of *Bildung*. It describes a socio-political-philosophical vision of science education aiming at dialogical emancipation, critical global citizenship, and socio-ecojustice. This has consequences for the science curriculum that needs to incorporate more thoroughly societal perspectives—under inclusion of indigenous perspectives—and needs to incorporate stronger socio-scientific issue–based science education of a “hot” type (Simonneaux 2014). Controversial, relevant, and authentic socio-scientific issues, e.g., from the sustainability debate, shall become the drivers for the curriculum (Simonneaux and Simonneaux 2012). Corresponding research, curriculum development, and teacher continuous professional development need to be intensified. Recently, Sjöström (2018) discussed eco-reflexive *Bildung* - and a *Vision III* – driven science education as an alternative to science education based on Western modernism. It integrates cognitive and affective domains and includes complex socio-scientific and environmental issues, but also philosophical-moral-political-existential and indigenous perspectives more in general.

Recent pedagogical approaches involving socio-scientific issues to teach science imply the role of science and technology for society, both present and future (Marks and Eilks 2009; Sadler 2011). Students are suggested to develop general skills facilitated by science education to achieve the goals of Education for Sustainable Development (ESD) (Eilks et al. 2013). In ESD-type curricula, learning encompasses the reflection and interaction of the application of science in its societal, economic, and ecological contexts (Burmeister et al. 2012; De Haan 2006; Wheeler 2000). ESD in connection with science education is suggested to have the potential to contribute to personal, societal, and vocational science teaching (Stuckey et al. 2013). It is relevant for individual action, e.g., in cases involving consumption of resources, participation in societal debates about issues of sustainable development, or careers related to sustainable chemistry and technology (Eilks and Hofstein 2014; Sjöström et al. 2015). Reflections on indigenous knowledge and its relatedness to Western modern science can form another focus in this selection of cases, especially if it becomes locally and regionally relevant.

Khaddoor et al. (2017) emphasized that the picture of science represented in many textbooks all over the world often neglects its societal and cultural components, and restricts it to a Western view on the history of science. Addressing indigenous knowledge in the framework of ESD, to promote relevant science education, may help students recognizing the
intimate connection between humans and nature in culture. It would create science learning directly relevant to daily life and society along with regional-specific examples, but could also lead to intercultural learning. Moreover, it could facilitate authentic science experiences, which engage students with cultural-historical views (Roth et al. 2008a).

6 Research Frameworks and Didactic Models for Adopting Indigenous Science in Science Education

There are different foci of research on integrating indigenous science in science education. Some scholars suggest attention to empirical research in anthropological and psychological paradigms. This research tries to investigate the process of knowledge transition from a student’s life-world into science classrooms, which forms a cross-cultural experience (Aikenhead and Jegede 1999). The research focuses on conceptualized transition as “cultural border crossing” (Aikenhead 1996) and cognitive conflicts arising from different cultural settings (Jegede 1995). They need to be addressed and resolved as “collateral learning.” Research suggests investigating the nature of student’s prior knowledge and beliefs about scientific phenomena when exposed to a cross-cultural topic (Herbert 2008).

Other research aims to design instructional approaches that introduce indigenous science into the science classroom. Abonyi (1999) explored the effect of ethnoscience-based instructional approaches on student’s conception of scientific phenomena and attitudes towards science. The study aimed to resolve the cognitive conflicts of African students as a result of differences between their cultural background and Western science. In a similar approach, Aikenhead (2001) developed instructional strategies by involving the aboriginal community. The strategies involved the discussion about local content with elders and the aboriginal community to construct an aboriginal science education framework. Key values as a context for integration were identified. However, conflict arose when students faced the problem of taking information from one knowledge system and placing it into another. Also contextualization by indigenous science is a topic of research and development (Chandra 2014; Hamlin 2013; Kimmerrer 2012; Sumida Huaman 2016; van Lopik 2012). Sometimes, indigenous science is used to contextualize curricula. This approach is suggested to be appropriate to accommodate sociocultural demands in science curricula as well as to meet students’ perception of relevance. However, it is necessary to consider the students’ perspectives about scientific phenomena formed by the two different knowledge systems (indigenous science and Western modern science) to avoid misconceptions and conflicts that can arise. The systemic evidence and research-based development of the curriculum is suggested to construct a reliable knowledge framework to fit indigenous science with currently operated science education curricula.

To introduce indigenous knowledge as content and contexts into science education, a multidiscipline view on science education is needed. For this, didactic models and theories might be useful. According to Duit (2015, p. 325), Didaktik “stands for a multifaceted view of planning and performing the instruction. It is based on the German concept of Bildung […] and] concerns the analytical process of transposing (and transforming) human knowledge (the cultural heritage) into knowledge for schooling that contributes to Bildung.” It is suggested that didactic models can help teachers in their didactic choices (why? what? how? to teach). Furthermore, they can be useful in the design, action, and analysis of teaching, but also for critical meta-reflection about for instance teaching traditions. When used systematically, they
can also be helpful in teacher professional development and have potential to contribute to research-informed teaching (Duit 2015).

Duit (2007) also has emphasized that multiple reference disciplines are relevant to understand and design science education. The reference disciplines are suggested to support science education research and development. These reference disciplines include the sciences, philosophy, and history of science, pedagogy, and psychology, and furthermore (Fig. 4). We suggest that local wisdom of indigenous science—where appropriate—could be named as a further reference discipline, or it could be understood implicitly as being part of science (incorporating also its non-Western body of knowledge), the history and philosophy of science (referring to the different history and maybe varying philosophy of non-Western science), and aspects of sociology, anthropology, and ethics.

A research-based model to dig into the content and context of indigenous knowledge for science education is the Model of Educational Reconstruction (MER) (Duit et al. 2005). This model links (1) the analysis of content structure, (2) research on teaching and learning, and (3) development and evaluation of instruction. It may also provide a framework to allow an educational reconstruction of indigenous science content in such a way that the resulting instruction meets students’ perspectives, abilities, and needs. Incorporating indigenous science perspective by educational reconstruction might provide a complex representation of indigenous science for education. The complexity may result from the integrated environmental, social, and idiosyncratic contexts, in order to demonstrate their role for the life of the individual in society. The integration of indigenous science as a sociocultural context for scientific questions can also provide social demand in science learning. Diethelm et al. (2012) and Grillenberger et al. (2016) adapted social demands in educational construction to develop the innovative topic of computer science. This approach suggests identifying social demands that are relevant for students to cope with requirements that society puts on them in their everyday lives. Transferred to the aspect of indigenous knowledge in science education, a resulting didactic model might look as suggested in Fig. 5.

Based on the educational design framework, any phenomenon or process from indigenous science in question shall be analyzed both from the Western and indigenous perspectives. The analysis can provide a different view on one’s own knowledge system as well as it has the potential to enrich both perspectives to create a thoughtful dialog (Stephens 2000). The context

![Fig. 4 A model of reference disciplines for science education (Duit 2007)](image)
and content relevant to the indigenous science issue, which are contrasted by the Western view on the phenomenon/process, are analyzed based on the three perspectives Western modern science, students, and teachers. The analysis is suggested to facilitate the process of elementarization and the construction of the scientific content structure for instruction that can be enriched by putting it into contexts that are accessible for the learners (Duit 2007). The indigenous perspective on the phenomenon/process has potential to offer authentic contexts for science learning and encompasses sociocultural aspects from local wisdom values (e.g., tradition, beliefs, ethics, supernatural) (Pauka et al. 2005; Rist and Dahdouh-Guebas 2006) as well as from sustainability values (e.g., nature conservation and adapting to climate change) (Snively and Corsiglia 2000; Snively and Williams 2016). It is necessary to analyze also the social demands of educational significance of the context generated from the indigenous perspective. It offers a chance to reflect Western views on science and nature in science education for contributing to the development of more balanced and holistic worldviews as well as the development of intercultural understanding and respect (Brayboy and Maughan 2009; Hatcher et al. 2009; de Beer and Whitlock 2009). Moreover, the indigenous ways of knowing can be used as starting points and anchors for scientific knowledge (Roth et al. 2008b). Thus, the indigenous ways of knowing might also help to shape the knowledge already held in Western societies. The investigation of teachers’ and students’ perspective on indigenous knowledge is needed in order to identify their attitude, belief, and experiences towards the system of knowledge (Cronje et al. 2015; Fasasi 2017). The analysis also provides valuable information to avoid the conflict that could arise when the learners face different knowledge systems.

For the purpose of curriculum design, different perspectives (science, students, teachers, and society) are suggested to be analyzed to identify suitable content, contexts, and phenomena/processes for teaching about indigenous science. The structure in Fig. 5 takes into consideration that Diethelm et al. (2012) added two significant components to the original educational reconstruction model by Duit et al. (2005). One component is that contexts and phenomena are integrated, which suggest that science learning should start from a “real-world” phenomenon embedded in a context to open connections to prior experience of the student. This aims at encouraging students’ interest, and to show application situations of the intended knowledge. The second improvement is the analysis of social demands, which is a very important step to consider the educational
The significance of intended learning content, especially when it comes to integrating indigenous knowledge as part of a society’s wisdom other than Western modern science. The social demands might differ substantially in different places and cultures (countries, school, rural, or city areas). Accordingly, it is necessary to assess the educational significance of a certain topic respecting the specific circumstances, especially if it is culturally bounded. Analysis of social demands is a very important step to identify the educational significance of a certain topic (Diethelm et al. 2012). In the context of indigenous science, the analysis could be emphasized on the role of indigenous ways of knowing to promote education for sustainability. By drawing on indigenous knowledge, the issues connected to sustainability education can be included in the curriculum to provide an essential context for learning science.

The analysis of the science content structure informs how the phenomenon can be explained scientifically as well as to determine the required knowledge needed to understand the phenomenon or process (Diethelm et al. 2012). This step decides which concepts of modern science have to be dealt with in the lesson (Diethelm et al. 2012; Grillenberger et al. 2016). Meanwhile, the investigation of the students’ perspectives includes their cognitive and affective perspectives (Diethelm et al. 2012; Kattmann et al. 1996). The aim is to find out more general perspectives of certain groups of learners and different conceptualizations that students have when explaining scientific phenomena, concepts, or methods. Diethelm et al. (2012) considered this perspective an “official” scientific view, even if it was correct or not. The teachers’ perspective is needed as a key factor for the learning design and its implementation. This is because every teacher has different domain-specific knowledge and attitudes. In order to investigate the perspective of the student and teachers’ perspective about the phenomena of indigenous science, Snively (1995) introduced a five-step approach for exploring the two perspectives (Western science and indigenous science), when teaching about one concept or topic of interest. The process includes the following: (1) choose the topic of interest, (2) identify personal knowledge, (3) research the various perspectives, (4) reflect, and (5) evaluate the process (Table 6). This approach emphasized that discussion of the two perspectives might interpret the scientific phenomena differently, but the learner should see the overlap and reinforce each other.

The selection of phenomena is the central focus of the suggested framework in Fig. 5. It emphasizes that learning science—as one out of different options—can start from a relevant indigenous context. Accordingly, certain phenomena should be perceived with senses and ideally have a surprising or mysterious element and thus triggers curiosity (Grillenberger et al. 2016). Indigenous science contains scientific phenomena embedded with spirits, magic, religion, and personal experiences (Pauka et al. 2005). Spiritual aspects of indigenous society are not used as religious instruction in the curriculum, but as an acknowledgement of the responsibility and dependence of living beings on ecosystems and respect for the mysteries of the universe (Kawagley et al. 1998). It can provide an interesting topic for the students as well as encourage them to explore local wisdom behind the scientific phenomena. Indigenous ways of knowing can become starting points and anchors for useful scientific knowledge (Roth et al. 2008b). Figure 5 suggests that indigenous science deals with scientific phenomena to be explained by science. Furthermore, the scientific phenomena are embedded in a particular cultural context that can be used to encourage students to explore the differences and similarities between their ideas, beliefs, values, and experiences between those coming from indigenous knowledge and Western science, respectively.

Design and arrangement of learning should include development and implementation as well as reflection of teacher and student experience. This process identifies ideas and concepts relevant for teaching as well as it includes developing design principles. The reflection can be
repeated in order to suit the learning environments to the particular demands of a given setting (Grillenberger et al. 2016). For the process of design and development, Diethelm et al. (2012) proposed the Berlin Model of planning processes (e.g., Zierer and Seel 2012; Duit 2015), which encompasses four different decision areas: intentions (objectives, competencies, outcomes), content (topics, knowledge), teaching methods, and media. In the development of learning design, it should be considered the pedagogical approach which accommodates the relevance of science learning for learners as well as to promote sustainability. Eilks et al. (2013) used ESD-type curricula to develop the general skills of students facilitated by science education to achieve the goals of education for sustainable development. This pedagogical approach also involved socio-scientific issues to raise relevance in science learning that implicates the role of science and technology for society both present and future (Marks and Eilks 2009). Burmeister et al. (2012) pointed out four different basic models to implement issues of sustainable development into science education:

1. Adopting principles from sustainable practices in science and technology to the science education laboratory work
2. Adding sustainable science as content in science education
4. Science education as a part of sustainability-driven school development

Models 2 (context-based) and 3 (socio-scientific issues-based) seem suitable for the integration of indigenous science context into science education. Indigenous science can provide the contexts for science learning with a view on sustainability when learners at the same time explore the Western science perspective related to the indigenous way of knowing and behind any natural phenomena.

### Table 6

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<tr>
<th>Step</th>
<th>Activity</th>
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<tr>
<td>Step 1: Choose the topic</td>
<td>Choose a science concept or topic from indigenous science (medicine, cultivating plants, animal migrations, geology, sustainability)</td>
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| Step 2: Identify personal knowledge | • Discuss the importance of respecting the beliefs of others  
• Brainstorm what we know about the concept or topic  
• Brainstorm questions about the concept or topic  
• Identify personal ideas, beliefs, opinions |
| Step 3: Analyze various perspectives | • Analyze the various science perspectives  
• Analyze the local traditional science perspective  
• Analyze the perspective of different indigenous peoples organize/process the information.  
• Identify similarities and differences between the perspectives  
• Ensure that authentic explanations from the perspectives are presented |
| Step 4: Reflect | • Consider the concept or issues from a synthesis of perspectives consider the consequences of a synthesis  
• Consider the concept or issue in view of values, ethics, wisdom if appropriate  
• Consider the concept or issue from a historical perspective  
• Consider the possibility of allowing for the existence of differing viewpoints  
• Consider the possibility of a shared vision  
• Ensure that students compare their previous perspective with their present perspective build consensus |
| Step 5: Evaluate the process | • Evaluate the decision-making process  
• Evaluate the effects of personal or group actions  
• Evaluate possibilities in terms of future inquiries and considerations  
• How did this process make each person feel? |
Moreover, students can be encouraged with socio-scientific issues (SSI) relevant to indigenous people including a discussion of differences in the ways indigenous and Western science, respectively, view natural phenomena, how modern Western and indigenous people develop solutions, and the reasons why they do so. This can establish a base for discussion about environmental and technological issues between people with (post-)modern Western and indigenous thinking for establishing sustainable societies (Snively and Williams 2016).

Accordingly, the SSI approach in the learning activity should give more attention to students’ soft skill development such as argumentation (Belova et al. 2015), decision-making (Feierabend and Eilks 2011), reasoning skills (Sadler and Zeidler 2005), and using appropriate information (Belova et al. 2015). In sociocultural means, for instance, it is about using the argumentation-based course to enhance the understanding of different worldviews (nature of science and indigenous knowledge) in global awareness of the impact of scientific, technological, and industrial activities on the environment (Ogunniyi and Hewson 2008). Another example is the discussion about the controversial issue regarding Western and traditional medicine. It can be discussed in terms of reflection on the moral principles that underpin science (de Beer and Whitlock 2009) and can be useful to develop argumentation and reasoning skills.

The integration of indigenous knowledge in science education also should consider the learning objectives based on the different target of educational level (school science, higher education, and across educational levels). In school science, some studies used context-based learning about indigenous knowledge to motivate and foster interest in science learning (Abonyi 2002; Hiwatig 2008; Fasasi 2017). This approach also could lead to intercultural understanding and respect in science learning (Brayboy and Maughan 2009; Hatcher et al. 2009; de Beer and Whitlock 2009), as stated by Burford et al. (2012) as interculturality, which means “the inherent equality of different knowledge systems is acknowledged, with collaborative decision-making and an awareness of learning together towards share goals” (p. 33). In terms of sustainability, the learning attention should emphasize to bring together indigenous and non-indigenous students to learn about the environments, respecting their each culture, and educating future citizens to make wise decisions regarding long-term sustainable communities and environments (Snively and Williams 2016). This is, however, not limited to the inclusion of indigenous knowledge but should aim at all the different cultures present in multicultural classrooms.

In higher education, indigenous perspectives can contribute to greener science (e.g., ethnochemistry, ethnobotany, ethnomedicine). This includes learning about other substances and processes adopted from indigenous science, which are also in the focus of green chemistry (e.g., Sjöström and Talanquer 2018) and green agriculture. For instance, it can involve learning activities that involves the discussion of the development of highly effective biodegradable pesticides from neem tree oil (Azadirachta indica) by East Indian and North African peoples over 2000 years ago (Snively and Williams 2016). The information about biodegradable pesticide compounds from the neem tree could be used as a starting point to develop green chemistry lab activities. Across the educational levels, the focus of learning can give more emphasis on the nature of science views (more transdisciplinary and holistic), which parallels the discussion on sustainable and green science. The learning activity must shift to a transformative style by using ideas from the science classroom and multi-perspective views about sustainable science to see and experience the world differently in learner everyday lives (Murray 2015; Pugh et al. 2017). Accordingly, transformative education should be driven to reform the existing ways of knowing and understanding, to critically reflect on the values, beliefs, and worldviews that underpin them as well as to share the meanings that can contribute to sustainability (Sjöström et al. 2016; Tejedor et al. 2018; Mack et al. 2012).
7 Conclusion

Indigenous knowledge about nature and science generally differs from the traditional and dominant Western modern view of science in research and technical applications (Nakashima and Roué 2002; Iacarino 2003; Mazzocchi 2006). It provides a different, alternative perspective on nature and the human in nature on its own right (Murfin 1994; Ogawa 1995) and therefore becomes authentic to persons having an indigenous background. It is also interesting that—more or less—similar ideas to the local wisdom of indigenous science also exist in Eastern spiritual thinking and alternative Western thinking. Such ideas are relevant to promote intercultural and intergenerational understanding and respect (Brayboy and Maughan 2009; Hatcher et al. 2009; de Beer and Whitlock 2009). From the discussion provided in this paper, it is suggested to carefully adopt views on and from indigenous knowledge into science education. Indigenous knowledge can provide further perspectives on nature and help us to reflect the nature of science. It offers rich contexts to initiate learning and connect science education with more holistic worldviews needed for promoting sustainability (e.g., Aikenhead and Michell 2011; Kim and Dionne 2014; Kim et al. 2017).

There is a lot of literature justifying a more thorough inclusion of culture into (science) education (e.g., Savelyeva 2017; Moon 2017; Wang 2016; Sjöström et al. 2017; Sjöström 2018). Justifications can be derived from different sources, like the concept of Bildung (Sjöström et al. 2017), as shown above. Indigenous cultures can play a role by strengthening the cultural component of science education (Hatcher et al. 2009; Murray 2015). For this, research on indigenous knowledge in science needs to be analyzed with respect to its potential for science education. It might be educationally reconstructed for integrating it into science teaching and learning. Here we have presented some frameworks and didactic models for how to elaborate on and design science education for sustainability that take indigenous knowledge and related non-Western and alternative Western ideas into consideration. Further work needs to focus on evidence-based curriculum development in science education on the integration of indigenous knowledge. This development, however, needs special care and sensitivity because it deals with different cultures, worldviews, and ethical considerations. Further discussion might also include aspects of the historical development of indigenous knowledge, the history of colonialism, and the long-term effects colonialism still has on societies and science education in many parts of the world (e.g., Boisselle 2016; Ryan 2008). Such a discussion, just like the discussion in this paper, needs respect to indigenous communities; if possible, it could be done in cooperation and exchange with persons from the corresponding communities.

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Compliance with ethical standards

Conflicts of Interest The authors declare no conflict of interest.

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A Multi-Perspective Reflection on How Indigenous Knowledge and Related...


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Integrating perspectives from indigenous knowledge and Western science in secondary and higher chemistry learning to contribute to sustainability education

Robby Zidny
Ingo Eilks

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Integrating perspectives from indigenous knowledge and Western science in secondary and higher chemistry learning to contribute to sustainability education

Robby Zidny a,b, Ingo Eilks a,*

a Department of Biology and Chemistry, Institute for Science Education (IDN) - Chemistry Education, University of Bremen, Leobener Str. NW2, 28334, Bremen, Germany
b Department of Chemistry Education, Faculty of Teacher Training and Education, University of Sultan Ageng Tirtayasa, 42117, Serang, Indonesia

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ABSTRACT

In this paper, we suggest integrating perspectives from indigenous and Western science into chemistry learning. Doing so is suggested to enhance students’ views on sustainability issues. Integrating indigenous and Western views can provide students with insight into using multiple perspectives. Cross-disciplinary knowledge offers ways to solve problems more holistically and to promote respect for different worldviews. This claim is supported by a case study testing a lesson plan incorporating indigenous science in secondary and tertiary chemistry education. The study was carried out in Indonesia and used a socio-scientific issues-based, sustainability-oriented approach and the context of the Baduy community. University student teachers (n = 73) and upper secondary school students (n = 40) participated in this study. The study focuses on pesticide use, including a discussion of alternative, green pesticide use in an indigenous community. The lesson focuses on the role of different perspectives taken from indigenous and Western science and connects the issue with chemistry concepts from general and organic chemistry. A post-intervention questionnaire (ten Likert scale items and one open-ended question) was used to explore students’ feedback regarding the learners’ experiences and attitudes towards the lesson plan. Data were analyzed using descriptive statistics and text analysis. Our findings indicate that students’ perception of the lesson was positive and that the lesson was considered to be interesting and relevant. Learning by integrating perspectives of indigenous and Western science aided students’ insight. It showed them that chemistry learning can be enriched by an interconnected system of worldviews in order to find solutions to sustainability issues.

1. Introduction

Delivering scientific content to students is the aim of chemistry education, however, a societal perspective to the application and impacts of chemistry also needs to be included (Hofstein et al., 2011). Modern chemistry teaching should prepare students for societal participation, including the development of an environmentally reflective attitude among students (Sjostrom et al., 2016). One way to achieve this goal is to integrate sustainability-related socio-scientific issues (SSIs) into chemistry lessons. This can help students to understand the role of chemistry in society and prepare them to become future responsible citizens (Holbrook and Rannikmae, 2007; Marks and Eilks, 2009; Sadler, 2011). The need for the inclusion of societal issues in chemistry learning has already been addressed by several different national science education standards (e.g., the National Curriculum in the UK and AAAS in the US (NC, 2004; American Association for the Advancement of Science, 1993)). This has also become part of international educational policy in general (UN, 2015) and, more specifically, with a direct reference to sustainability and green chemistry (UNEP, 2019).

Over the last twenty years, several cases were published which discussed the integration of chemistry education with sustainability issues. Some of them were following the socio-critical and problem-oriented chemistry lesson approach (Marks and Eilks, 2009). The studies addressed bioethanol usage (Feierabend and Eilks, 2011), learning about and evaluating plastics (Burmeister and Eilks, 2012), life-cycle analysis (Juntunen and Aksela, 2014), and comparing traditional and
green pesticides (Zowada et al., 2020). According to these studies, the integration of sustainability topics into chemistry education works well when focusing on controversial societal issues with direct links to science and technology (Burmeister et al., 2012; Sadler, 2004). This approach has also been suggested to make chemistry learning more authentic, interesting and relevant for students (Stuckey et al., 2013) in Western science classrooms. In Indonesia, socio-scientific issues-based (SSI) and sustainability-oriented education have been contextualized in inquiry-based chemistry learning which is suggested to have positive effects on students in terms of their perceived ability, interest, commitment and values (Rahayu et al., 2018). Socio-scientific issues are also suggested to consider aspects of socio-cultural and geographical aspects which have different characteristics in various countries (Wiyarsi and Calik, 2019). Research on SSIs and sustainability-oriented education in Indonesia is, however, still very limited.

This paper reports on a spin-off of SSI and sustainability-oriented education. It looks, in the case of Indonesia, at a country with indigenous communities and records their views about integrating science into their indigenous lifestyles. It is suggested that multiple perspectives on scientific worldviews could make a strong connection between indigenous and Western science, sustainability issues, cultural values, and the relevance of science learning (Murray, 2015; Stuckey et al., 2013; Zidny et al., 2020). Western science in this paper is understood as Western science knowledge and alternative Western thinking which is shaped by modern Western societies (Zidny et al., 2020). It is understood in its contemporary dominant interpretation of science in Western countries which in the literature is generally described as Western modern science. To avoid the impression that indigenous science is suggested as not being modern, we are using the term Western science in this means throughout this paper. It also needs to be said that although it has been suggested to name the science of indigenous communities as Indigenous science (with an upper case I) to show respect to the knowledge of indigenous communities we decided to use indigenous science (with a lower case i, later abbreviated as IS) as this is still the most often used term in the literature. This study aims to explore student’s perception and experiences toward a teaching intervention which integrates the perspective of indigenous and Western science in socio-scientific issues-based and sustainability-oriented learning.

2. Background

2.1. Pesticides as a controversial issue for chemistry learning

One controversial sustainability issue which has already been tested for chemistry learning is the use of pesticides (Zowada et al., 2020). The use of conventional pesticides, such as glyphosate, has been discussed by the mass media and in public debate for a long time. Pesticides undoubtedly help to increase agricultural output. However, they also harbor the risk of producing undesirable impacts on human health and the environment. The debate on the utilization of agricultural pesticides as a sustainability issue in education must be informed by three main viewpoints borrowed from the dimensions of sustainability: ecological, economic and societal sustainability (Burmeister et al., 2012).

From an ecological standpoint, pesticides pose a potential risk to human health and other organisms. They also may have undesirable environmental side effects such as decreasing biodiversity. Pesticides can accumulate in soil or water, then harm non-targeted plants, animals, birds, fish, and other wildlife species (Damasas and Ellefborhormosis, 2011). Recent research revealed pesticide side effects which can disrupt aquatic microbial environments (Maturi et al., 2017) and can have lethal and sub-lethal effects leading to decreases in bee populations in agricultural ecosystems (Azpiazu et al., 2019). Some reports also examined the persistence of pesticides and the possibility of atmospheric pollution (Nascimento et al., 2018, 2017; Yusa et al., 2009).

In economic and societal terms, it is impossible to deny that the use of pesticides has led to an increase in global production and yields of agricultural products. Pesticide consumption has increased in recent years, especially in the agricultural sector, where high productivity is necessary to cover market demand (Popp et al., 2013). Economic and environmental losses, however, also result from the use of pesticides and must be weighed against their benefits. For instance, the investigation of the application of pesticides in the United States has shown major economic and environmental losses. More than nine billion US dollars are spent each year on environmental and public health costs (Pimentel, 2005). The societal implications of pesticide use need to consider the need to increase food production in order to feed the global population. The world must find enough food to feed people where the human population increases every year. There is a continuing debate about the use of pesticides all over the world today. The UN Food and Agriculture Organization (FAO) estimates that up to 40% of global crop yields are lost each year due to pests (Popp et al., 2013). This issue raises the question of whether food production can be guaranteed without the use of conventional pesticides such as glyphosate (Zowada et al., 2020).

A discussion of sustainability issues surrounding pesticides considers benefit-risk factors. Such a discussion which contrasts the benefits and risks as portrayed in the public media offers a fruitful starting point for chemistry learning about sustainability. This has been the case when using a socio-scientific issues-based approach like the socio-critical and problem-oriented curriculum model for chemistry education (Marks and Eilks, 2009). The issue of pesticides fits well with the criteria used to select topics for this curriculum model (Stolz et al., 2013). It is authentic, relevant, open to evaluation, allows for open discussions, and deals directly with questions from science and technology. For Indonesia, the topic of pesticide use is closely related to the socio-economic and geographical background of the country which has a significant agricultural production. Although pesticide use is not a common topic in chemistry curricula at the high school and undergraduate level in Indonesia, this context is suggested to be relevant to Indonesian students because of Indonesia’s large agricultural economy and thus the question of pesticide use has potential to directly influence students’ live and should have meaning to them (Wiyarsi and Calik, 2019).

2.2. Chemistry learning and indigenous knowledge

So far, the implementation of socio-critical and problem-oriented chemistry education (Marks and Eilks, 2009) is mostly restricted to Western chemistry classrooms. Application has so far been restricted to incorporating Western scientific views into chemistry learning. Often, this does not integrate cultural components, which is also the situation in many countries worldwide (e.g., Iceland, 2018; Khaddoor et al., 2017). The question, therefore, arises whether such cultural components can enrich teaching and learning. This is especially relevant in countries where different cultural perspectives, values, and worldviews exist, for example, in countries with indigenous communities.

In this paper, we suggest adding relevance and meaningfulness to chemistry learning by considering the application of science in different cultural and socio-economic environments. In some regions of the world, for example in Asia, there are indigenous communities which still maintain their unique and diverse cultural traditions. Indigenous communities generally have unique knowledge about their direct surroundings, which is orally passed on in various forms of indigenous science (IS). In some literature, IS is also conceptualized under different names such as traditional ecological knowledge (TEK) (Kim and Dionne, 2014) or ethnoscience (Fassal, 2017).

The wisdom of indigenous knowledge is often based on a sacred respect for nature, due to indigenous peoples’ relationships and responsibilities towards their natural environment (Imudison and Suzuki, 1992). The practice of indigenous science generally centers around the utilization of natural resources in order to fulfill needs in the areas of agriculture, medicine, land and forest management, or water and soil conservation (Zidny and Eilks, 2018). We would suggest that indigenous science offers rich and authentic contexts for science learning which can
potentially interest students who live in the corresponding environments or coexist with indigenous communities, especially in times of globalisation. Indigenous perspectives can contribute to understanding the relationship between socio-cultural and environmental ethics. They can also help to better reflect upon Western views of science in order to develop more holistic perspectives (Snively and Williams, 2016). This is seen as necessary for relevant science education for sustainability (Sjöström et al., 2016). It has also been suggested that indigenous knowledge provides chances to reflect upon views of nature and science in contemporary (Western) science education. This can aid in the development of better-balanced, more holistic worldviews, intercultural understanding, and sustainability (Zidny et al., 2020).

2.3. Connecting learning about pesticide use with indigenous knowledge

In the recent debate on more green and sustainable chemistry, the search for agricultural pest management in a more sustainable manner came to the attention of chemists and environmentalists. Approaches have been tried which include integrated pest management and biobased control of pests (Metcalf and Luckmann, 1994). The use of green pesticides is currently one of the most popular options for dealing with pest problems without causing negative effects in the environment (Zuin and Ramin, 2018). Natural plant compounds are selected to develop green pesticides as an alternative to synthetic pesticides, due to their ecological compatibility (Hikal et al., 2017). Phytochemical compounds which can be employed as green insecticides include essential oils, alkaloids, flavonoids, glycosides, esters and fatty acids (Altémimi et al., 2017; Cantrell et al., 2012; Hikal et al., 2017; Kou, 2008). The utilization of plant extracts as bio-pesticides for pest control has already been used by indigenous communities. Studies in IS and ethnobotany have explored the potential use of phytochemical compounds showing pesticide activity (Gospel Ajuru, 2017; Mkindi et al., 2015; Vabeiryur et al., 2016). It has also been suggested that indigenous knowledge provides chances to reflect upon views of nature and science with their socio-cultural context regarding values, philosophy and environmental ethics. The application of indigenous knowledge in the Baduy community is based on mutually agreed principles and norms to maintain the sustainability of life in the community for both present and future generations. The Baduy have a philosophy that has a determination (pikukuh) to preserve nature, that is, "The mountain is not allowed to be destroyed, the river is not allowed to be destructed. If it is long, it is not allowed to cut and if it is short, it is not allowed to be connected." The essence of the Baduy's determination means that humans are not allowed to change anything that could cause damage to nature. As a sustainable approach to pest control, the Baduy use natural compounds extracted from plants as bio-pesticides, which we can consider to be green pesticides. In the process of pest control, the Baduy community has paddy treatment activities which they call "ngubaran pare". This treatment uses a blend of local plant ingredients as bio-pesticides known in the local language as "samarang punguhunan". These ingredients have a function as botanical pesticides to control pests in their paddy plantations. In accordance with their culture and belief, the production of bio-pesticide ingredients is accompanied by a traditional ceremony. The story of the life journey of the Baduy and a fairy tale about Nyi Pohaci Sanghyang Arti (the rice god) are presented in the ceremony (Senoaji, 2011). IS is generally in line with the principles of green and sustainable chemistry. This includes using biodegradable chemicals and avoiding environmental pollution. IS also offers valuable perspectives which can complement Western scientific views in order to achieve sustainability (Zidny et al., 2020).

The recognition of IS might enrich the debate about the global use of conventional pesticides. The issue of the use of potentially harmful synthetic pesticides is a concern in both agriculturally developed and developing countries, such as Indonesia. Studies indicated that the residues of harmful pesticides such as organochlorine pesticides (OCPs) can be found in food products (Shoiful et al., 2013) and contaminated rivers (Isworo et al., 2015) in Indonesia. We suggest that learning about pesticide use connected with IS will provide students with new insights. They will realize how using multiple perspectives and trans-disciplinary knowledge can lead to solving problems more holistically. This will also allow them to better contribute to collective decisions about the future. Another argument is to enrich chemistry learning by systems thinking (Mahaffy et al., 2018). Systems thinking means that chemistry education looks at the interconnection of chemistry with other systems. These include human societies, nature, biospheres, socio-economics, politics, legal systems and knowledge borrowed from other disciplines (Matlin et al., 2016). Reorientation of chemistry education around systems thinking can enhance learners’ understanding of chemistry concepts and principles in a rich social context. It can also address the impact of chemistry on global problems and advance sustainable development (Mahaffy et al., 2018).

The case study presented below provides an illustration of the ideas presented above. It describes the implementation of a teaching unit which incorporates science-related indigenous knowledge into sustainability-oriented chemistry education for students at the secondary and tertiary levels. The chemistry concepts behind the use of biopesticides produced from natural products are believed to better learning in the classroom. The case below shows a regional example from Indonesia, but also promotes education for sustainable development (ESD) and intercultural learning. An educational design framework was used which introduces IS as both content matter and context for science education (Fig. 1) (Zidny et al., 2020). The framework uses the ESD pedagogical approach in connection with science education based on socio-scientific issues (Burmeister et al., 2012). It combines social-cultural contexts, local wisdom, and the philosophical aspects of IS in the same sense that socio-critical sustainability issues do. Socio-cultural aspects of IS can be used in ESD as potential contexts to achieve science learning. This encourages teachers and students to develop enhanced respect for local cultures. It also provides pathways for teaching and learning locally relevant knowledge and skills, as well as promoting ESD simultaneously.

3. Integrating IS and chemistry learning in Indonesia

3.1. Research background, sample and method

The case study in this paper is part of a larger educational design project which aims at incorporating IS and perspectives of sustainability into modern chemistry education in Indonesia. The framework of the project (Fig. 1) was adapted from the Model of Educational Reconstruction (MER) (Duit et al., 2005). MER links together the analysis of content structure, research on teaching and learning, and the development and evaluation of instruction. The research framework further integrates multiple perspectives on science worldviews in order to arrive at stronger connections between IS and Western science, sustainability issues, cultural values and the relevance of science learning (Murray, 2015; Stuckey et al., 2013; Zidny et al., 2020). The phenomenon or process of IS serves as a source for socio-scientific and cultural issues, which are suggested to promote higher levels of relevance for science education.

Within the research framework, the study in this paper attempts to investigate students’ perception and experiences during a teaching unit which introduces pesticide sustainability issues based upon IS and Western perspectives. The learners’ responses are considered of significant value for the development and evaluation of potential future curriculum design. The study was conducted at the university and upper secondary school level in Indonesia. The total number of participants...
included two classes of university chemistry student teachers \( (N = 73) \) and 40 students in upper secondary school (12th grade, science majors). These groups of learners were chosen because all groups learn at institutions which are located near the Baduy indigenous community, an indigenous tribe on Java in Indonesia. The study involved two groups of participants to grasp students’ feedback toward the complexity of the issue at different levels of education, which is suggested important to better understand developing teaching and learning designs. After the intervention, students answered a questionnaire about their perceptions and learning experiences. The questionnaire was validated prior to the intervention by discussions with experts.

The research instrument for the study was a questionnaire administered after completion of the teaching unit. It contained ten Likert-scale items and one open-ended question. The development of the questionnaires involved a professor with relevant knowledge and experience in chemistry education. After the revision process, the questionnaire was translated into Indonesian language and reviewed by three Indonesian researchers in the field of chemistry education. Furthermore, the questionnaire was pilot-tested by a small group of students, then revised before finally being used in this research.

In the questionnaire, the Likert-based items focused on: 1) students’ interests, 2) their motivation for the topic, 3) the perceived relevance in the context of both their personal learning and the chemistry curriculum, 4) their concern about sustainability, and 5) the perspectives for IS and Western science to work together to solve sustainability issues and promote intercultural learning. Chronbach’s alpha as a measure of reliability of the Likert-questionnaires was 0.75 (between acceptable and good). The final, open-ended question focused on the student’s opinions regarding both the topic and the overall learning process.

The students’ answers to the Likert-items were subject to descriptive statistics, which attempts to obtain a general description of the feedback given about the teaching and learning design. The percentage distributions for agreement levels to the statements were calculated. Such analysis is typical in research-based design studies, in which the main objective is to yield cyclical improvement of instruction (Bodner et al., 1999).

The open-ended question was analyzed using DisplayR text analysis software. This software has the ability to create word cloud visualization and calculate sentiment analysis scores. (Both software and instructions are available online at https://www.displayr.com.) With the help of word clouds, every word or phrase in a student’s response to the questionnaire can be visualized. This is based on the size of words and the corresponding frequency with which the word is mentioned. The process of cleaning and processing the texts (translating to English, correcting spelling, stop-word removal, performance stemming, replacing words/synonyms) was conducted to concentrate the unique words or phrases found in the analysis into a manageable and meaningful collection.

Sentiment analysis in a survey is a technique which measures the overall attitude towards a particular topic or product. In terms of educational purposes, it can be used to analyze students’ attitudes towards learning experiences, based on their feedback to the open-ended question (e.g., Liu et al., 2019; Yu et al., 2018). DisplayR uses an R algorithm to analyze the text by scoring the words as positive (+1 scores), negative (−1 scores), or neutral (0 scores). For example, the word “interested” would generate a score of 1 instead of −1. The score calculation in the text or statement such as ‘I am really interested (−1)’ with the lesson, it was fun! (+1)’ would yield a score of +2. The final sentiment score is the sum of all the scores. The average sentiment score represents student attitudes and shows whether learners express positive or negative sentiments towards a given lesson.

3.2. Teaching intervention

The teaching unit centered around sustainability issues of pesticide use, compared to an alternative green pesticide selected from IS. During 2½ hours of teaching time, tasks were given to the students in the form of a set of worksheets, which encompass four activities. In the first session, the students’ preconceptions were explored to find their a priori understanding of pesticides, pesticide function, and the difference between synthetic and natural pesticides. Their knowledge of green pesticides was also examined. After this, the students wrote down their answers and explored them in a class discussion. A video entitled “Do we really need pesticides?” from TEDx (by Fernan Perez-Galvez) was presented to give the students new insights into sustainability issues surrounding pesticide use. The video has subtitles in Indonesian and 22 other languages. It can be found on the internet under the link: (https://ed.ted.com/lessons/do-we-really-need-pesticides-fernandez-galvez/watch ). This video discusses the history of the development of pesticides, the pros and cons surrounding pesticides, and global issues regarding the persistence of common synthetic pesticides in the environment. It also emphasizes the role of scientific developments when it comes to solving the problems of pesticide use. In this part of the lesson, students were given the task of watching the video and analyzing the controversial issues related to pesticide use. After that, the participants completed a worksheet, which examined the risks of using conventional pesticides and presented several ideas for avoiding potential risks. The learners were asked to decide which group they would join: the group supporting the utilization of synthetic pesticides or the group refusing to do so. Then the class was divided along these lines and expressed their arguments regarding their position in a class debate. The teacher guided the students as they explored their answers in an interview and in the class discussion.

In the next step, a discussion about multiple perspectives was initiated. An alternative view from a local indigenous context was...
introduced and contrasted with the developments of modern science in order to possibly resolve the issue. A short video on the utilization of natural pesticides in the indigenous community, the Baduy tribe, presented this context. Furthermore, the students read an article entitled “Indigenous Biopesticide: Bio-rational control of pest insects in the Baduy Community”. This article provided information about the Baduy agricultural system, their cultural values and philosophies about conserving nature, and information about their indigenous biopesticides. The learners were then given the task of discussing the alternative solution from the indigenous perspective, which offers the sustainable approach of using green pesticides from plant extracts. During the task, the students analyzed the risks and benefits of using natural (green) pesticides derived from local plants. Then they were guided by the teacher through a class discussion of their arguments.

In the end, the students were asked to apply concepts from chemistry in order to explain the different alternatives offered. The relationship between chemistry and pesticide use was connected to the three relevant dimensions of chemistry education: the personal, societal and professional context (Stuckey et al., 2013). In terms of the societal context, the students analyzed the case of DDT synthetic pesticides on the environment. In the personal context, chemistry content was related to the potential effects of pesticides on personal health. The professional context asked the students to explain the chemical phenomena in IS from a scientist’s point of view. Reflection was also carried out to find which chemical content was necessary for students to master these questions. This content analysis was based on the school curriculum and the general chemistry textbook. The structure of the unit is given in Table 1. The connection between problem-solving, the aspects of chemistry education’s relevance, and chemical content are shown in Table 2.

### 3.3. Findings

Students’ responses to the Likert-items in the questionnaire could be categorized into three main areas: (a) student interest in and motivation for the topic (items 1, 5, and 6), (b) perception of relevance to students and the chemistry curriculum (items 3, 9, and 10), and (c) student views on the integration of IS and Western science to solve sustainability issues and to foster intercultural learning (items 4, 2, 8 and 7).

The feedback from the student teachers (Fig. 2) and upper secondary school students (Fig. 3) reveals almost the same distribution of answers. In terms of the students’ interest and motivation, most of the students were interested in the lesson (over 90% agreed or mostly agreed among

### Table 1

<table>
<thead>
<tr>
<th>Activities</th>
<th>Tools and Tasks</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. The students explore their a priori knowledge about pesticides and green pesticides.</td>
<td>Worksheet 1</td>
<td>15’</td>
</tr>
<tr>
<td>b. The students watch a video about global issues regarding the risks of conventional pesticides in the environment. Then they express their arguments in writing and through a discussion.</td>
<td>Video from TEDx: “Do we really need pesticides?” Worksheet 2</td>
<td>45’</td>
</tr>
<tr>
<td>c. The learners consider an alternative approach borrowed from IS, based on an article. Then they review and discuss the arguments.</td>
<td>Article and video about pesticides from the Baduy communityWorksheet 3</td>
<td>45’</td>
</tr>
<tr>
<td>d. The participants apply chemistry concepts to answer questions about the topic.</td>
<td>Worksheet 4</td>
<td>30’</td>
</tr>
<tr>
<td>e. The students describe their own perceptions of the topic and the incorporation of alternative views taken from IS.</td>
<td>Questionnaire</td>
<td>15’</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Aspects of relevance</th>
<th>Problem-solving</th>
<th>Chemical content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Societal context:</td>
<td>DDT</td>
<td>- Structure of Matter (molecular structure)</td>
</tr>
<tr>
<td>The social issue of pesticides (a case study on DDT) on the environment</td>
<td>(Dichlorodiphenyltrichloroethane)</td>
<td>- Chemical bonding (polarity, stability or reactivity of compounds)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Organic chemistry (aromatic compounds, functional groups)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Structure of Matter (molecular structure)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Organic chemistry (aromatic compounds, functional groups)</td>
</tr>
</tbody>
</table>

| Personal context:    | Indigenous knowledge of bio-rational pest insects may be used as an alternative to synthetic pesticides. The Baduy community located in Banten (Indonesia) uses plants as natural pesticides to protect their crops (read the article). Please give a scientific explanation regarding the phenomena/processes of indigenous people to answer the questions: | - Chemical reaction (oxidation reaction) |
|                      | In your understanding, what makes DDT resistant to environmental degradation? Please give an explanation. (connected with chemical structure and solubility) | - Chemical reaction (oxidation reaction) |
|                      | In your understanding, what causes DDT to be accumulated in the fatty tissues of living organisms and exhibit toxicity? Please give an explanation. (connected with chemical structure and solubility) | - Chemical reaction (oxidation reaction) |
|                      | a. The Baduy community uses natural pesticides extracted from local plants to protect their rice crops. Some plants contain secondary metabolite compounds, which exhibit ‘strong scent’ to repel pest insects. In your understanding, what functional groups are responsible for those properties? | - Chemical reaction (oxidation reaction) |
|                      | b. To manufacture their crude extract of natural/botanical pesticides, the Baduy people use fermented sugar palm juice. What compounds might be formed from these solvents? Please give an explanation. | - Chemical reaction (oxidation reaction) |
|                      | c. Please predict what kind of chemical compounds (based on polarity) can be extracted using these solvents? Please give an explanation. | - Chemical reaction (oxidation reaction) |
|                      | d. In your understanding, how do chemists identify and analyze bioactive compounds in plants? Please explain the process. | - Chemical reaction (oxidation reaction) |

| Professional context: | How do students explain the chemical phenomena about IS from a scientist’s point of view? | - Chemical reaction (oxidation reaction) |
|                      | a. The Baduy community uses natural pesticides extracted from local plants to protect their rice crops. Some plants contain secondary metabolite compounds, which exhibit ‘strong scent’ to repel pest insects. In your understanding, what functional groups are responsible for those properties? | - Chemical reaction (oxidation reaction) |
|                      | b. To manufacture their crude extract of natural/botanical pesticides, the Baduy people use fermented sugar palm juice. What compounds might be formed from these solvents? Please give an explanation. | - Chemical reaction (oxidation reaction) |
|                      | c. Please predict what kind of chemical compounds (based on polarity) can be extracted using these solvents? Please give an explanation. | - Chemical reaction (oxidation reaction) |
|                      | d. In your understanding, how do chemists identify and analyze bioactive compounds in plants? Please explain the process. | - Chemical reaction (oxidation reaction) |
the student teachers; 80% among the secondary school students, respectively). Both groups of participants did not like chemistry learning which solely focuses on content matter and lacks any relationship to the societal issues surrounding sustainability (90%/80%). The student teachers were more motivated by the topic (90%) than secondary school students (60%).

Student responses to the relevance of the lesson to the chemistry curriculum and their personal learning experiences generally indicated a positive perception of the topic. Based on their personal learning experiences, both groups of students felt that the topic was relevant. Approximately 90% disagreed or strongly disagreed with the statement that the topic had no relevance for them. Over 70% of student teachers agreed or strongly agreed that the lesson was relevant to the chemistry curriculum. The same acknowledgment was echoed by nearly 65% of the upper secondary students. A majority in both groups (over 60%) agreed or strongly agreed on the importance of sustainability issues in chemistry lessons.

Student feedback on integrating IS and Western science in chemistry learning revealed significant support for the idea. Both groups of students (over 90%) agreed or strongly agreed that comparing IS and Western science is useful for addressing global issues. A majority of the student teachers supported decision-making based on multiple perspectives to realize sustainable science (over 90% agreed or strongly agreed). This point of view was also stated by approximately 80% of
secondary school students. In terms of promoting intercultural learning, roughly 75% of both groups of students acknowledged that the lesson had given them insights into different cultures.

The responses to the open-ended question varied. The word cloud analysis visualized the phrases the students used to express their feedback. The size of the words indicated the frequency with which they were mentioned (Fig. 4). “Interesting topic, interesting lesson, open insight, environmental care,” are words or phrases that were often mentioned by both groups of students. The phrases “interesting topic” and “interesting lesson” showed that learners liked the lesson, mostly because it was perceived as related to daily life. One student said: “The topic we discussed was interesting to me because it is related to daily life and it also gave me insight into the need for environmental conservation for sustainability”. Some of the students also stated that they were interested in the topic because they perceived it as relevant to societal, economic, and environmental issues. The words “open insight” appeared often in the students’ statements, referring to their learning experience. They felt that the lesson could open their minds. They accepted the responsibility to preserve nature by avoiding harmful pesticides. Some of the students also mentioned that learning using multiple perspectives can open insights to solve problems related to sustainability. The lesson also encouraged students to develop a sense of caring for the environment. This was usually mentioned by the phrase “environmental care”. This is illustrated by the quote: “The discussion on indigenous and Western science opened my eyes to environmental care. We need to preserve the environment with sustainable science.”

There were some words frequently mentioned by the student teachers which did not appear among the responses of the high school students, e.g., “understanding pesticides” and “connecting concepts”. The student teachers referred more often to understanding sustainability issues based upon connections with chemistry concepts: “My response to this lesson was very interesting with regard to different learning methods. The topics discussed were very interesting, relevant and helpful for studying chemical concepts in the context of everyday life”. A small number of secondary school students seemed to have had trouble recognizing the relationship between the context and the chemistry concepts behind it. This was expressed by “not fully understand” and “lack of concept”. One participant stated: “I was happy about this learning unit, but I did not understand a number of things related to organic chemistry”. Another student said: “The chemistry learning was good enough, but discussion about organic chemistry was lacking”.

Further analysis of the students’ attitudes towards their learning experience was based on the sentiment analysis performed on the open-ended question. This analysis tried to identify whether students’ attitudes towards the lesson were positive, neutral or negative. Fig. 5 shows the average sentiment scores for both groups of participants. The mean sentiment score of the high school group is with 1.2, a value which is slightly higher than that of student teachers (mean 1.0). Both results indicate that the average perception of the lesson was more positive than negative. In terms of the distribution of sentiment scores, the high school students had a greater proportion of both neutral (0) and slightly positive perceptions. The student teachers had slightly more negative sentiment scores and fewer total positive sentiments than among high school students.

4. Discussion and conclusion

The case study presented in this paper shows that chemistry learning can be enriched by encouraging higher levels of student interest and increasing the personal perception of a topic’s relevance. This can be done by (a) facilitating student learning with the help of authentic and controversial sustainability issues, (b) providing multiple perspectives on science, and (c) integrating locally relevant cultural aspects into the discussion on sustainable development. Our findings show that the participants gave significantly positive responses to the topic of pesticide use. They considered it to be both interesting and relevant to their personal learning experience. Sentiment analysis could also support such positive perceptions of the students for this lesson plan. These findings suggest that giving students more frequent opportunities to discuss sustainability issues in a broader, societally-embedded perspective is a good thing. This can also be connected to IS, which includes environmental ethics, cultural values, and the knowledge of indigenous communities. These factors can complement Western scientific worldviews to lend relevance to science education and promote learning for and about sustainability (Zidny et al., 2020).

The feedback from the students in both groups indicates that learning with the aid of multiple perspectives has great potential. Such learning can broaden learners’ insights and show that chemistry needs to be studied as part of an interconnected system, if we want to find solutions to global sustainability issues. Chemistry education should be interconnected with other science worldviews (including IS) and disciplines. This would allow us to collectively develop a comprehensive perspective on how physical and biological environment systems interact, behave and affect each other. Most of the students in the case study described above supported the multiple viewpoint stance. They believed that various disciplines need to be involved in decision-making to solve the problems facing sustainability. This showed that the overall learning process supported students’ awareness that chemistry has complex interactions with both society and the environment. This is in line with the philosophy of ESD (Burmeister et al., 2012), a growing awareness of the need for trans-disciplinary learning (Koutalidi and Scoullos, 2016; Matlin et al., 2016), and systems thinking (Matlin et al., 2016; Mahaffy et al., 2018) in chemistry education. Further research and curriculum development should identify further potential topics. It should also define the correct degree of connection between socio-scientific issues and content learning. In the current case, this
connection seemed to be appropriate for undergraduate student teachers, but needs further improvement concerning the upper secondary school level.

This case study is limited to the Indonesian educational context and is related to the perspectives and cultural values of a particular indigenous community. Further research might reveal how other perspectives and science worldviews in other indigenous communities and in different countries might also add to the relevance of chemistry learning for sustainability. These studies might also add to our knowledge about any long-lasting effects such teaching units will have if they are applied more regularly.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Robby Zidny: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Funding acquisition. Ingo Eilks: Conceptualization, Methodology, Formal analysis, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

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References


Bio-pestisida Indigenous

Pengendalian Bio-rasional Hama Serangga di Komunitas Suku Baduy

Suku Baduy adalah contoh masyarakat tradisional Indonesia yang terletak di dekat kawasan hutan dan masih mempertahankan pertanian tradisional. Mereka sangat bergantung pada hutan yang memainkan peran dalam hal ketahanan pangan, mata pencaharian, pertanian, dan sumber daya keanekaragaman hayati. Salah satu perilaku sentral masyarakat Baduy terkait dengan alam dalam hal perlindungan dan pelestarian lingkungan meliputi hal-hal berikut: (a) sistem pertanian, (b) sistem pengetahuan, (c) sistem teknologi, dan (d) praktik konservasi (Suparmini et al., 2013).

Untuk mengendalikan hama dan penyakit padi, masyarakat Baduy menerapkan pengetahuan indigenous (tradisional) dengan menggunakan berbagai pengelolaan hama seperti pengaturan waktu dan pola tanam yang mengantisipasi siklus hidup hama, pengaturan spesies padi yang ditanam menggunakan varietas lokal yang diatur secara adat, dan penggunaan pestisida nabati untuk mengendalikan hama.
Pengendalian Hama

"Samara Pungpuhunan"

Dalam proses pengendalian hama, masyarakat Baduy memiliki kegiatan pengobatan padi (Tabel 1) yang mereka sebut “ngubaran pare”. Pengobatan ini menggunakan ekstrak campuran bahan tanaman lokal yang dikenal dalam bahasa lokal sebagai “samara pungpuhunan”. Bahan ini memiliki fungsi sebagai pestisida alami/biopестиsida untuk mengendalikan hama di ladang padi mereka.

Sesuai dengan budaya dan keyakinan mereka, proses produksi ramuan ini disertai dengan upacara tradisional dan pembacaan mantra. Kisas perjalanan hidup orang Baduy dan dongeng tentang Nyi Pohaci Sanghyang Asri (Dewi Padi) disajikan pada upacara (Senoaji, 2011). Beberapa tanaman yang memiliki senyawa bioaktif yang sering digunakan untuk ramuan bio-pestisida seperti kulit jeruk bali (Citrus grandis) dan Achaasma walang yang menunjukkan “aroma kuat” untuk mengusir hama serangga. Masyarakat Baduy memilih untuk menggunakan ekstrak kasar tanaman untuk mengusir serangga dan hama lainnya dari tanaman padi, bukan pestisida sintetis (kimia) yang berpotensi meracuni dan merusak lingkungan.


Pestisida sintetik (kimia) dengan semua kelebihan dan kemudahannya sekarang mungkin masih menjadi pilihan pertama dalam industri pertanian untuk memenuhi permintaan produksi pangan. Tetapi dengan semua risikonya terhadap lingkungan, apakah hal ini dapat membuat kita hidup berkelanjutan (sustainable) di masa depan?. Tidak ada solusi pintas untuk menghadapi hama pertanian. Mungkin dengan kombinasi kearifan lokal masyarakat tradisional pada pemahaman ekosistem dan kesadaran lingkungan, dan teknologi tinggi yang ditawarkan oleh sains barat, kita memiliki kesempatan yang lebih baik untuk menemukan solusi holistik untuk pengendalian hama.

Pola ini serupa dengan sistem manajemen hama terpadu (integrated pest management) yang merupakan strategi berbasis ekosistem yang berfokus pada pencegahan jangka panjang hama atau kerusakan ekosistem melalui kombinasi berbagai teknik seperti pengendalian biologis, manipulasi habitat, modifikasi praktik budaya, dan penggunaan varietas tahan hama (Flint, 2012).

Penerapan pengetahuan indigenous (tradisional) di Baduy didasarkan pada prinsip dan norma yang disepakati bersama untuk menjaga keberlangsungan hidup masyarakat baik untuk generasi sekarang maupun mendatang. Mereka memiliki filosofi yang memiliki teka (pikukuh) untuk melestarikan alam, diantaranya yaitu:

"Gunung teu meunang dilebur, Lebak teu meunang diruksak."
"Lojor teu meunang dipotong, pondok teu meunang disambung".

Inti dari pikukuh Baduy berarti bahwa manusia tidak diperbolehkan mengubah apapun yang dapat menyebabkan kerusakan pada alam. Tujuan hidup mereka adalah untuk mencapai kehidupan yang sederhana, memadai, adil, makmur, aman dan damai.

"Gunung teu meunang dilebur, Lebak teu meunang diruksak."
"Lojor teu meunang dipotong, pondok teu meunang disambung".

"Samara Pungpuhunan"
Tabel 1. Pengobatan Padi di Baduy (Ngubaran Pare) melibatkan proses sistematis mengikuti fase perkembangan tanaman padi.

1) Periode pertumbuhan pertama padi (40 hari setelah penanaman padi) menggunakan bahan-bahan berikut:

<table>
<thead>
<tr>
<th>Nama local tanaman</th>
<th>Nama latin tanaman</th>
<th>Proses ekstraksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panglay</td>
<td>Zingiber cassumunar Roxb</td>
<td>1. Semua tanaman dihaluskan</td>
</tr>
<tr>
<td>Jawer Kotok</td>
<td>Coleus galeatus</td>
<td>2. Semua campuran ditambahkan air beras merah</td>
</tr>
<tr>
<td>Rotan</td>
<td>Plectocomia elongata</td>
<td>3. Ditambahkan air gua nira aren yang didiamkan atau difermentasi 5-7 jam kemudian diaduk rata.</td>
</tr>
<tr>
<td>Bingbin</td>
<td>Pinanga coronata</td>
<td>4. Semua bahan disebarkan pada tanaman padi</td>
</tr>
<tr>
<td>Sereh</td>
<td>Piper betel L</td>
<td>5. Proses pemberian ramuan ini diulang 7-9 kali</td>
</tr>
<tr>
<td>Hanjuang</td>
<td>Cardyline fruticosa</td>
<td></td>
</tr>
<tr>
<td>Bambu tamiang</td>
<td>Bambusa wrayi</td>
<td></td>
</tr>
<tr>
<td>Kiwura</td>
<td>Arenga porphyrocarpa</td>
<td></td>
</tr>
<tr>
<td>Pacing tawa</td>
<td>Costus speciosus</td>
<td></td>
</tr>
<tr>
<td>Barahulu</td>
<td>Amomum sp</td>
<td></td>
</tr>
</tbody>
</table>

2) Fase pertumbuhan cabang, sekitar 60 hari setelah periode penanaman padi. Bahan-bahan yang digunakan adalah:

<table>
<thead>
<tr>
<th>Nama local tanaman</th>
<th>Nama latin tanaman</th>
<th>Proses ekstraksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mengkudu (Noni fruit)</td>
<td>Morinda citrifolia L</td>
<td>1. Semua tanaman dihaluskan</td>
</tr>
<tr>
<td>Kulit jeruk bali</td>
<td>Citrus grandis</td>
<td>2. Ditambahkan abu sisa pembakaran kayu</td>
</tr>
<tr>
<td>Laja</td>
<td>Longus galanga</td>
<td>3. Ditambahkan air gua nira aren yang didiamkan atau difermentasi 5-7 jam kemudian diaduk rata.</td>
</tr>
<tr>
<td>Rendu carat</td>
<td>Bambusa wrayi</td>
<td>4. Semua bahan disebarkan pada tanaman padi</td>
</tr>
<tr>
<td>Harendong</td>
<td>Melastoma candidum D. Don</td>
<td>5. Proses pemberian ramuan ini diulang 7-9 kali</td>
</tr>
<tr>
<td>Bambu apus</td>
<td>Bambusa wrayi</td>
<td></td>
</tr>
</tbody>
</table>

3) Periode pembungaan padi. Pengobatan dilakukan dengan menyebar air kelapa hijau pada tanaman padi. Air kelapa yang mengandung hormon / regulator pertumbuhan tanaman. Air ini dapat meningkatkan pertumbuhan dan perkembangan tanaman (proliferasi akar, pemanjangan batang, induksi bunga).

4) Fase maturasi. Pada fase ini tanaman padi mulai muncul bulirnya. Pengobatan menggunakan bahan-bahan berikut:

<table>
<thead>
<tr>
<th>Nama local tanaman</th>
<th>Nama local tanaman</th>
<th>Proses penggunaan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walang</td>
<td>Achasma walang</td>
<td>1. Semua tanaman dibakar untuk menghasilkan asap yang berbau menyenang</td>
</tr>
<tr>
<td>Kanyere</td>
<td>Bridelia monoica</td>
<td>2. Asap ini kemudian ditebarkan disekitar tanaman padi</td>
</tr>
<tr>
<td>Bungur</td>
<td>Lagerstromia sp</td>
<td></td>
</tr>
</tbody>
</table>
Exploring Indigenous Science to Identify Contents and Contexts for Science Learning in Order to Promote Education for Sustainable Development

Robby Zidny
Solfarina
Ratna Sari Siti Aisyah
Ingo Eilks

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Exploring Indigenous Science to Identify Contents and Contexts for Science Learning in Order to Promote Education for Sustainable Development

Robby Zidny 1,2, S Solfarina 2, Ratna Sari Siti Aisyah 2 and Ingo Eilks 1,*

1 Department of Biology and Chemistry, Institute for Science Education (IDN)-Chemistry Education, University of Bremen, 28334 Bremen, Germany; robbyzidny@untirta.ac.id
2 Department of Chemistry Education, Faculty of Teacher Training and Education, University of Sultan Ageng Tirtayasa, Serang 42117, Indonesia; solfarina@untirta.ac.id (S.S.); ratnasari@untirta.ac.id (R.S.S.A.)
* Correspondence: ingo.eilks@uni-bremen.de

Abstract: Indigenous science is comprised of the science-related knowledge and associated practices of indigenous cultures. Indigenous science provides rich contexts that can contribute to understanding the relationship of sociocultural life and environmental ethics in certain communities. It can also lead to better reflection upon Western modern views of science. Based on a qualitative analysis of indigenous science in the Baduy community (Indonesia), we describe how indigenous science can provide relevant contexts for students to learn scientific concepts, as well as help them to recognise the value of promoting sustainability. We present potential topics encompassing the sociocultural context of Baduy science that can be associated with sustainability issues. Topics were identified from six themes (agriculture, medicine, natural dyes, household chemicals, renewable energy, and astronomy). Potential implications of these topics to science learning are also presented. We view contextualization of science teaching and learning by indigenous science as a promising source to enhance students’ perception of the relevance of science learning. It can also promote education for sustainable development.

Keywords: context-based learning; socioscientific issues; indigenous science; sustainability; education for sustainable development

1. Introduction

Context-based learning (CBL) has been widely applied in science education since the 1990s [1]. Many researchers suggest that CBL helps to improve meaningful science education. Problems that CBL is intended to respond to are viewed as stemming from various factors. These include too much focus on the decontextualized learning of facts and theories, a lack of skills developed to apply knowledge in new situations, perceived confusion among students about the actual purpose of learning science, and students’ perception of the science curriculum as irrelevant and incoherent [2]. CBL research has led to the implementation of programmes in several countries, including Salters in the UK, ChemCom in the USA, or Chemie im Kontext in Germany. All of these programmes have contributed to the understanding of meaningful science learning and start from real-world contexts [1]. However, specific contexts for science learning in one country may not be relevant in another land that has a different culture and traditions. Moreover, many contexts used in common CBL science curricula are mostly restricted to a Western modern view of the history and application of science. This view often neglects other cultural components (e.g., [3,4]).

There are some proposed ideas for raising the perception of the relevance of science learning. Some researchers have suggested that meaningful contexts must concern themselves with various natural and environmental phenomena. This includes any applications...
of science in a given cultural and socioeconomic environment. In the different regions of the world, there are various environments. Each has unique and diverse cultural influences, for example, with respect to indigenous communities. In such communities, the path of knowing about nature has been orally passed down from ancestors and forms various types of indigenous science (ISc). This knowledge may provide relevant contexts for science learning, which are potentially interesting to students living in or near a corresponding environment. Beyond the contextualization of science, indigenous perspectives might contribute to understanding the relationship between sociocultural and environmental ethics. They might also help to better understand the dominant Western modern view of science through the lens of more holistic perspectives [5]. Doing so might aid researchers to form a more balanced view of education for sustainability, as has already been suggested by Sjöström et al. [6].

The idea of using ISc to identify contexts for science education is not new [7–10]. Some researchers see science teaching connected to ISc as an aid to promote the values of nature conservation in the sense of sustainability. This can contribute to developing critical reflection on the interrelationship between science and culture. However, we must maintain caution in order to foster an understanding of ISc in science education. The focus of teaching should neither be restricted to teaching the content knowledge behind ISc and its applications nor to solely promoting the idea of conserving the natural environment. The context should include a view of societal issues that involves students in discussions about sustainability in all its dimensions (sociocultural, economic, and environmental) [11]. In this way, education can enable students to play a role as responsible citizens and provide them with a chance to make positive changes in their lives [12].

If we wish to integrate ISc into science education, pedagogical approaches have been suggested that incorporate the sociocultural context, local wisdom, and various philosophical aspects of indigenous lifestyles into the sense of sociocritical sustainability issues [5]. In our view, one potential pedagogical approach to science learning is the philosophy behind education for sustainable development (ESD). This approach combines a wider perspective on sustainability, connected with science education based on socioscientific issues (SSIs) [11]. ESD in connection with SSI-based science education is believed to contribute to all three domains of relevant science teaching (personal, societal, and vocational relevance) as suggested by Stuckey et al. [13]. It is relevant for individual action. Examples of this include cases involving the consumption of resources, participation in societal debates on issues of sustainable development, and career choices related to sustainable science and technology [14,15]. The sociocultural aspects of ISc can be incorporated into ESD and can serve as potential contexts for realizing relevant science learning. Such contexts can encourage teachers and students to gain respect for local cultures, as well as provide ways to teach and learn locally relevant knowledge and skills. This in turn can improve the relevance of science learning. It also promotes ESD by extracting value from the local wisdom of indigenous people and joining it with Western modern views of science [16].

An ISc case study of the Baduy tribe in Indonesia revealed that indigenous communities generally apply scientific principles and concepts in sustainable ways. We can understand these aspects as ethnochemistry, ethnobotany, ethnomathematics, and ethnoastronomy [17]. The current paper uses the ESD framework [11], socioconstructivist pedagogy [18], and the suggested five criteria for selecting socioscientific issues for science education [19] to reach its conclusions. The study discusses the incorporation of Baduy science-related indigenous knowledge (IK) into context-based, sustainability-oriented science education. Exploration of the Baduy community’s ISc is presented as a case study, which shows how to extract potential ISc topics that are related to sustainability issues. In this study, we analyse the relationship between ISc applied in the Baduy community within the science content of the Indonesian science curricula. The analysis identified related science content associated with the different educational levels in Indonesia. Using the concept of ESD, the study suggests different sustainability aspects that can be integrated in
science classrooms in Indonesia and in other countries. Then, it looks at the inferences that can be drawn from the study to aid in science education.

2. Theoretical Framework

2.1. Science in a Multicultural Perspective and ISc

Science is described as a collection of knowledge and methods that shape our perception of the natural world [20]. The theory of multicultural science education recognizes science as a cultural enterprise [21]. Thus, knowledge will be perceived differently according to the cultural traditions and the perspectives of the community who adhere to them. Ogawa defined the multiscience perspective as encompassing three categories: personal science (referring to science at the individual level); ISc (referring to science at the cultural or societal level); and Western, modern science (referring to a collective rational perceiving nature and technology shared and authorized by the scientific community) [22].

Within a multiscience perspective, ISc encompasses the science-related knowledge and practices of specific indigenous cultures [5]. It shapes the body of knowledge about nature and the interactions with nature practiced by indigenous peoples. These aspects are inherited by each culture and provide insights into indigenous societies [20]. ISc has also been interpreted by other academics under different names such as traditional (native) knowledge [23], ethnoscience [24], and traditional ecological knowledge (TEK) [5].

2.2. ISc as a Sociocultural Context for Science Learning to Promote ESD

Gilbert described “context” as a situation that gives meaning to words, phrases, and sentences [2]. He pointed out that well-suited contexts in science learning are very important. They have the potential to provide coherent meanings to science concepts, since they connect meanings to situations set within a broader point of view. Context in science education plays the role of a bridge that connects abstract concepts to everyday life experiences. Many researchers believe that this strengthens learners’ perception of the relevance and meaningfulness of science learning among students.

Contexts selected for science education should be essential to the life of the students in any given society. Science learning that starts with a context is viewed as relevant education if it is connected to authentic sustainability issues [14]. One contextual approach suggested for promoting ESD focuses specifically on ISc [16]. The acknowledgement of ISc has already been discussed also on a global educational policy level in order to promote sustainable development, which makes it relevant for ESD. The United Nations Educational, Scientific and Cultural Organization (UNESCO) initiated the Local and Indigenous Knowledge System (LINKS) [25]. This programme explores the ways that indigenous and local knowledge systems can contribute to understanding, mitigating, and adapting to climate change, environmental degradation, and biodiversity loss. Recent research trends in science education [7–10] use the sociocultural context of ISc to promote environmental education and ESD. They do so by focusing on socioecological issues such as biodiversity loss.

2.3. ESD in Science Education and Related Pedagogical Approaches

Sustainable development is commonly depicted by numerous models. The most widely accepted ones encompass ecological, economic, and sociocultural sustainability. These aspects are interconnected through various pathways [26]. The corresponding educational paradigm, which is related to sustainable development, is called ESD [11]. Based on a literature review, Burmeister et al. identified four basic strategies of ESD pedagogy when it comes to science education [11]. They include green laboratory practices, contextualizing science learning by sustainability questions, using sustainability questions for socioscientific issue–based science education, and operating sustainable development as part of the development of educational institutions. As Burmeister et al. [11] and Juntunen and Aksela [18] have already pointed out, SSI-based education is among the most promising strategies for achieving ESD in science education. SSIs encourage learners to participate in ethical, political, and environmental realms, which are related to science, technology,
society, and the environment in everyday life [27]. The applications of socioscientific issues in science education are believed to be controversial, up-to-date, complex, and relevant to the daily lives of students [28]. Simonneaux and Simonneaux even pointed out that sustainable development itself can be considered as a complex and highly relevant socioscientific issue [29].

Juntunen and Aksela [18] and Sjöström et al. [6] have suggested socioconstructivist and critical pedagogical approaches when carrying out ESD in science education. Some elements of the pedagogical approach presented by Juntunen and Aksela [18] should be involved when teaching ESD in science, for example, inquiry, interdisciplinary, and argumentation (Figure 1).

![Figure 1. Elements of a context-based socio-constructivist education for sustainable development (ESD) pedagogy (adapted from Juntunen and Aksela [18]).](image)

Science learning with ESD should teach science in context- or SSI-based educational environments. These activities encourage students to act based on their own ideas and experiences. Accordingly, the context of science learning should be provided by SSIs. In other words, they should be sociocritical, problem-oriented issues. Marks and Eilks [19], later supplemented by Stolz et al. [30], suggested five criteria for selecting issues to deliver the context for sociocritical and problem-oriented settings:

- Authenticity: the topic is authentic when it is up-to-date and currently being discussed within society and public media.
- Relevance: the topic is relevant if respective decisions are to come that will affect the current or future lives of students or other citizens within society.
- Evaluation is undetermined in socio-scientific respect: the public perception of the issue includes different points of view that are part of the public debate.
- Allows for open discussion: the topic can openly be discussed in a public debate without harming individuals or groups in society.
- Deals with questions from science and technology: this topic concerns itself with a techno-scientific query.

Within these different theoretical frameworks, the ISc of the Baduy community in western Java (Indonesia) is explored and reflected upon to see whether it can provide any useful contexts for science education. The study is an educational analysis of the results of previous ethnographic research [17] in the inventory of Baduy ISc.

3. Materials and Methods

This study is a part of a larger educational design framework to incorporate indigenous ISc into science education [16]. In a previous study [17], ethnographic research was conducted on the Baduy community with the help of observation, interviews, documentation, and FGD (focus group discussion) to explore their ISc-related knowledge. Further analysis is given in this paper to expand upon the relationship between ISc applied in the Baduy community within the content of the Indonesian science curriculum. The analysis was carried out using the basic tenets of qualitative content analysis according to
Mayring [31]. To ensure validity of the data, triangulation was utilized. It compared data obtained in previous field studies with other pre-existing literature related to ISc of the Baduy community (see [32,33]). The data were analysed in two stages:

Stage 1—Thematic analysis focusing on example topics that could be used as contexts for science learning: The thematic analysis involved six phases: familiarizing ourselves with the data, generating initial codes, searching for themes, reviewing the themes, defining and naming themes, and documentation [34]. The data taken from the previous field study [17] were then inductively analysed by the first three authors in our study to generate the initial codes. In a group discussion, the selected codes were further classified into more general categories of themes and then refined in a cyclical process. The subcategories were refined until they gave a representative picture of the data. To ensure the reliability of the data, all final decisions on categorization of the themes were reached by referring to the negotiated agreement approach. This method is described by Garrison et al. [35] and was supported with the help of consensual coding [36]. Based on the identified themes, a literature review was undertaken. This allowed us to analyse any scientific background and potential content for science learning that could be associated with and explored using ISc. In order to search the scientific background of the identified ISc, we used scientific literature search systems such as Google Scholar, Science Direct, Web of Science, and National Center for Biotechnology Information (NCBI) and using peer reviewed literatures from the search results. The literature search and analysis was conducted in 2018. Because most ISc knowledge dealing with natural resources is related to derivatives from indigenous plants, the literature for the scientific background for the indigenous plants was very limited. Our search techniques employed keywords that were combined with the Latin name of the plants related with the topic or theme of indigenous science resources in the Baduy community that we found in the field study. For example, we use the keywords “biopesticide from Noni fruit (Morinda citrifolia)” that related with the theme of agriculture. This allowed us to find related articles that discussed the scientific explanations and benefits of these plants. For other themes, the keywords used were as follows: medicine (“phytochemicals in Orthosiphon aristatus”); household cleaning materials (“phytochemical of soap nuts or Sapindus rarak”); natural dyes (“natural dyes from Indigofera tinctoria”); renewable energy (“renewable oil from Pangium edule”); astronomy (“ethnoastronomy in the Baduy tribe”).

Stage 2—Interpretation of contexts and content from ISc for SSI-based science education: For the discussion and interpretation of the data, science content and contexts related to the curriculum were reviewed. These included the exploration of local wisdom, values, and the foci of ESD. Based on information about the scientific background information on ISc, we could identify content in the science curriculum. The content was then analysed using both the syllabus for Indonesian upper secondary schools and an introductory, university-level science textbook. We explored local wisdom and sustainability values of the ISc topics by identifying the Baduys’ philosophical ideas, cultural elements, and values with regard to sustainability. This step included an analysis of social demands within an educational design framework, so that we could incorporate ISc into science education as was suggested in Zidny et al. [16]. Local wisdom and sustainability values found in ISc are essential when considering the educational significance of possible learning content, especially if these aspects are culturally bound. After this, the ISc content and contexts identified within the Baduy community were discussed using the five criteria for selecting sociocritical, problem-oriented issues for science teaching [19] in relation to a context-based, socioconstructivist pedagogical approach (see [18]). This analysis identified potential ISc topics having sustainability aspects that could be taught in science classes (Figure 2).
4. Results

Our field research on the Baduy community [17] revealed a lot of ISc-related knowledge that could offer learning contexts and contents for science. The data analysis identified six different themes (see Table 1). Scientific explanations were then derived from the literature as key information (e.g., [37]) in order to identify content that could be contextualized for science learning in secondary and higher science education. As shown in Table 1, the ISc-related knowledge of the Baduy community aligns closely with several modern, Western science concepts. Thus, ISc provides local contexts to approach science concepts from a Western viewpoint. Both views complement each other in this instance and can provide benefits for learners of socioculturally contextualized ESD. Based on the curriculum coverage in Indonesian curricula for secondary schools and college level education, it is suggested that different educational levels fit with the related science content.

Table 1. Six themes of the sociocultural context of science in the Baduy community.

<table>
<thead>
<tr>
<th>Themes</th>
<th>ISc of the Baduy Community</th>
<th>Science Background</th>
<th>Related Science Content</th>
<th>Suggested Educational Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>The Baduy community uses plants as biopesticides to control pests in their rice plantations: Noni fruit (Morinda citrifolia L.), Momordica charantia, Achasma wulang, Bridelia monoica.</td>
<td>160 phytochemical compounds in Noni fruit have been explored for possible benefits, such as antiviral, antifungal, antibacterial, or antinematode function [37].</td>
<td>Chemistry: organic compounds, pesticides, phytochemistry, chemical analysis Biology: classification of plants, bioactivity of compounds, bioassay, biodiversity</td>
<td>Higher education and upper secondary school</td>
</tr>
<tr>
<td>Medicine</td>
<td>Some medicinal plants are used by the outer Baduy community to treat different diseases. For example, Orthosiphon aristatus, a species in the family of Lamiaceae is used [32].</td>
<td>Phytochemicals in Orthosiphon aristatus have been isolated, which have antidiabetic, anti-inflammatory, antioxidant, hepatoprotective, analgesic, and nephroprotective activity. These include terpenes, organic acids, and flavonoids [38].</td>
<td>Chemistry: phytochemistry, chemical analysis, organic chemistry Biology: biodiversity of medicinal plants, classification of plants, bioassay, bioactivity of compounds</td>
<td>Higher education and upper secondary school</td>
</tr>
<tr>
<td>Natural dyes</td>
<td>Craftsmen in Baduy society use natural dyes from plants for their distinctive clothing (Batik Baduy) such as indigo from the leaf of Indigofera tinctoria.</td>
<td>Indigo is formed in damaged leaves by the oxidation of hydrolysis products of various precursors such as indican (indoxyl-β-D-glucoside) or isatan B (indoxyl ketoglucurate) to indoxyl [39]. The process is affected by the activity of decomposing bacterial enzymes.</td>
<td>Chemistry: chemistry of dyes, chemical reactions, chemical extraction Biology: classification of plants, enzyme activity, natural dyes</td>
<td>Junior high and upper secondary school</td>
</tr>
</tbody>
</table>
### 5. Discussion

Generally, indigenous people try to use their knowledge of nature in combination with the idea that humans should respect nature and the natural balance. They attempt to practically apply their knowledge without devastating the environment [5,16]. They use a variety of natural resources to fulfil their needs and consider the impacts their use may have on their future [5,17]. For instance, the Baduy community avoids synthetic chemicals both in agriculture and for daily living needs. As an alternative, they use natural products that are biodegradable in the environment, such as biopesticides in agriculture or natural clothing dyes [17]. This is an example of the application of sustainability principles in their life. They also use their knowledge to survive climate change. The ethnoastronomy knowledge that they apply to rice farming helps them overcome the impacts of seasonal weather swings during their agricultural planting period, thus avoiding crop failure. Such knowledge may provide fruitful contexts for science learning in connection with learning about culture and sustainability. The topic is based on the culture of the surrounding community, which is close to the lives of many Indonesian students. Moreover, students can learn from the perspectives of indigenous peoples and contrast them to Western views about how to use nature and how to solve the global challenge of sustainability [16].

The aspects of interdisciplinarity in science education can also be found in the learning process based on ISc. As shown in Table 1, each theme contains some interrelated learning content uniting the fields of chemistry, biology, and physics. Each topic is also related to questions about culture, ecology, and the local economy. This is in line with the learning approaches in ESD, which emphasize multi- or interdisciplinary problem-solving strategies [43] and the need for multisystem thinking [44]. Students learn to analyse SSIs from various perspectives of the scientific field and beyond. This allows them to obtain a more holistic view of the corresponding issue. For instance, in the context of learning about household cleaning materials, students can learn about the aspects of compounds and chemical reactions in soap-making. Moreover, they can also study soap quality parameters based on surface tension from the point of view of physics. Then, students can

### Table 1. Cont.

<table>
<thead>
<tr>
<th>Themes</th>
<th>ISc of the Baduy Community</th>
<th>Science Background</th>
<th>Related Science Content</th>
<th>Suggested Educational Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household cleaning materials</td>
<td>Lime (Citrus aurantifolia), soap nuts (Salindus rarak), Pteris vittate, and Mischocarpus fuscescens are used for body cleaning products.</td>
<td>The pericarps of soap nuts (Salindus rarak) contain saponins, high-molecular-weight glycosides consisting of a sugar moiety linked to an aglycone [40]. Saponins have detergent or surfactant properties, because they contain both water-soluble and fat-soluble components.</td>
<td>Chemistry: chemistry of detergents, solubility Physics: surface tension Biology: classification of plants</td>
<td>Junior high and upper secondary school</td>
</tr>
<tr>
<td>Renewable energy</td>
<td>The Baduy people have no access to electricity and fossil fuels such as kerosene for lighting. They extract the oil from the fruits of picung (Pangium edule) and make it into oil for lamps [32].</td>
<td>Pangium edule contains methyl esters that can be considered a future biodiesel source. This biodiesel produces cloud, pour, and cold filter plugging points of −6, −4 and −8 °C, respectively. This shows the viability of using this biodiesel in cold countries [41].</td>
<td>Chemistry: organic chemistry, chemistry of biofuels Physics: environmental thermodynamics. Biology/biochemistry: enzyme activity in esterification reactions</td>
<td>Upper secondary school and higher education</td>
</tr>
<tr>
<td>Astronomy</td>
<td>The Baduy have culturally maintained the traditional calendar (Pranata Mangsa) for the swidden farming cycle (slash-and-burn agriculture). The most important constellations for the Baduy community are Orion (Bintang Kidang) and the Pleiades (Bintang Kertika).</td>
<td>The stars of the Pleiades usually appear two weeks before the appearance of Orion, when the sun is in the northern hemisphere. According to the Baduy, this is when the land is cold. In comparison, when Orion begins to set on the western horizon and cannot be seen, rice should not be grown, because the soil is hot, and many insect pests appear at this time [42].</td>
<td>Physics: astronomy, stars and the solar system, Kepler’s laws of planetary motion, Newton’s laws of gravity. Biology: plant physiology, swidden farming, (slash-and-burn agriculture)</td>
<td>Junior high and upper secondary school</td>
</tr>
</tbody>
</table>
simultaneously use biology to explore the classification of plants that naturally produce surfactant substances to locate a sustainable and economically benign resource.

In terms of local wisdom and philosophical aspects, the application of ISc by the Baduy meets the mutually agreed-upon principles and norms. It maintains the sustainable life of the community for both present and future generations. The Baduy people have a philosophy containing a determination (*pi̱kukuh*) to preserve nature, that is, “... *gunung teu meu̱nang dilebur, lebak teu meu̱nang diruksak, lojor teu meu̱nang dipotong, pondok teu meu̱nang disambung...*” (“... the mountain is not allowed to be destroyed, the river is not allowed to be destructed. If it is long, it is not allowed to be cut and if it is short, it is not allowed to be connected ...”). The essence of the Baduy idea is that humans are not allowed to change anything that can cause damage to nature. They are required to conserve their environment, described by protecting mountains, forests, and rivers, which are the main sources of life. Their purpose in life is to achieve an adequate, fair, prosperous, safe, and peaceful existence. Despite living under strict rules, they are born as independent people and uphold the values of honesty and discipline. This philosophy has become the life principle of the Baduy community to sustain their people. The philosophical aspects of indigenous peoples can provide new insights into accommodating the values of environmental ethics in science learning.

The field research performed by Zidny and Eilks [17] also revealed that the Baduy community has cosmological beliefs, norms, and cultural aspects from their ancestors that are concerned with protecting nature. They believe that land, forests, and other natural resources have a spirit, so they must protect their homeland. They will not let anything harm the ecosystem and the sacred forest where they live. In their agricultural system (upland rice planting), nine kinds of traditional rituals are predominantly undertaken by the Baduy community for management of the swidden farming system [33].

The Baduy people understand that the existence of their community not only depends on the sustainability of natural resources but also on the integrity of their culture. Figure 3 illustrates several activities that the Baduy people perform to fulfil their daily needs. Some taboos are additionally imposed in a social and cultural context in order to protect their norms, beliefs, culture, and behaviour from outside influences. The Baduy community has a unique traditional governance, which still exists to regulate their customs. In order to enforce customary laws and prevent violating taboos, various self-control mechanisms and social controls exist, including the imposition of punishment. Because of the local wisdom of the Baduy community, they can maintain the integrity of their culture. This aspect of local culture might become a new perspective in science education to foster intercultural understanding among students. It can also provide a different view of how societies might achieve sustainability.

The sociocultural context of ISc can be associated with sustainability education. The context found in learning has the chance to address both ISc and modern, Western knowledge. It can extend both knowledge systems and find values and new perspectives for teaching and learning [45]. The given context should help learners develop critical thinking and decision-making skills. These confront learners with the influence of ideological, cultural, and historical contexts of science [15]. In order to identify potential topics of ISc for ESD, the context of science from the literature presented in Table 1 was analysed based on socioconstructivist pedagogies [18]. Further analyses included the five criteria for selecting socioscientific issues for sociocritical learning (see [19]) and topical issues in ESD [11]. The potential topics are individually categorized and organized around the six themes (see Table 2).

All the topics identified from ISc can be connected to sustainability issues for learning (Table 2). They are authentic and relevant and not just for the Baduy community. These topics are open-ended and controversial with regard to whether behaviour in industrialized societies should change to more closely mirror Baduy ideas concerning sustainability. Each topic also deals with science and its applications. They all offer promising contextual approaches for science education. These contexts can be placed into an SSI teaching and
learning setting. This will encourage learners to compare the ISc of the Baduy community with modern, Western science and its related applications, when confronted with critical thinking situations.

![Image of Baduy community activities](image-url)

**Figure 3.** The daily activities of the Baduy people (pictures were taken with permission).

**Table 2.** The potential topics for education from ISc of Baduy community.

<table>
<thead>
<tr>
<th>Themes</th>
<th>Potential Topic</th>
<th>Sustainability Aspect to be Learned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>Bio-rational control of pest insects using indigenous materials vs. synthetic pesticides</td>
<td>Learning about risk-benefit analysis between synthetic and green pesticides. Green chemistry approaches to isolate and explore eco-benign pesticides.</td>
</tr>
<tr>
<td>Medicine</td>
<td>Investing in research on traditional medicinal plants as starting points for chemical drug development</td>
<td>Comparison of risks and benefits regarding modern, Western and traditional medicine.</td>
</tr>
<tr>
<td>Natural dye</td>
<td>Natural dyes from local plants: chemistry applications and sustainability assessment</td>
<td>Risks of chemical textile dyes and eco-friendly alternatives from ISc.</td>
</tr>
<tr>
<td>Household cleaning materials</td>
<td>Using plant-based biodegradable compounds from ISc as household chemical</td>
<td>Addressing the issues of water pollution and considering alternative biodegradable household chemicals from ISc.</td>
</tr>
<tr>
<td>Renewable energy</td>
<td>Oil lamp from ISc (<em>Pangium edule</em> Reinw.): A nonedible oil feedstock for biodiesel production.</td>
<td>Issues associated with fossil fuel use and renewable energy sources from plants.</td>
</tr>
<tr>
<td>Astronomy</td>
<td>The role of ethnoastronomy to determine rice planting and harvest times as a response to climate change.</td>
<td>Introducing the issue of climate change effects to the agricultural season and reflectively adapting land use to mitigate harmful effects by comparing ISc and modern, Western science.</td>
</tr>
</tbody>
</table>
We suggest that when the student is confronted with ISc, they must be involved in the discussion of controversial issues within a multiperspective, multidimensional view of science. The choice of context must consider the interest that the learner has in the topic. The teacher, however, has the role to provide the lesson plan and the relevant content and contexts for the course and offering a suitable pedagogical approach to allow students to follow both their interests and guidance in achieving the learning goals. The relevant aspects of science learning in the school curriculum should also consider the educational background level of students. For instance, junior high school students might prefer to choose topics such as synthetic and natural dyes or household chemicals, because they deal with smaller-scale, less complex societal controversies. On the other hand, themes such as the controversial use of pesticides or renewable energy sources deal with more complex issues. These seem more suitable for upper secondary school or undergraduate students with higher critical thinking skills. The implications of the context of science learning in ISc is more meaningful if it is associated with sustainability issues in SSI-based education. The emphasis on science learning is not only restricted to the process of content learning and contextual understanding. It might also promote the development of critical scientific literacy [46] and add to the level of intercultural understanding among learners [17].

6. Implications and Conclusions

In science learning, the integration of ISc as an SSI for ESD should be more than just teaching about the issue and the related problems. To deliver the issues, teachers need to encourage students to participate in active learning through student-oriented, cooperative learning or with the aid of inquiry-based science teaching [18,19]. The issues discussed in the learning process are complex and require problem-solving skills. For this reason, the role of the teacher is very important in describing problems in ESD from various perspectives at a level that students can understand. Educators must be able to connect personal actions and student questions to the process of developing solutions to those problems [18,27]. If applicable, the point of view should include perspectives both from ISc and Western, modern science. For instance, the lesson can facilitate the student to express their ideas and argumentation in inquiry learning related to sustainability issues (e.g., investigating harmful effects of pesticides use) by comparing different perspective from ISc and Western, modern science in search for alternative green pesticides [47]. This might allow the development of a more comprehensive understanding of the problem of sustainability, in local communities in particular and in the larger society in general. In addition, the teacher also should be able to interconnect the values of local wisdom and sociocultural and philosophical aspects of ISc and add them to the modern, Western view of science. This is certainly a challenge for educators in science education, since they are required to promote intercultural understanding within different cultural perspectives in science to foster ESD.

The sociocultural context of ISc can be an innovative educational approach in science education to promote ESD, especially in regions with strong cultural roots that differ from the West, such as parts of Asia, Africa, or Latin America. ESD is an educational perspective initiated by the UNESCO with a goal of global realization [48,49]. The application of ESD in science education has already started in developed countries such as Germany, Spain, and Canada, since the Decade of Education for Sustainable Development [50] was begun. For instance, the implementation of ESD in formal and non-formal education was conducted in Spain through citizen science initiatives [51] and programmes to inspire technological scientific vocations in an environment of equality and sustainability [52]. However, the application of ESD has not yet been optimal in developing countries, such as Indonesia. Based on a UNESCO report on ESD implementation [53], the ESD concept has been implicitly integrated into the educational system in Indonesia through programmes and activities relating to ESD. These include schools, university programmes, and activities related to ESD themes such as green school and green campus. However, ESD remains rather superficial in the science teaching and learning process in regular classrooms. This
is due to teachers and teachers-in-training not being sufficiently equipped with ESD knowledge to integrate ESD into their teaching practices.

The low level of ESD implementation in the case of Indonesia draws our attention to the existing curriculum in Teacher Education Institutes (TEIs). Indonesia has 12 public TEIs (Teacher Education Institutes) and more than 100 private TEIs spread throughout the country. These offer pre-service training for more than 700,000 student teachers, who constitute the majority (27.16%) of all university students [53]. These prospective teachers are potential initiators of change and potential future practitioners of ESD. They should learn how to incorporate ESD into their teaching without needing to make significant changes in the curriculum. Reorienting TEIs’ focus implies empowering schools and teacher educators to develop ESD awareness on the part of students. To realize this, innovations to the educational curriculum can include introducing relevant contexts (such as those identified from ISc) to students, while at the same time promoting ESD through a sociocultural approach to science—raising sustainability issues belongs to this area. Such ideas can infuse values from local wisdom into the curriculum. The integration of ISc into science curricula would provide a different sociocultural context of science. This connects ethics, culture, and human philosophical aspects regarding nature, which offer a more holistic view of science to reach a sustainable society [16]. It also offers a socioscientific view of the different perspectives of science (ISc and Western, modern science) when finding strategies to achieve a sustainable lifestyle. Globally, this approach could add innovation to science education with regard to promoting ESD in developing countries.

ISc and other non-Western viewpoints of science offer a rich context that reveals the sociocultural aspects of science [16]. Contexts borrowed from ISc can be fruitful topics that can be tied to the science curriculum. This may help students learn science from a different cultural environment based on contexts that are close to real-life experiences [5]. This aspect can make science be perceived as more personal, meaningful, and relevant by students. Integrating views and contexts from ISc into science teaching has the potential to allow learning about the social implications of scientific knowledge. This ties in directly with the welfare of a given society, in our case the Baduy community in Indonesia. Integration of ISc into the science curriculum also provides a chance for dialogue and the consolidation of two different knowledge systems (ISc and modern, Western science). This offers the opportunity to merge the advantageous aspects of different world views in regard to sustainability [16] and to promote eco-reflective, relevant education for sustainability [6,54].

The analysis of science content and contexts from the ISc of the Baduy community that was conducted in this study offers a new way to show how to incorporate and reconstruct the valuable knowledge, culture, and local wisdom of indigenous peoples into the formal science curriculum. Since local indigenous wisdom and the sacred respect of indigenous peoples to nature are similar in many indigenous communities, this paper might also lead educators in other environments for investing in curriculum development with respect to their own indigenous living neighbours. Using this analysis, educators can be facilitated to bring relevant and authentic science into class that really is close to the student’s cultural background and environment. This is an important chance for curriculum development, since it can provide meaningful contexts. Such contexts consider the relevance of science for life and development, while simultaneously promoting sustainability [14]. ISc provides a transdisciplinary view of sustainability, which aims to respect various ways of knowing things. Accordingly, this approach gives learners a broader view of the world. This allows them to understand both scientific knowledge and holistic views in order to better understand the role of social and cultural contexts in the production of scientific knowledge [20,55]. In this sense, the trans-disciplinary aspects of sustainability are viewed as a transformational stream of sustainability science [56]. This approach also provides a chance for science learning in an integrated way and encourages student’s interest in science, technology, engineering, and mathematics (STEM), which is necessary for achieving better solutions to the global sustainability issues [52] and also might better include aspects of arts and the humanities in the future. Further research needs to dig deeper
into the knowledge base of indigenous peoples. Evidence-based curriculum development and research is needed to pinpoint and explore the full potential of integrating ISC into science education. In the context of the sustainable development goals (SDGs), this study focuses on several aspects, e.g., not only those SDGs focusing on the preservation of the environment and safe access to water and food but also those on equality and societal justice. The discussion about the culture and gender equitability as well as the equitable respect to ecological sustainability and protection of the environment social and economic issues in science learning is also an important aspect that should be explored in future studies in more detail.

7. Limitations

This study is necessarily limited, since its only focus on just one group of indigenous people in Indonesia. Further research might reveal whether similar examples are available in other countries where part of the population is indigenous, whether findings are similar or different. Limitations in our approach do arise, since this study is qualitative and interpretative in nature. This is, however, due to the circumstances caused by focusing on a community that is very different than the typical subjects of common educational studies. However, this can also be a strength, if we are seeking alternative viewpoints and perspectives to topics.

Author Contributions: Conceptualization, R.Z. and I.E.; methodology, R.Z., S.S., R.S.S.A., I.E.; formal analysis, R.Z., S.S., R.S.S.A.; data curation, R.Z., S.S., R.S.S.A.; writing—original draft preparation, R.Z.; writing—review and editing, R.Z., I.E.; supervision, I.E.; project administration, I.E.; funding acquisition, R.Z., I.E. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

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A case study on students’ application of chemical concepts and use of arguments in teaching on the sustainability-oriented chemistry issue of pesticides use under inclusion of different scientific worldviews

Robby Zidny
Ayu Ningtias Laraswati
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A case study on students’ application of chemical concepts and use of arguments in teaching on the sustainability-oriented chemistry issue of pesticides use under inclusion of different scientific worldviews

Robby Zidny, Ayu Ningtias Laraswati, Ingo Eilks

Abstract

The aim of the case study presented in this paper was to explore students’ application of chemical concepts and their use of argumentation in an educational research framework to incorporate and reconstruct indigenous science in chemistry education. This framework fosters education for sustainable development (ESD) in chemistry learning by integrating intercultural and multi-perspective scientific worldviews. The current study focuses on the role of multiple perspectives borrowed from indigenous and Western modern science. It connects them with chemistry concepts in general and organic chemistry. A socio-scientific issues-based, sustainability-oriented pedagogical approach was employed in a teaching intervention. Worksheet tasks, videos and an article were used in an inquiry-based teaching module in secondary (N=40) and tertiary (N=73) Indonesian chemistry education classes. Student responses to the worksheet questions were analyzed using qualitative content analysis. The results indicate that university students showed a better understanding of the chemical concepts compared to upper secondary school students. In terms of argumentation, both groups of students were able to broaden their spectrum of arguments, especially in the area of ethical arguments. These results can potentially contribute to the development of ESD in chemistry education with the support indigenous science and culture as a new pedagogical approach.

Keywords
Chemistry education
Chemical concepts
Argumentation
Education for sustainable development
Multiple worldviews

Introduction

Preparing students to comprehend global sustainability issues and to make value-based decisions, both in their personal and professional lives, is necessary to make them critical, democratic and responsible citizens (Elmose & Roth, 2005; Sjöström et al., 2016). Therefore, we need science education about and for sustainability in order to encourage students to foster their evaluation and reflective skills. Learners need to understand the costs and benefits of scientific and technological development issues within the framework of social and political dimensions. This is true for science in general and in chemistry in particular (Burmeister et al., 2012). In recent years, the development of learning designs promoting education for sustainable development (ESD) in chemistry and science education has begun in some Western countries. The aim is to implement the sustainable development goals (SDGs) introduced by the United Nations (UN, 2015). New pedagogical approaches for chemistry ESD have been developed in several countries. Examples of the topics include plastics and their evaluation (Burmeister
& Eilks, 2012) in Germany, life-cycle analysis (Juntunen & Aksela, 2014b) in Finland, and hydraulic fracturing (Zowada et al., 2018) in the United States. The implementation of ESD in chemistry education is inherent to socio-scientific issues (SSIs) (Burmeister et al., 2012). SSI-based education has the potential to play a significant role in developing students’ argumentation, decision-making, and informal reasoning skills (Sadler, 2011). These skills are crucial in fostering learners’ scientific literacy level and in helping them better integrate their knowledge holistically in order to contemplate controversial scientific issues and dilemmas (Liu et al., 2011).

The movement towards ESD-based approaches by SSIs in chemistry learning has thus far been dominated by Western modern scientific (WMSc) worldviews. The role of environmental technology in solving environmental problems is one of the central focal points. Cultural and philosophical components have not been widely integrated into science education in general (e.g., Ideland, 2018; Khaddoor et al., 2017) and in relation to ESD in chemistry education in particular (Zidny et al., 2020). It is, however, that contexts and issues addressed by ESD vary depending on the culture, geographical conditions and the level of development of each country or community (Wiyarsi & Çalik, 2019). Providing local cultural perspectives may affect chemistry teaching and learning when it tackles the challenge of sustainability. This is even more relevant in countries where different cultural perspectives, values, and worldviews exist in parallel. This is the case in countries with diverse indigenous communities such as Indonesia. We would suggest that a need for the reorientation of ESD exists. This would allow educators to better integrate interdisciplinary and multi-perspective worldview thinking into their teaching. It can also focus on the development of education for responsible citizenship and on the inclusion of philosophical-cultural values (Eilks et al., 2013; Simonneaux, 2014; Sjöström et al., 2016; Zidny et al., 2020).

IUPAC has also suggested more inclusion of culture in chemistry learning (Mahaffy, 2006). This relates to raising attention to the human elements in chemistry education in terms of understanding how cultural backgrounds affect learning objectives and classroom practices. Sjöström and Talanquer (2014) called the integration of humanistic approaches into chemistry education the Critical-Reflexive Chemistry Perspective. According to this idea, chemistry knowledge and practices are not merely limited to making decisions and solving problems within the closer chemistry context. Critical analysis of the nature and cultural source of such knowledge and of knowledge production is also concerned. Accordingly, chemistry education needs to be connected to everyday life, technology, society, culture, history and the philosophy of science.

A recent study investigated various integration perspectives combining indigenous and WMSc. It was carried out in Indonesian secondary and higher chemistry classes. The study involved a teaching intervention focused on the topic of pesticides use in a multi-perspective science worldview approach, which focuses on indigenous knowledge (IK) and WMSc. The study received positive feedback from the students in this area (Zidny & Eilks, 2020). Learners viewed the lesson as both interesting and relevant to them. They thought that it fostered their insights into how chemistry learning should be interconnected with other scientific worldviews and cultures to find solutions to sustainability issues. More research is needed to identify how teaching interventions based on multiple worldviews effect the ESD skills necessary to develop critical, eco-reflexive scientific and technological literacy, especially related to the ability of the application of chemical concepts and use of arguments (Sjöström et al., 2016; Sjöström & Eilks, 2018). The current study attempted to exploring and analysing students’ use of
chemical concepts and arguments dealing with sustainability issues while they conducted the learning activity
tasks during teaching intervention.

**Theoretical background**

**Different perspectives on scientific worldviews**

According to the main orientations of scientific literacy, Roberts (2007, 2011) distinguished between two visions
of scientific literacy. Vision I focuses on the learning of scientific content and processes for later application.
Vision II emphasizes understanding the usefulness of scientific knowledge, beginning with everyday life and
societal contexts. Recently, Sjöström and Eilks (2018) suggested a more advanced vision of science literacy,
which they called Vision III. Vision III focuses on transdisciplinarity, philosophical values and critical practice
with respect to the application and effects of science and technology in society. Vision III also aims at eco-
reflexivity (Sjöström et al., 2016) and is tied to the Central/Northern European educational and cultural tradition
called **Bildung** (Sjöström & Eilks, 2018). **Bildung** emphasizes a student’s capability to participate in a democratic
society, show empathy and solidarity with others, and exercise the ability to determine one's own way in life based
on the socio-cultural environment (Sjöström et al., 2017). The implication of Vision III for the science curriculum
is a reconsideration of the contents and contexts of science education. Education needs to incorporate societal
perspectives and controversial, authentic and relevant SSIs into itself (Hofstein et al., 2011). One suggestion was
to include the sustainability debate in the application of science and technology because of its interdisciplinary
and multiple perspectives (Burmeister et al., 2012). This implication coincides with recent educational
frameworks like Education for Sustainability (EFS) (Sjöström et al., 2015), transformative learning (Thomas,
2009) and systems thinking (Mahaffy et al., 2018).

Based on Vision III, educators should consider multifaceted cultural perspectives in terms of the norms, values
and worldviews in any corresponding society when they select and teach certain content matter (Sjöström & Eilks,
2018). The different educational and cultural backgrounds of students affect learners' attitudes and values when
dealing with complex issues in society. Multifaceted cultural perspectives should integrate and contrast WMSc
with other cultural identities, including but not limited to Eastern cultural perspectives, alternative Western
philosophies, and IK (Zidny et al., 2020).

IK is inherited orally from ancestors and makes up various forms of indigenous science (ISc). This knowledge is
potentially interesting and personally relevant context to students from the corresponding society. A recent
literature review revealed that ISc has the potential: 1) offer rich and authentic contexts for science learning,
2) provide chances to reflect upon different views of nature and science in contrast to WMSc in order to develop
more balanced and holistic worldviews, and 3) promote intercultural understanding as a basis for sustainability
(Zidny et al., 2020).

From this point of view, science educators and teachers have designed new curricula that represent a more
balanced perspective by introducing students to multiple ways of understanding science (Snively & Williams,
Indigenous perspectives may provide insight and guidance into environmental ethics when it comes to solving complex societal problems in order to achieve sustainability. The wisdom of IK is generally based on a sacred respect for nature caused by the closer relationship indigenous peoples tend to have with nature (Knudtson & Suzuki, 1992). Accordingly, learning about ISc may help students to recognize the intimate connection between humans and nature in local and global cultural environments. Murray suggested three dimensions for the foundation of science education with sustainability in 2015. In Murray’s diagram (Fig. 1), the term Vision III is used for multiple perspectives on scientific worldviews, including IK systems which complement WMSc. This falls in line with Vision III of scientific literacy as proposed by Sjöström and Eilks (2018). One implication for the science and chemistry curriculum emerges. We need to better incorporate different societal perspectives by including indigenous perspectives and other non-Western modern worldviews. Furthermore, ESD in chemistry education should also integrate multiple perspectives on science worldviews. This would allow it to accommodate the three dimensions of the relevance of science education: individual, societal, and professional relevance (Stuckey et al., 2013). In this case, ISc can serve as a source for socio-scientific and cultural issues to promote the relevance of science education.

![Figure 1. The three visions of science education with sustainability science as the foundation (Murray, 2015)](image)

In the current study, multiple perspectives on scientific worldviews were employed. This was carried out by integrating views and aspects borrowed from ISc into chemistry teaching and learning. The teaching intervention was intended to contribute to “Critical-Reflexive Chemistry” (Sjöström & Talanquer, 2014), an idea which engages students with humanistic approaches to chemistry learning focusing on ethical values. The lesson plan is designed to engage students in class debates about the socio-scientific and sustainability-related issue of pesticides use. A reflective analysis of the philosophical and cultural aspects of IK and its perspectives is believed to complement contemporary WMSc.

**An educational design framework to integrate multiple perspectives on scientific worldviews**

This study is part of a larger educational design project employing ISc for chemistry education. It was created for secondary and tertiary chemistry classes in Indonesia. Its goal is to enhance the relevance of science and chemistry
learning among students, as well as promoting ESD. An educational design framework was used to introduce ISc as both content and context into chemistry education (Zidny et al., 2020). The framework in Figure 2 was adapted from the Model of Educational Reconstruction (MER) (Duit et al., 2005). This approach links the analysis of science content structure to both research on teaching and learning and to the development of instruction. The idea of multiple perspectives on scientific worldviews was also integrated. This provides a stronger connection between ISc and WMSc, sustainability issues, cultural values and the relevance of science learning (Murray, 2015; Stuckey et al., 2013; Zidny et al., 2020). ISc has already been suggested as a source for socio-scientific and cultural issues in order to promote higher levels of relevance in science education. Based on this framework, ESD in connection with SSI-based science education was incorporated into the lessons (Burmeister et al., 2012). Pedagogical elements such as interdisciplinarity and argumentation were chosen to represent the socio-constructivist and critical components found in advanced ESD (Juntunen & Aksela, 2014a). According to the framework, it is suggested to analyze the students’ perspectives in terms of their views, concepts, and arguments about scientific phenomena formed by the two different knowledge systems (ISc and WMSc) as well as about how these multiple worldviews help developing solutions to sustainability issues.

Figure 2. Educational design framework to incorporate ISc into science education (Zidny et al., 2020).

**Application of chemical concepts and argumentation**

If students are to achieve scientific literacy, several elements are crucial. These include the ability to understand relevant science concepts found in various topics and contexts. They also require the skill to evaluate the pros and cons of any scientific or technological development. The aim of Vision I and II of scientific literacy according to Roberts (2007) is the application of scientific content knowledge to understand everyday life situations. Accordingly, students’ ability to connect science content to real-life socio-scientific issues needs to be developed. However, other skills are needed beyond the mere accumulation of knowledge. The literature suggests that problem solving, argumentation and decision-making skills belong in this tool kit. These abilities include complex, higher-order thinking tasks (Broman & Parchmann, 2014; Dori et al., 2003). Higher-order thinking engages students in meaningful learning by using non-algorithmic understanding. It analyzes complex problems
with multiple solutions that involve the application of multiple criteria and uncertainty (Zohar & Dori, 2003; Zohar, 2004).

The field of argumentation skills is considered especially important when it comes to dealing with SSIs in the science classroom (Sadler, 2004; Sadler & Zeidler, 2005). In recent years, research on the connection between SSI and argumentation has been emphasized (Erduran et al., 2015). Several studies have indicated that a relationship between scientific epistemological views and reasoning in socio-scientific issues exists (Liu et al., 2011). This impacts the development of reflective judgment skills in students (Zeidler et al., 2009). A further implication is that students’ argumentation skills are probably influenced by their epistemological beliefs. This is because these beliefs are the source of skepticism and criticism about different knowledge claims found in SSIs. Accordingly, multi-disciplinary and multi-perspective thinking is necessary in learning science in order to foster learners’ argumentation skills about complex SSIs (Karpudewan & Roth, 2018; Lee & Grace, 2012; Rundgren et al., 2016). Such thinking aspects can contribute to students’ open-mindedness, their understanding of controversial SSIs, their bias identification skills, and their critical reflection skills when dealing with SSIs (Oulton et al., 2004).

The literature on argumentation skills in science education reveals the relationship between conceptual understanding and argumentation (Sadler, 2004). Science educators have seemingly assumed that understanding science content is needed when justifying decisions made about SSIs (Patronis et al., 1999). Sadler (2004) points out that conceptual understanding is necessary for SSI informal reasoning. The main arguments are that: 1) the lack of conceptual understanding could limit informal reasoning and 2) conceptual understanding may improve the overall quality of reasoning.

Argumentation in this study refers to any arguments and informal reasoning. It can involve the evaluation of complex or ill-structured SSIs. This includes claims, data and justifications which may be supported by evidence, modal qualifiers or rebuttals (Erduran et al., 2004; Sadler, 2004). This view of argumentation is important, especially when an SSI is open-ended, debatable, and complex and provides no definitive answers. Arguments can be constructed from multiple perspectives, beliefs and moral judgments in order to provide supporting evidence to a claim (Lee & Grace, 2012; Sadler, 2004).

**Focus of the study and research questions**

This study focuses on a classroom task analysis. It examined students’ use of chemical concepts and arguments about pesticides use from the perspective of both WMSc and ISc. Based on the framework shown in Figure 2, the case study attempts to explore and evaluate students’ initial ideas. It looks at the learners’ application of chemical content knowledge and their arguments concerning the sustainability issues of pesticide use. The arguments were then analyzed to describe the students’ stance on the issue, which is an essential part of a socio-constructivist approach to ESD (Juntunen & Aksela, 2014a; Marks & Eilks, 2009). Problem-solving in a related context was also investigated to see if the students could connect chemical concepts with the real-world phenomena found in society and ISc. Based on the responses to the intervention tasks, an analysis was conducted to answer the following questions: 1) How do students apply chemical concepts to pesticide use based on the approach
specifically selected for this study? and 2) What level of argumentation skills do the learners show in context of pesticide use when being taught with a multi-perspective approach?

Method
Teaching intervention

The teaching intervention was conducted in a total of two and a half hours focused on the sustainability of pesticides use. It compared common modern chemistry approaches to alternative green pesticides found in ISc. Multiple perspectives were offered on the issue, including the view of WMSc and ISc. Several worksheet tasks were used to promote conceptual understanding and argumentation skills among the learners. Three worksheets were introduced which engaged the learners in a discussion based on watching two videos and reading an article on the issue (Fig. 3).

<table>
<thead>
<tr>
<th>Activities:</th>
<th>Time [min]:</th>
<th>Tools/Media:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to the contexts</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Pre-Argumentation task: Analyzing the global issue of pesticides use</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Post-Argumentation task: Considering multiple perspectives from ISc and Western modern science</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Applying chemistry concepts &amp; Collecting feedback</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. The design of the teaching intervention

In the beginning, the students engaged in a discussion about their general understanding of pesticides use and green pesticides. This session explored the prior knowledge of the participants and linked their perceptions to the current sustainability SSI of pesticides use. After this, students watched a video from TEDx (by Fernan Pérez-Gálvez) entitled “Do we really need pesticides?” (https://ed.ted.com/lessons/do-we-really-need-pesticides-fernandez-galvez#watch). This activity led to a brainstorming exercise in which the participants identified the various aspects surrounding the common synthetic pesticides used worldwide. The video describes the history of pesticides and discusses the benefits and risks of pesticide use in the environment. It also emphasizes the role of the development of scientific technology (in the sense of WMSc) in order to overcome the problems of synthetic pesticide use. In this session, the students watched the video and then analyzed the controversial issue. They made a decision based on arguments presented by worksheet 1 (Tab. 1). The learners were divided into pro and con groups which would debate (especially synthetic) pesticides use in front of the class. The teacher guided the groups in exploring their arguments through both an interview and class discussion. These activities in this study were labeled as “Argumentation task 1”.

---

7
Table 1. The discussion questions on the global issues of the use of pesticides

<table>
<thead>
<tr>
<th>Q1 : Perception about global issues of the potential risk of pesticides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthetic pesticides have improved over time and are currently regulated by strict safety standards, but they still have the potential to pollute soil and water, impact wildlife, and even harm us. Moreover, they also lead to the rise of “superbugs” which are resistant to different insecticides.</td>
</tr>
<tr>
<td>a. Considering all these risks, do we really need pesticides? Please explain your reason.</td>
</tr>
<tr>
<td>b. How do you suggest resolving or addressing the potential risk of pesticides?</td>
</tr>
</tbody>
</table>

In the next section, discussion of the issue based on multiple perspectives in scientific worldviews was initiated. Alternative views borrowed from ISc in the local area were introduced. Then they were contrasted with developments in WMSc and technology in order to possibly resolve the issue. A video about natural pesticide use by the Baduy tribe, an indigenous community in Indonesia, was presented in this context. Furthermore, an article entitled “Indigenous bio-pesticide: Bio-rational control of pest insects in the Baduy community” was provided (Fig. 4). This article explains the Baduy’s agricultural system, their cultural values and philosophies about conserving nature, as well as their use of indigenous bio-pesticides. The article emphasizes how the Baduy maintain their culture and philosophy to preserve nature. They have a philosophy called pikukuh. This states: “…gunung teu meunang dilebur, lebak teu meunang diruksak, lojor teu meunang dipotong, pondok teu meunang disambung…” (“…the mountain is not allowed to be destroyed, the river is not allowed to be destroyed. If it is long, it is not allowed to be cut and if it is short, it is not allowed to be connected…”). The essence of the Baduy’s philosophy means that humans should respect nature. They are not allowed to change anything that could cause damage to the environment. The article also informs the readers about the cultural tradition of the Baduy with regard to pest control on rice paddy crops, which they call "ngubaran pare". During this ceremonial activity, the story of the life journey of the Baduy and a fairy tale about Nyi Pohaci Sanghyang Asri (the rice god) are presented (Senoaji, 2011). The process of paddy crop treatment uses a blend of indigenous plant ingredients as bio-pesticides, known in the local language as "samara pungpuhunan". These ingredients function as botanical pesticides, which are considered to be green pesticides.
The second worksheet (Tab. 2) asks the students to discuss the alternative solution from the ISc perspective, which offers the sustainability approach of using green pesticides from plant extracts. The participants analyzed the risks and benefits of using natural (green) pesticides derived from local plants. Then the teacher guided them through a class discussion of their arguments. This task was labeled as “Argumentation task 2”.

Table 2. The discussion questions on multiple worldviews on the issue of pesticides use

<table>
<thead>
<tr>
<th>Q2 : Perception about the multiple perspective worldview on the sustainability issues of pesticides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Today, scientists search for alternative bio-rational pest control strategies that balance the demands of food production with environmental concerns. Indigenous knowledge could become a source of inspiration for Western science to develop sustainable agriculture. For instance, the Baduy community in Indonesia have unique knowledge and traditions to control pest insects. They use integrated pest management and utilize natural pesticides extracted from local plants as insect repellent.</td>
</tr>
<tr>
<td>a. Can indigenous bio-pesticides become the future of green pesticides? Please analyze the pros and cons of using natural pesticides from local plants as an alternative to synthetic pesticides.</td>
</tr>
<tr>
<td>b. The Baduy people view nature in an integrated worldview with respect for all living things. They use bio-pesticides not to kill the insects, but to repel them. The natural balance is maintained and environmental pollution avoided. Should we consider the perspective of indigenous people to add insight and guidance to the environmental view in Western modern science? Please explain your arguments.</td>
</tr>
</tbody>
</table>

The open-ended questions (Tab. 1 and 2) were designed not only to elicit “yes” or “no” decisions. They encourage respondents to explain their reasoning when arguing and making decisions about the issue. The feedback to these questions was analyzed as a whole to explore individuals’ ideas regarding this controversial issue.
At the end of the session, participants were asked to apply chemistry concepts in order to explain the phenomena or processes from ISc. The third worksheet (Tab. 3) demands chemistry problem-solving that connects the chemical content with: 1a) a societal issue concerning a case study on DDT in the environment, 1b) a personal context dealing with the effects of DDT pesticide on personal health and 2) a professional context presenting an explanation of the phenomenon of ISc from the point of view of a scientist.

**Table 3. The chemistry problem-solving task**

<table>
<thead>
<tr>
<th>Q3 : Applying chemistry concepts about the related context</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. DDT (Dichlorodiphenyltrichloroethane) is a synthetic insecticide belonging to the family of organic halogenated compounds. Although it was very useful, it is resistant to environmental degradation because of great stability. DDT also can be accumulated in the fatty tissues of living organisms for long periods of time and exhibit toxicity.</td>
</tr>
<tr>
<td><img src="image" alt="DDT Structure" /></td>
</tr>
<tr>
<td>a. In your understanding, what makes DDT resistant to environmental degradation? Please give an explanation (connected with chemical structure and stability).</td>
</tr>
<tr>
<td>b. In your understanding, what causes DDT can be accumulated in the fatty tissues of living organisms and exhibit toxicity? Please give your explanation (connected with chemical structure and solubility).</td>
</tr>
<tr>
<td>2. Indigenous knowledge of bio-rational control of pest insects could be used as an alternative to synthetic pesticides. The Baduy community located in Banten (Indonesia) uses plants as natural pesticides to protect their crop (read the article). Please give your scientific explanation regarding the phenomena/process of the indigenous people to answer the following questions:</td>
</tr>
<tr>
<td>a. The Baduy community uses natural pesticides from local plants to protect their rice crops. Some plants contain secondary metabolite compounds which exhibit “strong scent” to repel pest insects. In your understanding, what functional groups are responsible for those properties?</td>
</tr>
<tr>
<td>b. To manufacture their crude extract of natural/botanical pesticides, the Baduy people use fermented palm sugar juice. What compounds might be formed from these solvents? Please give an explanation.</td>
</tr>
<tr>
<td>c. Please predict what kind of chemical compounds (based on polarity) can be extracted using those solvents? Please give an explanation.</td>
</tr>
<tr>
<td>d. In your understanding, how do chemists identify and analyze bio-active compounds in plants? Please explain the process.</td>
</tr>
</tbody>
</table>

In general, the problem-solving task is related to concepts from organic chemistry, chemical bonding and the structure of matter (molecular structure). The intervention was adjusted in terms of theoretical depth to both the upper secondary school chemistry curriculum and the general chemistry level at the university.
Sample

The participants in this study were taken from two different educational levels. The total number of participants were from two classes of first-year university chemistry student teachers (N=73) and two classes of upper secondary school students (12th grade, science major) in Indonesia (N=40). The study looked at two different levels to compare the effects of the intervention at different educational phases. This has previously been suggested in order to better understand what happens when developing teaching and learning designs. Chemistry concepts and content related to the topics were adjusted to the depth of discussion of general and organic chemistry for upper secondary schools and entry-level university students. Both groups learned at institutions which are geographically near the Baduy community. The cultural background of the students was diverse. Some learners lived in rural areas near indigenous environments, but did not live indigenous lifestyles. Most of the students had contact with IK in their daily lives, but had been primarily influenced by the majority culture of contemporary Indonesian society.

Data collection

A total of three worksheets were used in this study. These worksheets were developed and validated in a previous study (Zidny & Eilks, 2020) by involving a professor and three experts in the field of chemistry education. An Indonesian translated worksheets were then piloted in a small group of students. After that, it was revised for final use. The first worksheet was used to explore students’ arguments on the issue of pesticides use based on modern chemistry perspective (Tab. 1). The second worksheets employed sustainability argumentats which consider an additional perspective borrowed from ISc. This was contrasted with the development of WMSc in order to possibly resolve the issue (Tab. 2). The third worksheet (Tab. 3) was used to assess the learners’ ability to apply chemistry concepts to the pesticides use sustainability issue. Each person voluntarily took part in the study. All official Indonesian regulations for carrying out studies with human beings in educational settings were respected.

Data Analysis

The student questionnaires were analyzed using qualitative content analysis (Mayring, 2000). Categorization of the responses to the worksheets was conducted based on the classification presented in Table 4. Worksheets 1 and 2 (Tab. 1 and 2) answers were categorized based on Liu et al. (2011). The arguments were classified either as socio-economic, ethical, ecological or scientific. The analysis did not emphasize the quality of the students’ argumentation. Rather we sought to discover how students relate arguments by analyzing aspects of a sustainability issue. The arguments expressed by both groups (high school and undergraduate students) in the first and second argumentation task were analyzed in terms of where they fit into the four categories (socio-economic, ecological, scientific and ethical arguments). Key concepts and examples for each category are presented in Table 5.

Students’ responses to chemical problem-solving in worksheet 3 (Tab. 3) were analyzed using four modified categories taken from Akkuzu and Uyulgan (2016) and Broman and Parchmann (2014). An explanation of these
categories is also provided in Table 4. The categorization of all data took place in two rounds carried out by two raters with expertise in chemistry education (R.Z. and A.N.L.). Any disagreements were solved through negotiation. The score of the final inter-rater reliability was high, with the Cohen’s kappa score of $k = 0.923$ for the analysis of the student’ application of chemical concepts and $k = 0.968$ for the analysis of the student’ arguments.

Table 4. Categorization of student answers based on their argumentation and application of chemical concepts.

<table>
<thead>
<tr>
<th>No</th>
<th>Worksheet Questionnaire</th>
<th>Category of answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Student’s argumentation on the issue of potential risks of pesticides use</td>
<td>Students’ arguments was categorized as:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- socio-economic</td>
</tr>
<tr>
<td>Q2</td>
<td>Student’s argumentation on the multiple perspectives of scientific worldviews from WMSc and ISc</td>
<td>- ethical, - ecological - scientific</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The categorization was adopted from (Liu et al., 2011)</td>
</tr>
<tr>
<td>Q3</td>
<td>Applying chemistry concepts in a related context</td>
<td>The student’s response was categorized as:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- C1: Student answered the task by connecting a chemistry concept to the context</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- C2: Student answered the task using an inappropriate chemistry concept as explanation or has misconceptions for the context</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- C3 : Student answered the task by repeating the question</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- C4 : Student was unable to answer the question / no response</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The categorization was modified from (Akkuzu &amp; Uyulgan, 2016; Broman &amp; Parchmann, 2014)</td>
</tr>
</tbody>
</table>

Table 5. Student argument classifications and illustrative examples

<table>
<thead>
<tr>
<th>Categories</th>
<th>Key concepts</th>
<th>Illustrative examples</th>
</tr>
</thead>
</table>
| Socio-economic | Economic development, cost or benefits to a person or society (e.g, in the form of gains) | "From an economic standpoint, indigenous pesticides (natural pesticides) are easier to obtain and you do not need to spend a lot of money."
|              |                                                                              | “Synthetic pesticides are still needed, especially for basic crops that support people's lives, despite all the health risks they cause.” |
|              |                                                                              | “The most important value in life is to be happy and sustainable.” |
|              | Values or personal opinion related to aesthetics or the future, environmental ethics (e.g, What is right What is wrong? What should be | “We must pay attention to environmental ethics so that future knowledge does not deviate from natural law.” |
| Ethical      |                                                                              | “Indigenous knowledge is based on mutually agreed upon principles and norms. Indigenous people have a philosophy to |

12
Ecological
Effect on the environment or ecosystem and human ecological action (e.g., eco-friendly products)

preserve nature.”
“The advantage of using natural pesticides is that they can repel insect pests from plants without poisoning and damaging the environment.”
“We must limit the use of synthetic pesticides that can damage the ecosystem or food chains that exist.”

Scientific
Natural resources, technologies, evaluation of risk and safety

“Natural pesticides are not durable enough to protect plants from pests for long because they evaporate faster”.
“Combining indigenous knowledge and technology can lead to extraordinary new innovations.”

Findings and Discussion
Students’ application of chemistry concepts in the final problem-solving task

The percentage distribution of the students’ answers in the categories from Tab. 4 are shown in Table 6.

Table 6. Distribution of student answers based on the categories

<table>
<thead>
<tr>
<th>Problem Solving Chemistry (Q3)</th>
<th>Undergraduate student’s response in each category (%)</th>
<th>Secondary school student’s response in each category (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>1a</td>
<td>80,8</td>
<td>6,9</td>
</tr>
<tr>
<td>1b</td>
<td>37,0</td>
<td>9,6</td>
</tr>
<tr>
<td>2a</td>
<td>75,3</td>
<td>0</td>
</tr>
<tr>
<td>2b</td>
<td>38,3</td>
<td>1,4</td>
</tr>
<tr>
<td>2c</td>
<td>26,0</td>
<td>0</td>
</tr>
<tr>
<td>2d</td>
<td>28,8</td>
<td>1,4</td>
</tr>
</tbody>
</table>

The results show that the average number of responses of undergraduate students to the problem-solving task (column C1) was greater than among secondary high school learners. Undergraduate students used more chemistry concepts to answer the problem-solving task as compared to secondary school participants. There was, however, quite a number of students who were unable to apply any chemical concepts to the context presented in the problem-solving task.

To explore how students applied chemistry concepts when answering the problem-solving task, the analysis looked deeper into the responses coded C1 and C2. For task 1a, most of the correct responses from both groups made a connection between the structure of matter, organic chemistry and chemical bonding. The students suggested that the stability of DDT structure is affected by the benzene functional group. For example, one person stated that “DDT is resistant to degradation because it contains the benzene structure that is very stable.” However, this type of answer tends to use factual knowledge to answer the task. The learner remembers that the presence of a benzene structure can make molecules quite stable. Whether these students could give the real reason
for the relative stability of the benzene structure (electron delocalization) remains unclear. More complete answers for Task 1a were given by most of the university students. For example: “From its structure, the DDT compound is very stable because it consists of two benzene rings which can undergo electron delocalization. The process of decomposing the compound is very difficult and requires great amounts of energy to separate the bonds.” In this type of response, students showed a deeper understanding by connecting the concepts of a benzene molecular structure with electron delocalization and considering aspects of chemical thermodynamics. The concept of “structure resonance” which is caused by oscillating double bonds in the benzene ring was also found in many university student answers. An interesting answer from one secondary school student attempted to provide a personal explanation of the benzene structure: “Benzene has strong bonds. These are difficult to break down because the electrons are back and forth around the ring.” Nevertheless, more advanced explanations which explain the stability of the structure by looking at halogen atom (chlorine) substitution were not found in either of the groups. This is not surprising, since the effects of substituent groups in benzene compounds are only taught in the second year of university chemistry in Indonesia.

In task 1b, the problem-solving question also focused on the structure of matter, chemical bonding and organic chemistry. The chemical concepts used by both groups of students included solubility, polarity, and hydrophobicity. In both groups, many of the responses linked the solubility to its polarity by using the principle “like dissolves like”. As one student mentioned: “DDT can be accumulated in fatty tissue due to its non-polar properties. According to the principle of "like dissolves like", DDT will dissolve in fatty tissue (non-polar).” In addition, most of the upper secondary school students emphasized the connection between the benzene structure in DDT with its solubility, which their answers depicted: “In DDT, there is a benzene structure, which is non-polar, just like human fatty tissue. So when benzene compounds enter human fatty tissue, they will be equally soluble, because both are non-polar.” This example shows that this person used the structural formula as a strategy to answer the question and combined it with recalled, memorized, factual knowledge. More of the university students were able to elaborate on the concepts of polarity, molecule structure, and hydrophobicity and tie them to solubility properties: “DDT is non-polar as indicated by the number of carbon atoms contained in two benzene groups. DDT is able to interact with the fat in non-polar body tissues as well. DDT has difficulty reacting with water in the blood, because it is hydrophobic. This causes DDT to accumulate in fat and not be transported by the blood so that it cannot be excreted.”

Task 2 is related to the content areas of the structure of matter, chemical bonding, organic chemistry, chemical reaction and chemical analysis. Most correct responses in both groups were able to apply the concept of organic functional groups to the physical properties of bio-pesticide compounds. The answers predicted that the “strong scent” insect repellent properties of secondary metabolite compounds in bio-pesticides was the result of common molecular functional groups in organic compounds which contain either ester groups or aromatic compounds. Some university students also mentioned essential oil structures in their responses, while secondary school students did not. The reason for this is that upper secondary school does not teach the concept of essential oils in the school curriculum. Furthermore, the students were asked to predict the chemical reaction creating the solvent (fermented palm sugar juice). They were also asked to identify the chemical properties of the solute compounds used in the extraction process of indigenous bio-pesticides. The answers mentioned the concepts of carbohydrates,
fermentation reactions, alcohol and carboxylic groups, and the polarity of compounds. In both groups, students mentioned alcohol and carboxylate groups as the potential groups in the solvent based on sugar fermentation. The secondary school students were unable to explain the sugar fermentation reaction in symbolic representation. The university students were able to elaborate on more concepts in their answers. One student wrote: “Palm sugar juice usually contains carbohydrates, which can be broken down into glucose, sucrose and fructose. Glucose is converted to pyruvic acid in anaerobic reaction and can produce alcohol (ethanol) under those conditions.” Most university students were also able to predict that the compound extracted by these solvents must be a polar compound. They connected the concepts of the polarity of alcohols and the “like dissolves like” principle. One person mentioned that “the extract compounds probably contain the functional groups of alcohols, aldehydes, carboxylic acids, and esters. The reason is that these compounds have polar properties and can be extracted based on the "like dissolves like" principle.” This task was more challenging for secondary school participants, because the structural formula of the compounds was not given as a clue. As a result, most of these students were unable to predict the nature of the solvent. They also had difficulty naming the kinds of potential chemical compounds (based on polarity) and the potential nature of compounds which are extractable using those solvents.

The last problem-solving task dealt with a chemical analysis of the bio-active compounds in plants. Both groups of learners showed limitations in their knowledge of analytical chemistry. Some of the university students were able to explain general techniques in natural products analysis. One student wrote: “The steps of the analysis are: taking a sample from the plant, selecting the appropriate reagents to test its compounds, separating or extracting bio-active compounds from the plant, and identifying the bio-active content.” However, they were unable to mention details of the qualitative or quantitative analysis of organic compounds. They could not describe separating or purification techniques for natural products such as chromatography, steam distillation, solvent extraction, etc. According to the Indonesian upper secondary school curriculum, the area of analytics in organic chemistry is limited to qualitative analysis of organic compounds. Analysis focuses only on the qualitative identification of the alcohol, aldehyde, ether, ester, carboxylic acid, etc. functional groups. More advanced organic chemical techniques, like separating or purification techniques, are studied only at the university level.

In conclusion, both groups contained several students who were able to link the context and concepts like the structure of matter, chemical bonding, organic chemistry and analytical chemistry (see Table 7). The upper secondary school students, however, tended to recall factual knowledge. This indicates the dominance of the rote learning of chemical content knowledge. This finding has also been highlighted by previous research (Broman & Parchmann, 2014). The university students were able to better elaborate a more constructive explanation of the tasks and to make better connections between the concepts. The most often-used ideas referred to molecular structure stability, solubility, polarity, the functional groups on organic compounds, aromatic compounds, the chemical and physical properties of organic compounds, and analytical chemistry. This indicates that these concepts are available to students - at least to a certain extent - in order to understand the chemical problem in question. These concepts are closely related to the topics of general chemistry and organic chemistry, and the interplay between concepts within the topics is crucial (Duis, 2011).
Table 7. Common concepts used in student responses to the problem-solving questions (Q3)

<table>
<thead>
<tr>
<th>Number</th>
<th>Topic in problem-solving</th>
<th>Content area</th>
<th>Example of concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (a)</td>
<td>The social issue of pesticides (a case study on DDT) in the environment</td>
<td>Structure of Matter, Chemical bonding, Organic chemistry</td>
<td>Stability of chemical structure, benzene, aromatic compound, electron delocalization, bonding energy, structure resonance</td>
</tr>
<tr>
<td>1 (b)</td>
<td>The issue of pesticides that endanger human health</td>
<td>Structure of Matter, Chemical bonding, Organic chemistry</td>
<td>Solubility, polarity, hydrophobic molecule, like dissolve like, Benzene, functional groups</td>
</tr>
<tr>
<td>2 (a,b,c,d)</td>
<td>How students explain chemical phenomena from IS from a scientist’s point of view</td>
<td>Structure of Matter, Chemical bonding, Organic chemistry, Chemical reaction, Chemical analysis</td>
<td>Functional groups, carbohydrates, fermentation reaction, polarity, like dissolve like principle, chemical reagent, extraction</td>
</tr>
</tbody>
</table>

Some misconceptions were also identified in the answers, especially with regard to the concepts of solubility and the structural stability of organic compounds. Table 8 shows some of the statements which involve misconceptions. The most common misconception occurred when the learners tried to relate the concept of chemical structure stability to the concepts of hydrophobicity or the carbon chain length. For instance, one university student confused and misused the concept of hydrophobicity of a compound with its reactivity or stability: “Benzene (in DDT) is hydrophobic, so there is no water in the environment, so it is difficult to react.” The student generalized water as a universal solvent in a chemical reaction. Interaction with water was considered crucial for reactivity or stability. Another student used an inappropriate explanation to connect structure stability to the carbon chain length, boiling point and energy of the reaction: “DDT is difficult to decompose because it has a large number of carbon atoms in the chain, which makes its boiling point higher, and requires more energy.” In this example, the person misinterpreted the concept of chemical change (chemical degradation or reaction) as a physical change (the boiling process). This kind of misconception was also found among secondary school students: “DDT compounds contain benzene, which is difficult to decompose, because it is difficult to evaporate due to its high boiling point.” The students’ difficulties in understanding concepts related to solubility as well as to the physical properties of functional groups in organic compounds. This has been reported by Akkuzu and Uyulgan (2016). The obstacle of explaining boiling points and solubility of organic compounds in relationship with the structure and intermolecular force has also been discussed (Henderleiter et al., 2001). Another misconception related to the stability of chemical structure appeared when one upper secondary school learner used the full electron configuration as a reason for structural stability: “DDT is difficult to degrade because it has halogen group compounds that have a full electron configuration.” It seems that the students misuse the concept of atomic stability in order to explain compound structural stability. This student generalized the stability in one atom to cover the structural stability in the whole molecule.
### Misconceptions of university students

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Misconception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability of chemical structure, Hydrophobicity, Benzene</td>
<td>Benzene is hydrophobic. There is no water in the environment, so it is difficult to react.</td>
</tr>
<tr>
<td>Stability of chemical structure, Carbon chain length, boiling point, reaction energy</td>
<td>DDT is difficult to decompose because it has a large number of carbon atoms on the chain, which makes its boiling point higher, and requires more energy.</td>
</tr>
<tr>
<td>Solubility, polarity, Halogen (Cl) groups</td>
<td>DDT accumulates in fat due to the polarity of CCl₃ groups.</td>
</tr>
<tr>
<td>Solubility, carbon-chain length, boiling point,</td>
<td>DDT structure has many C atoms, causing the boiling point to be higher and making it difficult to dissolve in water.</td>
</tr>
</tbody>
</table>

### Misconceptions of upper secondary school students

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Misconception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability of chemical structure, halogen group, electron configuration</td>
<td>DDT is difficult to degrade because it has halogen group compounds that have a full electron configuration</td>
</tr>
<tr>
<td>Stability of chemical structure, Benzene, boiling point, evaporation</td>
<td>DDT compounds contain benzene, which is difficult to decompose because it is difficult to evaporate due to its high boiling point</td>
</tr>
<tr>
<td>Solubility, lone pair electron, polarity, solvent</td>
<td>Compounds that have a lone electron like Cl can dissolve in a polar solvent.</td>
</tr>
<tr>
<td>Polarity, electronegativity, CCl₃ group</td>
<td>DDT is very polar because it has a very electronegative CCl₃ group.</td>
</tr>
</tbody>
</table>

Another finding of the study is related to misconceptions about the concept of solubility of organic compounds when dealing with other concepts like polarity, electronegativity and carbon chain length. For instance, one misconception was found in both groups of students. Some people tried to connect the concept of solubility with the polarity of the molecule, as the following quotes show:

“Compounds that have a lone pair electron like Cl can dissolve in a polar solvent.”

“DDT accumulates in fat due to the polarity of CCl₃ groups.”

“DDT is very polar because it has a very electronegative CCl₃ group.”

It seems that this misconception leads these students to falsely claim that DDT is polar and can dissolve in polar solvents due to the electronegativity of the halogen (Cl group) in the molecule. The students focused solely on the halogens groups (CCl₃) in the structure without considering the overall structure and geometry of the whole molecule. Similar results were reported previously by Akkuzu and Uyulgan (2016). These mistakes can also be tied to students struggling with the ideas of bonding, solubility and molecular polarity (Broman & Parchmann, 2014; Reid & Hassan, 2004). Furthermore, another misconception appeared when an upper secondary response linked the concepts of solubility, boiling point and carbon chain length: “DDT structure has many C atoms,
causing the boiling point to be higher, so it will be difficult to dissolve in water.” It seems that some students confuse the size of the molecules and their boiling points of the compound with the concept of solubility.

In summary, several misconceptions were discovered in the responses of both groups. These were frequently related to the concepts of molecular structure stability, solubility, polarity, and chemical and physical properties of organic compounds. These misconceptions were more readily apparent when students had to work on problem-solving focusing on the interrelationship between different chemical concepts. Similar findings were also reported by Rushton et al. (2008). Misconceptions can be influenced by several factors. This includes the presence of different or alternative students’ preconceptions when learners transfer chemical concepts into a new context. The issue of pesticide sustainability and the indigenous phenomena in this study fall into this category. This may be the result of the formal learning environment. It can also include factors such as the students’ understanding of previous chemistry learning, a misuse in application, the limits of one’s understanding of models in science, or even linguistic misinterpretation (Rushton et al., 2008; Taber, 2001).

**Student arguments related to the context of the pesticide sustainability issue in a multi-perspective scientific worldview approach**

Examples of student arguments are presented in Table 5. Figures 5 and 6 show that learners (in both groups) generally expressed more arguments in all categories in the Argumentation task 2 as compared to the Argumentation task 1. Both groups also shared a quite similar trend in the proportion of arguments in both first and second argumentation tasks. The discussion of the holistic approach in which Western modern chemistry and technology and ISc are involved in resolving sustainability issues had an impact on the students’ argumentation in all of the categories. The number of students’ expressing socio-economic, ethical and ecological arguments increased in the second argumentation task, while the scientific arguments showed only a slight increase. Ecological arguments were mentioned most often by both groups in all of the tasks. Ethical arguments appeared least often the Argumentation task 1. Only 2 out of 40 upper secondary school and 1 out of 73 undergraduate students used ethical arguments. After the intervention, 30 upper secondary school and 48 undergraduate students began to use ethical arguments.

![Figure 5. Upper secondary school students’ arguments](image-url)
The results indicate that the discussion of multiple scientific worldviews regarding pesticide use can potentially improve students’ argumentation skills. The activity gave the students a chance to observe the issue from different viewpoints and to make their decisions more holistically.

From the students’ arguments, we can see that the controversial issue of pesticides use was viewed as close to the students’ personal lives. One student said: “I live in a rural area and my father is a rice farmer. We have been using indigenous bio-pesticides from a plant extract, which is the legacy of our ancestors. It is more ecological-friendly and protects the fertility of the land.” Connecting the sustainability issue to local experiences and multiple scientific worldviews seems to increase the students’ interest in expressing their ideas more broadly. This can be seen from the rising number of students who expressed arguments in terms of socio-economic, ecological, and ethical arguments. This indicates that chemistry lessons including the local context of ISc can serve as a bridge for students to connect global issues to the knowledge they already possess. Students reconstruct more integrated knowledge about an issue using their experiences taken from multiple perspectives. Learning about complex socio-scientific issues requires a fundamental understanding of natural systems and the relationship between humans and the living and non-living environment (Colucci-Gray et al., 2006; Hogan, 2002). Therefore, research suggests considering multiple viewpoints when making decisions (Eisen et al., 2009; Zeidler et al., 2009).

Ecological arguments were the most often mentioned in both the first and in the second argumentation tasks. This result is not surprising, because the topic is closely related to environmental concerns. It seems that the students' initial view was mostly restricted to the risks of pesticides use on the environment. The majority of students connected the issue with environmental damage due to the use of synthetic pesticides. One person stated: “Currently, we are not required to use (dangerous) synthetic pesticides, because they present a high risk to the environment. If the use of synthetic pesticides is ongoing, it will cause new resistant strains of pests. Pests are difficult to stop and adversely affect the environment. The residue of pesticides in foodstuffs will cause disease and in the long term is harmful to health.” The student tried to frame environmental concerns through a different point of view related to both ecology and the socio-economical aspect of health.
All tasks completed by the participants involved discussing the role of scientific technology. Both groups of students expressed a wide array of scientific arguments, which appeared in almost equal measures during the first and second argumentation tasks. This result is in stark contrast to other studies (Sadler and Zeidler, 2005; Albe, 2008) in which students generally tended to involve less scientific knowledge in their arguments on ESD issues. The students in the current study linked their arguments to the development of scientific technology to solve the pesticides use problem, but they began to do so in a reflective manner. As one student stated: “We still need synthetic pesticides, because they are very helpful in eradicating crop pests for farmers. But we need to have effective and specific ways so that the risk of synthetic pesticide use can be reduced and not be widespread. For example, we could spray pesticides on target crops using drones so we don’t have too much impact on wildlife, the environment and human health.” The role of collaboration between Western modern chemistry and ISc was also considered. In this case, the knowledge claims were not compared to one another. Instead suggestions for collaboration were made to drive innovation: “In my opinion, we can combine the local wisdom of traditional knowledge in Indonesia with the technology offered by Western science in order to collaborate and produce natural pesticides that are durable, but do not damage the environment.”

The level of socio-economic arguments increased in the post-intervention task. It appears that a discussion of the pros and cons of synthetic pesticides versus indigenous bio-pesticides can potentially encourage students to link the issue with socio-economic factors. One student argued that: “From an economic standpoint, the materials of indigenous pesticides (botanical pesticides) are easier to obtain from the garden and we do not need to spend a lot of money to produce this pesticide.” Another student contrasted a socio-economic argument with a scientific explanation: “Indigenous bio-pesticides could become a candidate for green pesticides. Their advantages can minimize soil damage. These pesticides are cheaper, because in rural areas the ingredients are easy to obtain. However, such pesticides has the disadvantage of not being very selective in eradicating certain pests. The material tends to be volatile, so it should be applied in large quantities periodically.”

There was a very significant increase in the students’ ethical arguments in the second argumentation task. In the first argumentation task, ethical arguments were very rarely expressed. After ISc perspectives were presented to complement WMSc views, students were encouraged to express their ethical arguments. It seems that they viewed cultural and philosophical values stemming from indigenous local wisdom as a new insight. This provoked further ethical considerations when making a decision. Two examples can illustrate this:

“The philosophical perspective and the values of an indigenous society should be considered, especially in terms of environmental ethics, where nature should be well maintained for present and future generations. Because, in fact, humans need nature and not the opposite. So we should care for nature in a way that doesn’t pollute the environment by controlling the use of pesticides and using green pesticides.”

“I think the indigenous perspective should be considered to provide ethical insight and guidance to Western knowledge. This perspective teaches humans to use pesticides wisely and not to kill insects excessively in order to maintain the natural balance and ecosystem. This is important because when insect populations are lost, no organisms are left to aid in the decomposition of carcasses or the pollination of flowers, so that the situation ultimately disrupts other ecosystems.”
Based on both arguments above, indigenous perspectives also encouraged the learners to analyze moral and philosophical questions, such as whether insects should be destroyed to protect human crops. This discussion is closely related to the philosophical aspects of eco-reflexivity, wherein people participate in community decisions. This includes advocating factors which affect both living and non-living entities in the environment (Mueller, 2009). The current study seemed to support students’ awareness that chemistry has complex interactions with both society and the environment. This is one of the focal points of system thinking skills in chemistry education.

The philosophy of ESD and SSI-based education emphasizes the societal and ethical dimensions of chemistry education in order to help learners more meaningfully participate in classroom practices (Burmeister et al., 2012; Zeidler & Sadler, 2008). This includes the aspects of values and attitudes, which are related to the students’ affective domain. These aspects can be developed and connected to an individual’s socio-cultural background. This allows the student to view facts from a cross-cultural viewpoint (Rundgren and Rundgren, 2010). Cultural or sociological perspectives are areas of pedagogical importance which are central to SSI-based teaching. They underscore the necessity to view students as moral agents, who are intimately involved with their own cultural, natural, and technological environments (Zeidler et al., 2005). Accordingly, integrating multiple scientific worldviews to study sustainability issues in chemistry education is important. It can provide learners a chance to connect chemistry more closely with their own cultural and ethical values. This provides insights and allows students to reflect upon current developments in science and technology.

**Conclusion and Implications**

This study examined students’ application of their chemistry content knowledge and arguments. By doing so we obtained insights into how the ESD pedagogical approach can function. Combining the topic of pesticide use with a multi-perspective approach based on different scientific worldviews can improve both of these two important scientific literacy goals. This study confirms previous evidence showing how science learning can be enriched by the ESD framework in order to improve students’ argumentation skills (Burmeister & Eilks, 2012; Juntunen & Aksela, 2014b).

This case study provided students with opportunities to apply chemical content, which is closely related and relevant to their lives, in the context of ISC. In terms of applying chemical concepts, we found that the two groups of students engaged in real-world connections between chemistry and context-driven tasks. University students showed higher levels of understanding by providing explanations and linking concepts. Their high school counterparts generally tended to simply recall factual knowledge as an answer. It became quickly clear that teachers need to pay more attention to the existence of misconceptions. This is especially true if the students are unfamiliar with the problem-solving task or are asked to transfer chemical concepts from different chemistry sub-disciplines into a new context. For this reason, we suggest that basic chemistry content knowledge related to the context should be reinforced. Also, the relationship between students’ current knowledge and the newly-provided information should be fostered through various forms of activities that encourage higher-order thinking skills (Akkuzu & Uyulgan, 2016; Broman & Parchmann, 2014).
In terms of argumentation, both upper secondary school and university students made large improvements in employing socio-economic, ecological, scientific and ethical arguments. This factor is crucial in developing learners’ understanding of sustainability issues. It helps them in value-based decision-making processes both in their personal and professional lives, which in turn allows them to become critically-thinking, democratic-minded citizens. One promising aspect was that the intervention broadly fostered the level of ethical argumentation among the participants. This is also important, because it is uncommon for most students to pass ethical judgment on socio-scientific issues (Juntunen & Aksela, 2014b). This case study revealed that the indigenous perspective in terms of knowledge, culture, and the philosophy of local wisdom can enhance and provide broader insights into students’ ethical considerations concerning sustainability. This falls in line with the current discussion of eco-justice in science education (Mueller, 2009). It has been suggested that science teachers should encourage their students to have more connections to cultural knowledge and human relationships. This aids them when participating in decision-making processes for the environment.

Teaching interventions based on ESD-oriented chemistry learning have existed for quite some time. The inclusion of multiple perspectives from scientific worldviews seems to add to the effectiveness and relevance of teaching and learning chemistry. Learning chemistry from an authentic ESD context associated with different knowledge systems aids the learners in their efforts. They can better apply chemical concepts in a new context containing socio-scientific, cultural and philosophical aspects. The ability to apply chemical concepts showed differences among students at different educational levels. The successes observed, however, can be viewed as promising, considering the short time frame of the intervention and the complex nature of the topic studied. This approach mirrors the humanistic dimension of learning chemistry, which integrates aspects of culture into chemistry education (Mahaffy, 2006). The human element in chemistry education plays an important role in connecting chemistry concepts to students' life worlds and cultural environments. Teaching about pesticides from a Western modern view (see e.g. Zowada et al., 2019) was enriched by its engagement with ISc. From this case study, we can see that indigenous phenomena can act as a bridge for students to link their local and regional environments with chemical content knowledge. This offers them an alternative perspective to the development of WMSc and its related technology. The study presented in this paper has provided a valuable insight for teachers, educational practitioners and policy makers on how this pedagogical approach provides a potential contribution to develop critical scientific literacy (Sjöström & Eilks, 2018). This efforts can be done by integrating multifaceted scientific worldviews and cultural perspectives in terms of the norms and philosophical values in any corresponding society when they select and prepare certain content for science and chemistry learning.

The current study is necessarily limited in scope. The tools employed describe students' ability to apply conceptual knowledge and to use arguments to describe the results. The study does not, however, describe the relationship between these two variables. Several studies (Tytler et al., 2001; Sadler, 2004; Sadler & Zeidler, 2005) have found that that understanding content knowledge is related to the quality of argumentation presented for socio-scientific issues Sadler (2004). However, they found no evidence suggesting that individuals with different levels of content knowledge relied on different modes of informal reasoning (rationalistic, emotional, and intuitive). Understanding the science content behind a controversial issue does not necessarily imply that the students will base their
decisions on science content. As Sadler (2004) has already suggested, we support the idea that educators can use sustainability-oriented SSI instruction to encourage students to participate in meaningful learning regarding the science concepts behind these issues.

Recommendations

This research is only employed two groups of students and one indigenous phenomenon. It is necessary to conduct further research based on different perspectives chosen from other cultures, knowledge areas, and backgrounds. Further research could integrate the discussion of indigenous phenomena to foster learners' procedural knowledge in green science laboratory activities. This includes green chemistry learning about valuable natural substances. It also covers processes from ISc that can be explored in school science or at the undergraduate level. For instance, information about biodegradable botanical pesticide compounds from indigenous plants might be used as a starting point to develop new green chemistry lab activities.

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**Authors Information**

**Robby Zidny**  
https://orcid.org/0000-0002-4727-3984  
*Department of Biology and Chemistry, Institute for Science Education, University of Bremen, 28359 Bremen, Germany*

**Ayu Ningtias Laraswati**  
Madrasah Aliyah Negeri 2 Kota Serang, Indonesian Ministry of Religious Affairs, Serang, Indonesia  
Contact e-mail: aayularaswati@gmail.com
Teacher Training and Education, University of
Sultan Ageng Tirtayasa,
42117 Serang, Indonesia
Contact e-mail: robbyzidny@untirta.ac.id

Ingo Eilks

https://orcid.org/0000-0003-0453-4491
Department of Biology and Chemistry, Institute for
Science Education, University of Bremen,
28359 Bremen, Germany
Contact e-mail: ingo.eilks@uni-bremen.de
Learning about phytochemical aspects of botanical pesticides adapted from ethnoscience as a contribution to green and sustainable chemistry education

Robby Zidny
Ingo Eilks

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Learning about phytochemical aspects of botanical pesticides adapted from ethnoscience as a contribution to green and sustainable chemistry education

Robby Zidny\textsuperscript{a,b,}\* Ingo Eilks\textsuperscript{a}

\textsuperscript{a} Department of Biology and Chemistry, Institute for Science Education (IDN) - Chemistry Education, University of Bremen, Leobener Str. NW2, 28334, Bremen, Germany

\textsuperscript{b} Department of Chemistry Education, Faculty of Teacher Training and Education, University of Sultan Ageng Tirtayasa, 42117, Serang, Indonesia.

**ABSTRACT**

This study shows how students can learn about green and sustainable chemistry using the knowledge perspective of a local, indigenous culture as a starting point. This learning approach encourages students to learn chemistry by connecting culture with learning about green chemistry. The cultural context selects the use of a phytochemical agent (d-limonene) from a local plant (Citrus grandis), which is a traditional botanical pesticide used by the Baduy Tribe in Western Java, Indonesia. A simple low-cost extraction method using a kitchen microwave was chosen to introduce modern green extraction methods to learners. This facilitates students' ability to evaluate the "greenness" of this method as compared to more conventional extraction methods such as Soxhlet and steam distillation. The learning activities were conducted during the Corona pandemic situation of 2020 with the help of an online learning management system (SPADA) and Google Meet. Students' feedback and selected results are discussed below.
INTRODUCTION

Green chemistry searches for cleaner industrial processes, safer chemical products, and the increased use of renewable resources when manufacturing products. The idea was first initiated in the 1990s by Paul Anastas and John Warner. They suggested a total of twelve principles of green chemistry to serve as a framework for more benign chemistry. Green chemistry offers various tools and strategies as technical and practical conditions for sustainable chemistry. Both, green and sustainable chemistry look for ways to realize innovations in chemistry which increase ecological, economic, and societal sustainability.

Green, sustainable chemistry is not solely concerned with research and industry. It is also seen as an integral part of chemistry education. Such education should integrate and reflect upon the concepts and practices of green chemistry at both the secondary and higher educational levels. The integration of issues selected from education for sustainable development and green chemistry is one area of focus. Chemistry education should offer students contemporary and authentic learning experiences. This will,
in turn, raise their personal perception of the relevance of chemistry learning in all its personal, societal and professional dimensions.\textsuperscript{7-10}

Chemistry education began with the idea of incorporating sustainability and green chemistry into chemistry education at all the various educational levels\textsuperscript{11}. Then we expanded the idea into both the higher\textsuperscript{12-13} and secondary\textsuperscript{14-16} educational levels. Various green and sustainable chemistry learning contexts were selected and introduced, including organic laboratory courses\textsuperscript{17-19} and general chemistry lectures \textsuperscript{7,20}. Such thematic topics as bioethanol usage, plastics chemistry, and green pesticides,\textsuperscript{14,21,22} were employed to carry this idea further. The implementation of green and sustainable chemistry in education, however, remains mostly focused on the context of traditional chemistry sub-disciplines and industrial applications. It all too often centers around one specific field or topic in a single-discipline chemistry approach.

In order to innovate chemistry education, it is necessary to introduce both cross-disciplinary learning and systems thinking approaches.\textsuperscript{23-25} This allows educators to provide holistic perspectives of just how different and multifaceted the challenges facing green and sustainable chemistry are.\textsuperscript{26-28} One aspect is still often neglected, but has the potential to enrich the chemical perspectives concerning sustainability, one is the field of ethnoscience or, more specifically, ethnochemistry.\textsuperscript{26} Ethnoscience is the traditional knowledge of indigenous peoples. It is closely related to the sustainable use of renewable resources found in nature.\textsuperscript{26,29}

In this paper, ethnoscience is discussed with a view to chemistry education. We look at how it can enrich chemistry education with regard to green and sustainable chemistry. One learning approach to integrate green and sustainable chemistry is examined by the current study. It evaluates undergraduate chemistry education in Indonesia, including an evaluation of green chemistry laboratory activities. This paper describes an evidence-based case study, which analyzed the implementation of the lesson plan "Ethnochemistry in the Lab" in second-year undergraduate chemistry teacher education. This lesson plan encourages students to learn about substances and processes selected from natural pesticide use in an indigenous culture. These were adopted from ethnoscience to serve as a starting point for developing green chemistry lab activities. Specifically, microwave assisted extraction (MAE) using a kitchen microwave was chosen to highlight the differences with more conventional extraction methods such as
Soxhlet and steam distillation. Student teacher (N=41) feedback and evaluations of the teaching unit are also presented.

**ETHNOSCIENCE AND ITS IMPLICATIONS FOR GREEN AND SUSTAINABLE CHEMISTRY**

Ethnoscience can be defined as the system of knowledge about nature, which is owned by a particular indigenous or traditional culture. Such knowledge covers both ecological aspects and the mutual relationships between humans and nature. Ethnoscience is sometimes referred to by other names such as indigenous science or traditional ecological knowledge. This can consist of the knowledge of indigenous expansionists (e.g. the Aztecs, Mayans, or Mongolian empires) or long-term residents (e.g., the aboriginal peoples of Africa, the Americas, Asia, or Australia). From this point of view, ethnochemistry includes the chemistry of a particular indigenous society or culture, which has a different way of doing science than modern Western chemistry might suggest.

Although ethnoscience has been passed down from generation to generation over the centuries, its existence is still largely neglected and tends to be generally omitted from science curricula. With the growing awareness of the challenges of sustainability issues such as global diseases or environmental pollution, the limitations of Western modern science and technology in overcome many basic challenges has become a topic of discussion. This discussion has raised the interest of the global community, which has begun to take other worldviews and their indigenous knowledge more thoroughly into account.

Among other aspects, indigenous pest control practices have come under new scrutiny for wider use in tropical countries. One ancient plant known to exhibit bio-pesticide activity is *Azadirachta indica*. It contains chemical compounds that act as a pivotal insecticidal ingredient and therefore can be used as a green pesticide. Across the globe, science has started to mine ethnoscience in order to advance fields such as chemistry, medicine and agriculture. Researchers have started uncovering the potential of chemical compounds derived from plants or other sustainable materials which can benefit agriculture or medicine (see Table 1). Table 1. Examples of phytochemical compounds used by indigenous peoples

<table>
<thead>
<tr>
<th>Structure</th>
<th>Phytochemical compounds Name</th>
<th>Function</th>
<th>Use/ originally derived from</th>
</tr>
</thead>
</table>


Azadirachtin | Pivotal insecticidal ingredient
---|---
Produced from *Azadirachta indica*, a poisonous plant with bio-pesticide activities, which is commonly used in Africa and Asia.

Aspirin | Medication used to reduce pain, fever, or inflammation
---|---
Derived from practices developed in ancient Egypt (using dried myrtle leaves) and Greece (with willow bark).

Artemisinin | Anti-malarial agent
---|---
Produced from the Chinese herb Qinghao or sweet wormwood, used initially as traditional Chinese medicine for chills and fevers.

Etoposide | Anti-cancer agent
---|---
Synthesized from podophyllotoxin, produced by the American mandrake plant; used in various remedies in Chinese, Japanese and Eastern folk medicine.

In terms of sustainability, ethnoscience can provide alternative green pesticides for agriculture which can sometimes replace risky or controversial synthetic ones like glyphosate. Ethnoscience can also yield ideas for deriving new medications from plants in order to combat the issue of global diseases such as malaria and cancer. In more advanced chemical research and technology, knowledge gained from ethnoscience can even be used to inspire cheap, biodegradable and sustainable electronic material solutions. These can then be used in display applications, photovoltaic cells, and integrated-circuits or sensors, or indigenous knowledge can be employed in analytical chemistry.

**ETHNOSCIENCE AND CHEMISTRY EDUCATION**

There are several educational aims that can be promoted by integrating ethnoscience into chemistry education. One is engaging students in cross-cultural learning, which has also been recommended by IUPAC. IUPAC suggests that we should better integrate the human element in understanding how
people learn in different cultures. This also includes how cultural dimensions can influence classroom practices, learning objects, the mediation of scientific literacy, and the visualization of topics or processes.\textsuperscript{39} Another aim is to make chemistry learning more personally relevant to students, especially in countries with indigenous or traditional communities.\textsuperscript{26,40} Contention with ethnoscience in the classroom may help learners better reflect upon different cultural backgrounds. It might also improve their understanding of the different knowledge claims and worldviews with respect to chemistry.\textsuperscript{41-42}

Further goals deal with promoting systems thinking to support green and sustainable chemistry education. An ethnochemistry viewpoint can foster student awareness and add insight into various points of view. This can combine or contrast elements of ethnoscience and Western modern chemistry. It may also offer new perspectives for decision-making and for finding solutions to sustainability issues.\textsuperscript{23-26}

Burmeister et al.\textsuperscript{10} described four different basic models to carry out education for sustainable development in chemistry education. These include: 1) adopting green chemistry principles into chemistry lab work; 2) adding green and sustainable chemistry content to the chemistry curriculum; 3) using controversial sustainability issues as socio-scientific issues to drive chemistry education; and 4) making sustainability issues and education for sustainable development a part of school development.

A previous study in Indonesia\textsuperscript{25} focused (in terms of model 3) on the controversial sustainability issues of pesticide use by taking into account the role of different perspectives from ethnoscience and Western modern science. The feedback on the lesson from the students was positive. They considered the chemistry lesson to be both interesting and personally relevant. This case study focused on models 1 and 2 in order to design a lesson plan, which centered around the integration and application of concepts of green and sustainable chemistry in chemistry learning.

**TEACHING INTERVENTION**

The lesson plan "Ethnochemistry in the Lab" was structured for second-year chemistry student teachers at an Indonesian university. It was carried out in an elective environmental chemistry course. The intervention was 150 minutes long and focused on botanical pesticide use by the Baduy Tribe on Java (Indonesia). The Baduy people are an indigenous community which maintains traditional
agricultural practices, and have the philosophy of preserving nature. This includes avoiding potentially harmful synthetic pesticides on their crops.\textsuperscript{40} As a sustainable alternative, the Baduy use a botanical pesticide in the form of a plant extract. The method the Baduy use is to crush and mash the peels of the \textit{Jeruk Bali} (Indonesian name) or pomelo (scientific name \textit{Citrus grandis} or \textit{Citrus maxima}) manually by hand, using a stone mortar and pestle. Then one-day-old fermented sugar palm juice is added as a solvent. The mixture is stirred well until a good blend is achieved. Then the mixture is manually spread onto the crops in the rice paddy. The process is repeated 7-9 times at different periods. This botanical pesticide is commonly used to repel pest insects in the paddies, specifically \textit{Leptocorisa acuta}, \textit{Oseolia orizae}, and \textit{Grylotalpa africana}. All of this information is given to the students in the accompanying teaching materials during the introductory activity.

During the lesson, students have to extract the above-mentioned information from a text article and a video explaining the ethnoscience of the natural pesticides used by the Baduy. The information includes aspects of Baduy culture and philosophy. It also highlights their knowledge of their utilization of a natural pesticide taken from \textit{Jeruk Bali} (pomelo). Pomelo is a local, highly relevant plant from the grapefruit family. It is abundant and widely available in South East Asia, especially in Indonesia. Pomelo peels contain a quite large amount (>94\%) of d-limonene,\textsuperscript{43} which has been suggested as an eco-friendly bio-pesticide.\textsuperscript{44,45} After receiving this information, the students then take up the role of a chemist, who must identify the natural pesticide compound (d-limonene) found in pomelo peels. The selected learning activities have the objectives that students: (1) learn about the context of ethnochemistry connected to a local indigenous culture, (2) use an online chemical database of natural products in order to identify and predict the attributes of the phytochemical compound in the botanical pesticide, (3) analyze the structure of the phytochemical agent, and (4) analyze and evaluate different extraction methods (Soxhlet extraction with alcohol, steam distillation, and MAE) based on green chemistry principles.

In order to illustrate green chemistry in practice, we chose a cost-effective method which can also be used in high schools. The experiment consisted of a low-cost, green Microwave-Assisted Extraction (MAE), which used an unmodified kitchen microwave and very simple lab equipment\textsuperscript{46} inspired by other MAE experiments.\textsuperscript{47-49} The learning approach selected involved the participants directly in applying green chemistry principles to laboratory techniques. It forced them to evaluate and compare the level of
“greenness” of various, conventional extraction methods (Soxhlet and steam distillation) and a modern extraction method (MAE).

An unmodified home microwave (Brand: OK type, power max. 1000 Watt) was used for the experiment, in order to extract d-Limonene from the pomelo peels. The sample was first prepared by washing and cutting the peel it into small pieces with the help of a grinder. Then 100 grams of the sample were placed in the setup as shown in Figure 1. A beaker with 50 mL of water was used to counterbalance the temperature inside the microwave. The extraction process lasted seven minutes at 600 Watts of power. After the extraction, 5-10 minutes were given to allow the steam to condense completely. The oil was then cooled down and separated by decanting and pipette extraction. Identification of the essential oil component was performed by visual interpretation of the graphic spectrum. Visual interpretation can be conducted by comparing the retention indices and mass spectrum to published data, then matching the recorded mass spectrum with references in a computer database.50

Figure 1. Kitchen microwave extraction set up.

The study was conducted during the 2020 Corona pandemic situation. An online learning management system SPADA (developed by an Indonesian Higher Education Institution, Figure 2) and Google Meet were used for teaching. A video demonstration highlighted the MAE procedure. All of the learning materials including worksheets, articles, videos and evaluation sheets could be accessed in SPADA. These learning materials encouraged the students to analyze and evaluate this green chemistry experiment via online learning. A simple green star metric assessment51 was used to evaluate the
greenness of the extraction methods. These were based on protocols the students could choose from in order to make decisions on their own. One advantage of this form of assessment is that students can evaluate the greenness of an experiment without the need to personally perform laboratory work. They can identify the best-performing isolation routine and the purification steps with the aid of the different protocols available in the literature.\textsuperscript{51}

![Figure 2. SPADA online page](image)

During the intervention, five main activities were given to the students via SPADA (Figure 3). The first phase asked the students to locate initial information regarding the lesson, including: (a) the context of ethnochemistry in the indigenous community of the Baduy, (b) an internet search about different extraction methods (Soxhlet, steam distillation and MAE) in terms of their principles, solvents and reagents, duration of analysis, energy, and yields, (c) finding information about chemical analysis of phytochemicals, and (d) searching for information about green chemistry principles.

The next step was to use a chemical database to predict which phytochemicals in pomelo peels might function as green botanical pesticides. The students read information about local plants in an article found in SPADA. Then they were guided to find the plant’s specific phytochemical compounds by entering the scientific name into several phytochemical information databases (e.g., napralert.org, phytochem.nal.usda.gov, ncbi.nlm.nih.gov, cb.imsc.res.in/imppat). Learners were then asked to identify the plants’ relevant compounds and their functional groups as the basis for analysis. Furthermore, the
students used internet searches to identify further information on bio-pesticide use. They examined the corresponding phytochemicals found in reliable sources (e.g. research articles) and used the information to identify the relevant compounds, which could be confirmed by the teacher.

In the next step, the students analyzed a video about different extraction methods supported by worksheets. Based on the worksheets, the participants then mimicked the work of a chemist, who is asked to evaluate the extraction process of phytochemical compounds and predict which compound causes the bio-pesticide activity. They compared more conventional extraction methods (Soxhlet and steam distillation) to the MAE method. In the video, the teacher gave a general overview about the three extraction methods and conducted an MAE using an unmodified kitchen microwave (see explanation above). Finally, the teacher then showed a qualitative analysis of the compounds and gave the chemical structural formula as a hint.

For the final task, the students and teacher met in Google Meet to discuss the result of the experiment in the video demonstration. In this session, the students were divided into groups to discuss the worksheet questionnaire related to the experiment. The questionnaire focused on the following tasks: (a) identifying the chemical functional groups in the pomelo peel extract based on their literature search; (b) explaining which phytochemical compound is relevant for bio-pesticide use; (c) estimating and
comparing the total energy consumption of the three extraction methods; and (d) evaluating the extraction methods in the experiment based on the green star metric assessment. The green star metric evaluation used a Microsoft Excel spreadsheet. In the beginning, the students had to fill out the metric individually in order to make them familiar with both the information and the instructions. Then they discussed the results in groups of five to make a collective decision.

The evaluation of the extraction methods based on green chemistry became the focus of the discussion at the end of the session. Students discussed how to evaluate the extraction methods based on the green star metric criteria as an evaluation instrument. The full green star assessment simultaneously considers almost all of the principles of green chemistry. It can be used to evaluate a reaction, a synthetic pathway, a chemical process, etc. It provides a holistic assessment which is intended to show a systemic metric of the inherent benignness or "greenness" of the chemical procedure. At the end of the discussion, the students presented their results from the assessment to the group. They gave their reasons for believing which method falls most in line with green chemistry principles.

EXPERIENCES AND RESULTS

Student feedback on the lesson plan

A feedback questionnaire was given to the students (n = 41) after studying the lesson plan "Ethnochemistry in the Lab". The questionnaire consists of 5 Likert scale items (5 step answers). It focuses on student responses to the two main objectives of teaching unit: 1) learning chemistry connected to an indigenous culture, and 2) learning about other substances and processes adopted from indigenous science as a starting point for developing green chemistry practices.

Overall, the feedback from the university students (Figure 4) was very positive with respect to the teaching unit. The majority of students agreed or fully agreed that the lesson plan had encouraged them to learn chemistry across cultures (starting from an indigenous culture). Most of the students (92.7%) felt that the lesson was personally motivating to learn chemistry ideas from an indigenous culture. The lesson also facilitated the students in their own self-awareness and understanding of chemical phenomena related to a specific cultural environment. As shown by their responses, most of the students (95.1%) agreed or fully agreed that the lesson had helped them to understand indigenous life in their
society from a chemistry point of view. Chemistry learning across cultures broadened students’ insights into the development of chemistry. They realized that such development not only comes from the sophistication of Western modern technology, but can also be inspired by indigenous or traditional knowledge. According to the student feedback, most participants (90.2%) agreed or fully agreed that the lesson had provided them with insights into the generation of scientific technology. This included the fact that new ideas and processes can also be derived from sources like indigenous, cultural knowledge.

Chemistry learning was also regarded in a very positive light at the end of the lesson. The students were content with the green chemistry lab activities and their new-found abilities. During the intervention, the learners were directly involved in green chemistry lab assessment. Accordingly, they gained experience of how to implement green chemistry principles in lab instruction. Most student responses (90.2%) stated that the lesson plan had encouraged them to learn new green chemistry principles. Moreover, almost all of the participants (97.5%) had realized that the design, process and development of chemical products should meet the principles of green chemistry if sustainability is the goal. This new understanding should be instilled in future university students, if we wish to produce responsible scientists and teachers for the next generation.

![Figure 4](image_url) Responses of the students to the feedback questionnaire (N=41).
In the teaching intervention, the green star metric was employed to evaluate the greenness of the three extraction methods. In general, the green star metric can encompass any or all of the twelve principles of green chemistry. The green nature of the method is expressed by awarding scores of 1, 2, or 3. In this case, which only examined the isolation steps in the procedure, students only used a total of six principles which were applicable to the evaluation of the experiment. The description of the six principles used as criteria is shown below in Table 2.

**Table 2. The principles of green chemistry used to assess the extraction (Adopted from Duarte et al.**)

<table>
<thead>
<tr>
<th>Principle</th>
<th>Criteria description</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1, prevention</td>
<td>It is better to prevent waste than to treat or clean up waste after it has been created.</td>
</tr>
<tr>
<td>P5, safer solvents and auxiliary substances</td>
<td>The use of auxiliary substances (e.g., solvents, separating agents, etc.) should be made unnecessary wherever possible and innocuous whenever used.</td>
</tr>
<tr>
<td>P6, increase energy efficiency</td>
<td>Energy requirements of chemical processes should be recognized for their environmental and economic impacts. They should be minimized and, if possible, synthetic methods should be conducted at ambient temperature and pressure.</td>
</tr>
<tr>
<td>P7, use renewable feed stocks</td>
<td>A raw material or feedstock should come from renewable sources rather than limited ones whenever technically and economically practicable.</td>
</tr>
<tr>
<td>P10, design for degradation</td>
<td>Chemical products should be designed so that they break down into innocuous degradation products at the end of their functional life. These end products should be ephemeral.</td>
</tr>
<tr>
<td>P12, safer chemistry for accident prevention</td>
<td>The identity and form of a substance used in a chemical process should be chosen to minimize the potential for accidents, including chemical releases, explosions, and fires.</td>
</tr>
</tbody>
</table>

The result of the groups’ green star analysis was generally the same. All of the groups considered steam distillation and particularly MAE to be greener than the Soxhlet method (Figure 5). Based on the student evaluation, criteria P5 (safer solvents and auxiliary substances) and P12 (safer chemistry for accident prevention) received the lowest valuations for the Soxhlet extraction, with the average score ending up below 1. The participants were concerned that using organic solvents (in this case ethanol) in the Soxhlet method might potentially present significant risks to human health and the environment. Flammable organic solvents like alcohol can also contribute to increased risk in the form of a chemical
accident or fire. As one student explained during the discussion and as an answer on the worksheet: "The Soxhlet method uses an organic solvent, so that extraction occurs continuously. One fear is that the solvent is not easily degraded. Work safety also has a fairly moderate risk". The students also emphasized the potential risk of producing a considerable amount of chemical waste due to the use of an organic solvents. Another student stated: "Soxhlet extraction can potentially produce chemical waste which is quite dangerous for the environment and humans, because the solvents used in the extraction method are organic solvents such as alcohol". This factor contributed to the low overall score of P1 (prevention) for the Soxhlet method.

<table>
<thead>
<tr>
<th></th>
<th>Soxhlet</th>
<th>Steam Distillation</th>
<th>MAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>GSAI = 53.33</td>
<td>GSAI = 82.50</td>
<td>GSAI = 88.33</td>
</tr>
<tr>
<td>P7</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>P6</td>
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<td></td>
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<td>P10</td>
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<td>P12</td>
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<td>P1</td>
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</tbody>
</table>

Figure 5. Mean score of the student’s green star metric assessment. GSAI is the green star area index. It represents the percentage ratio of the green star area compared to the total area of a green star of maximum greenness.

The scores for criteria P7 (use renewable feedstocks) and P10 (design for degradation) should be the same theoretically, because they use the same feedstock and produce the same product. However, the P7 and P10 average scores in the student green star metric were quite different for the three methods. This was especially true for the Soxhlet method, which received the lowest scores. Based on the group discussion, a few students misinterpreted solvents as part of the feedstock and chemical waste as part of the products. Nevertheless, this minor issue could be discussed in the classroom, where the teacher guided the students to filter and confirm the information. This made their final conclusion more reliable and valid.

In terms of criteria P6 (increase energy efficiency), students considered the MAE method to be better than the other two methods. Although it requires large initial electric power usage (600 Watts), the MAE
method is much more time efficient than the other two methods. Several students stated: "MAE is very efficient in terms of the time required, even though the initial energy used for the analysis is quite large". Based on the analysis average, MAE received the highest scores, followed by the steam distillation and the Soxhlet method. However, there was only a slight difference between MAE and the steam distillation. This neglected to take into account the necessarily long heating time of several hours which steam distillations regularly require. The students considered the MAE to best represent the ideas of green chemistry principles.

In general, the students developed a comprehensive ability to evaluate extraction methods based on green chemistry principles. Participants learned how to compare and evaluate the advantages and disadvantages of each extraction method. Using the green star metric allowed the learners to interact directly with the principles of green chemistry and to reflect upon their importance, uses, and advantages. These activities offer students new forms of laboratory learning. They engage learners in deciding on a set of alternative experiments or methods which optimize chemical greenness, instead of merely following a prescribed protocol without any deliberation.

CONCLUSION

We can conclude that the participants in the study perceived the lesson as very interesting and personally relevant to them. Learning chemistry in real-life situations selected from their cultural environment was a positive experience. It helped them to foster their scientific literacy. It also broadened their insights into the importance of other sources of chemistry knowledge which can contribute to the development of green and sustainable chemistry. Examining the chemistry behind indigenous knowledge by means of personal investigation was an important factor in this. Students analyzed natural compounds and processes in the context of green chemistry lab activities. This included important knowledge and skill sets for becoming responsible scientists or teachers in the future.

The present study offers a new pedagogical approach for innovating green and sustainable chemistry concerns across both disciplines and culture. The lesson plan gave the students new insights. They realized that the integration of other knowledge and worldviews (e.g., ethnoscience or ethnochemistry) can be of benefit to advance Western modern science and achieve green, sustainable chemistry goals.
The accompanying learning activities engaged the students with hands-on activities, which can enrich science classes. The learners also gained experience in evaluating more conventional procedures with alternative methods.

ASSOCIATED CONTENT
Supporting Information
The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX. [ACS will fill this in]

Experiment procedure (DOCX)

AUTHOR INFORMATION
Corresponding Author
Robby Zidny - Department of Biology and Chemistry, Institute for Science Education, University of Bremen, 28359 Bremen, Germany; Department of Chemistry Education, Faculty of Teacher Training and Education, University of Sultan Ageng Tirtayasa, Serang, Indonesia; orcid.org/0000-0002-4727-3984; Email: robbyzidny@untirta.ac.id

Author
Ingo Eilks - Department of Biology and Chemistry, Institute for Science Education, University of Bremen, 28359 Bremen, Germany; orcid.org/0000-0003-453-4491; Email: ingo.eilks@uni-bremen.de

Notes
The authors declare no competing financial interest.

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Supporting Information (Experiment procedure)

**Microwave assisted extraction (MAE) of d-limonene from pomelo (Citrus grandis) peels using a kitchen microwave**

Based on Chemat et al. (2006); Chen et al. (2016); Hackleman (2015)

**Experiment principle:**
Microwaves interact with dipolar molecules, causing rotation and vibration of the molecular bonds. This results in the heating of the sample and produces steam surrounding the oil molecules. The steam given off by the sample condenses at the icy bottom of the porous funnel. The more volatile oil condenses in the ice and drips into the small beaker glass.

**Materials**
- sample of pomelo peel (100 gram)
- 1 L borosilicate beaker
- 150 mL borosilicate beaker (2 piece)
- porous funnel (borosilicate glass or plastic microwavable material)
- ice
- 2 glass tubes
- borosilicate glass lid
- 25 mL separating funnel/ 25 mL volumetric flask/5 mL measuring cylinder glass
- pipette
- 0.001 M potassium permanganate (VII) / KMnO₄

**Method**
- Prepare the sample of pomelo peel by washing and cutting it into small pieces (or use a grinder).
- Weigh out 100 grams of the sample.
- Set up the equipment according to Figure 1.
- Place 50 mL of water into the small 150 mL beaker and place it next to the equipment. This will serve to balance the overall temperature inside the microwave.
- Perform the extraction using the microwave set for 7 min at 600 Watts.
- Wait 5-10 minutes for the steam in the glass to condense completely into the 100 mL beaker. Do not wait so long that the oil evaporates!
- Separate the oil using a pipette. Place the upper layer of the crude extract into a 25 mL volumetric flask or 5 mL volumetric cylinder. Remove the oil from the surface layer very carefully with the pipette.

**Qualitative analysis of chemical functional groups of d-limonene**

**Qualitative test for carbon double bonding in d-limonene (using strong oxidizing agent)**
- Prepare two small test tubes: one for the sample and one as a control. Label each test tube.
- Using the pipette add 3 drops of crude sample extract into the first test tube.
- Then add 3 drops of distilled water into the second test tube with the pipette as a control.
- Pipette 3 drops of 0.001 M potassium permanganate (VII) in each test tube.
- Shake the tubes gently and observe any physical or chemical changes (color/precipitation/gas) in the mixture.
- Heat the mixtures and observe any new physical or chemical changes.
- A positive reaction for double bonds occurs if the color changes from purple to dark brown. The purple permanganate, MnO$_4^-$, has reacted with a double bond in d-limonene to form MnO$_2$ (dark brown).

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