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Article

Learning about Pesticide Use Adapted from Ethnoscience as a Contribution to Green and Sustainable Chemistry Education

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Abstract: This study shows how students can learn about green and sustainable chemistry by 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 that is used by the Baduy tribe in Western Java, Indonesia. A simple low-cost extraction method that uses a kitchen microwave was chosen to introduce modern green extraction methods to learners. This facilitates the 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 COVID-19 pandemic with the help of an online learning management system (SPADA) and Google Meet. The students' feedback and selected results are discussed below.

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

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1. Introduction

Green chemistry searches for cleaner industrial processes, safer chemical products, and the increased use of renewable resources in the manufacturing of products [1]. The idea of green chemistry was first initiated in the 1990s by Paul Anastas and John Warner. They suggested a total of twelve green chemistry principles to serve as a framework for more benign chemistry [2]. Green chemistry offers various tools and strategies as technical and practical conditions for sustainable chemistry [1]. Both green and sustainable chemistry, which is a concept that was suggested around the same time in Europe [3], look for ways to realize innovations in chemistry that increase ecological, economic, and societal sustainability [4].

Green and sustainable chemistry are not solely concerned with research and industry. It has been suggested that they also become an integral part of chemistry education [5]. Such education should integrate and reflect upon the concepts and practices of green chemistry at both the secondary and higher educational levels [5,6]. The integration of issues that are selected from education for sustainable development and green chemistry into teaching and learning practices is one area of focus. Chemistry education should offer students contemporary and authentic learning experiences. This will, in turn, raise their perception of the relevance of learning chemistry [7].

There is a growing interest in the idea of incorporating sustainability and green chemistry into chemistry education at all the various educational levels [8], including both the higher [9,10] and secondary [11–13] educational levels. Various green and sustainable chemistry learning contexts have been selected and introduced, including organic laboratory [14–16] and general chemistry courses [7,17]. The implementation of green and sustainable chemistry in education, however, remains mostly focused on the context of the traditional chemistry subdisciplines and industrial applications. It all too often centers around one specific field or topic in a single-discipline chemistry approach [8].

In order to innovate chemistry education, it is necessary to introduce both cross-disciplinary learning and systems thinking [18,19]. This allows educators to provide holistic perspectives on just how different and multifaceted the challenges that face green and sustainable chemistry can be when considering multiple perspectives and eco-reflexive thinking [20–23]. One aspect that can enrich the chemical perspective with regard to sustainability is the field of ethnoscience and related knowledge, which can be considered as "ethnochemistry" [24]. Ethnoscience is the traditional knowledge of indigenous peoples. It is closely related to the sustainable use of the renewable resources that are found in nature [21,24,25].

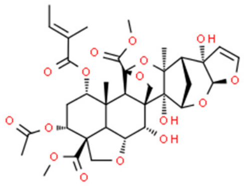
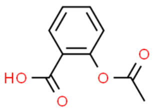
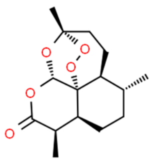
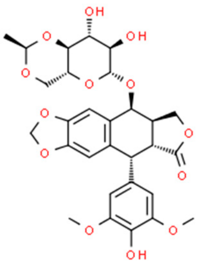
In this paper, ethnoscience is discussed with a view to chemistry education. We look at how it can enrich chemistry education with regard to green and sustainable chemistry. One learning approach to the integration of green and sustainable chemistry is examined by the current study. It evaluates undergraduate chemistry education in Indonesia, including an evaluation of the green chemistry laboratory activities. This paper describes an evidence-based case study that 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 the substances and processes that were selected from the natural pesticide use in an indigenous culture. These were adopted from ethnoscience to serve as a starting point for the development of green chemistry lab activities. Coming from an ethnochemistry practice that is operated by an indigenous people, microwave-assisted extraction (MAE) with a kitchen microwave was chosen to highlight the differences with more conventional extraction methods, such as Soxhlet and steam distillation, to obtain a biopesticide that is used by the indigenous community of the Baduy in Western Java, Indonesia. Student teacher (N = 41) feedback and evaluations of the teaching unit are also presented.

2. Ethnoscience and Its Implications for Green and Sustainable Chemistry

"Ethnoscience" can be defined as a system of knowledge about nature that is owned by a particular indigenous or traditional culture. Such knowledge covers both ecological aspects and the mutual relationships between humans and nature [21,24]. Ethnoscience is sometimes referred to by other names, such as "indigenous science" or "traditional ecological knowledge". Ethnoscience 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) [21,25]. From this point of view, ethnochemistry includes the chemistry of a particular indigenous society or culture that has a different way of conducting science than modern Western chemistry might suggest.

Although ethnoscience has been passed down from generation to generation over centuries, its existence is still largely neglected by modern Western science and it tends to be generally omitted from science curricula [21]. With the growing awareness of the challenges of sustainability issues, such as global diseases and environmental pollution, the limitations of modern Western science and technology in overcoming 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 indigenous knowledge more thoroughly into account [26,27]. Among other aspects, indigenous pest control practices have come under new consideration for wider use in tropical countries. One ancient plant that is known to exhibit biopesticide activity is *Azadirachta indica*. It contains chemical compounds that act as pivotal insecticidal ingredients and, therefore, it can be used as a green pesticide [28]. Across the globe, science has started to mine ethnoscience in order to advance fields such as chemistry, medicine, and agriculture. Researchers have started to uncover the potential of chemical compounds that are derived from plants or other renewable materials that can benefit agriculture, medicine or technology (see Table 1) [24,28–32].

Table 1. Examples of phytochemical compounds used by indigenous peoples.

Structure	Phytochemical Compounds Name	Function	Use/Originally Derived from
	Azadirachtin	Pivotal insecticidal ingredient	Produced from *Azadirachta indica*, a poisonous plant with biopesticide activities, which is commonly used in Africa and Asia. [24,28,33]
	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). [29]
	Artemisinin	Antimalarial agent	Produced from the Chinese herb, Qinghao, or "sweet wormwood", used initially as traditional Chinese medicine for chills and fevers. [30,34,35]
	Etoposide	Anticancer agent	Synthesized from podophyllotoxin, produced by the American mandrake plant, used in various remedies in Chinese, Japanese, and Eastern folk medicine. [30,31,35,36]

In terms of sustainability, ethnoscience can provide alternative green pesticides for agriculture that can sometimes replace risky or controversial synthetic ones, such as glyphosate. It should be noted, however, that plant-based pesticides are not "good" per se. On the one hand, plant-based pesticides are made from renewable raw materials and they are biodegradable. On the other hand, there might be the probability of risk in the production and application of certain plant-based pesticides for human health or for the environment. For instance, there are some reports about safety concerns with regard to the potential toxicity of some plant-based pesticides to humans and nontargeted animals, such as the plant-based pesticides that are derived from neem plant [37], tuba root, and sweet flag [38]. Therefore, for green pesticides as well, the benefits and risks need to be assessed systematically.

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 [29,31]. In more advanced chemical research and technology, the knowledge that is 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 [32], or indigenous knowledge can be employed in analytical chemistry [33].

A recent study explores the ethnoscience of a traditional community in Indonesia, namely, the Baduy [34]. In terms of ethnoscience, the Baduy apply the utilization of natural products or phytochemicals in agriculture, medicine, or as natural dyes and household chemicals. Baduy knowledge can be considered closely related to sustainable chemistry.

Their application of science in a traditional way can help to reflect the sustainability concerns of industrialized societies in a different way.

This study focuses on ethnoscience in terms of the use of phytochemicals in agriculture. The teaching intervention was inspired by the ethnoscience of the Baduy in Indonesia. To avoid potentially harmful synthetic pesticides, the Baduy use biopesticides from natural products that are biodegradable, namely, d-limonene from pomelo extracts. d-limonene and other terpenoid compounds can serve as repellents and fumigants against insects [35]. The repellent effect of terpenoids lays in the functional group activity, which causes neurotoxicity or interaction with one or more receptors in insects [36]. Terpenoids can inhibit insect acetylcholinesterase (AChE) enzyme activity, which can block nerve functions [39]. Fumigant activity is linked to the high volatility and lipophilic properties of terpenoid compounds, which help to penetrate the insects rapidly and interfere with their physiological functions [39]. By comparing synthetic pesticide use with the practices that are applied by the Baduy, students can learn about sustainability aspects, such as the risk and benefit analysis, when comparing synthetic and natural pesticides [20], as well as about ways towards eco-benign pesticide use that is inspired by ethnoscience.

3. 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 the IUPAC [40]. The 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 [40]. Another aim is to make chemistry learning more personally relevant to students, especially in countries with indigenous or traditional communities [21,41]. The introduction of ethnoscience in the classroom may help learners to better reflect upon different cultural backgrounds. It might also improve their understanding of the different knowledge claims and worldviews with respect to chemistry [42,43]. Further goals deal with promoting systems thinking to support green and sustainable chemistry education. An ethnochemistry viewpoint can foster student awareness and add insight to various points of view. This can combine or contrast the elements of ethnoscience and modern Western chemistry. In this combination, science and chemistry education can be enriched with multicultural perspectives and worldviews that include aspects of the knowledge, cultural values, and environmental ethics from other cultures [20]. It may also offer new perspectives for decision making and for finding solutions to sustainability issues [18–21].

Burmeister et al. [11] describe four different basic models that can be used to carry out education for sustainable development (ESD) in chemistry education. These include: (1) Adopting green chemistry principles into chemistry lab work (e.g., the implementation of microscale chemistry to reduce chemical consumption, risk, and waste [44]); (2) Adding green and sustainable chemistry content to the chemistry curriculum (e.g., the integration of green chemistry concepts into the context of industrial chemistry in school [45]); (3) Using controversial sustainability issues as socioscientific issues to drive chemistry education (e.g., connecting chemistry learning with controversial issues, such as bioethanol usage [46]); and (4) Making sustainability issues and education for sustainable development a part of school development (e.g., ESD implementation at a whole school organization in Sweden [47]).

A previous study in Indonesia [20] 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 modern Western 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 that centered around the integration and application of concepts of green and sustainable chemistry into chemistry learning. The core of the innovation in this study focused the question on what students can learn from the ethnoscience of an indigenous community (namely, the Baduy in Indonesia) about sustainable chemistry practices. The intervention aimed to inspire reflections on science in terms of sustainability when comparing the science in an industrialized society to the ethnoscience of an indigenous people. To achieve this aim, a teaching intervention was applied in which the students explored the science and its application from the Baduy in a combination of theoretical and practical learning.

4. Method and Intervention

4.1. Research Framework and Method

This study is part of a wider research project on the inclusion of indigenous science (ethnoscience) and its perspective on sustainability in chemistry education in Indonesia [21]. The research framework behind the project is adapted from the Model of Educational Reconstruction (MER) [48]. The research framework (Figure 1) combines the analysis of the content structures, the development of pedagogical interventions, and studies on teaching and learning practices and their evaluation. The research aims to provide students with multiple perspectives on different scientific worldviews in order to make a better connection between the knowledge and cultural values within ethnoscience in relation to modern Western science, sustainability issues, and the relevance of learning science [21,49,50]. On the basis of the framework, the study in this paper had the objective of gaining insight into the students' perception of a learning design about green and sustainable chemistry by using the perspective of a local indigenous culture (the Baduy). The results of this study are presented in order to provide information for the development, implementation, and evaluation of further pedagogical approaches and curriculum designs.

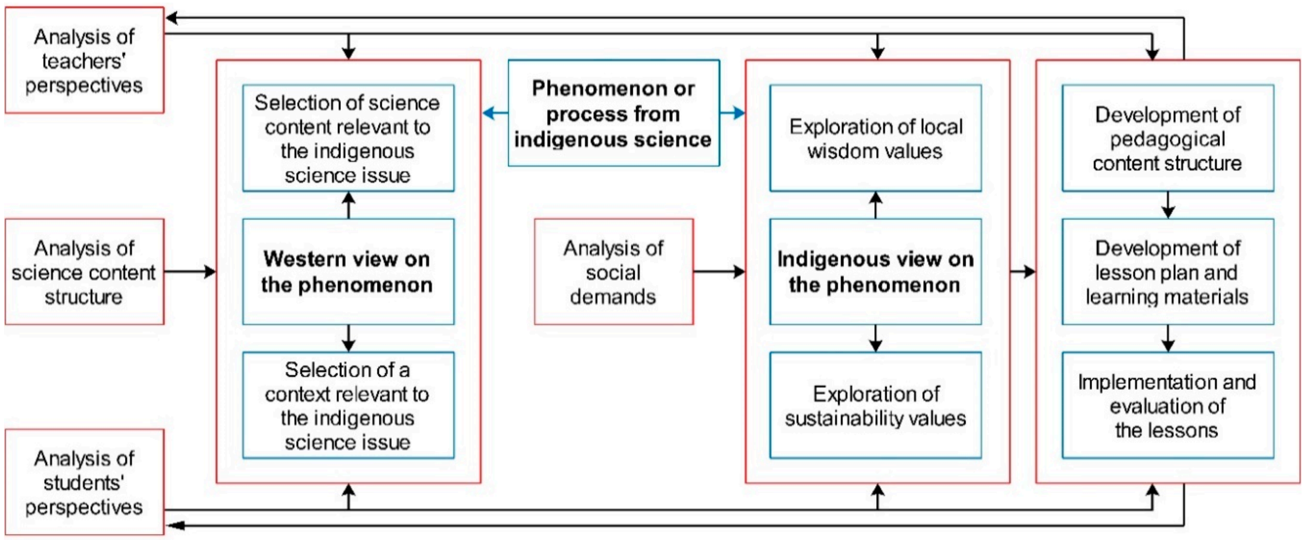


Figure 1. Educational design framework for the inclusion of ethnoscience in science education.

The participants of the study were two classes of university chemistry student teachers (N = 41) in Indonesia. The university is located near to the Baduy indigenous community in Java. The indigenous context of the ethnoscience in this study was adapted from this community. The participants participated in the teaching intervention and then they filled out a voluntary questionnaire about their perceptions and experiences with the lesson plan.

The lesson plan in the study, and its related teaching materials, were initially designed by the first author. The learning design was reviewed by other experts in chemistry education. After the design phase, the lesson plan was translated into the Indonesian language to be reviewed and validated by local science educators and university teachers. After the revision process, the lesson plan was tested in a small group of 10 chemistry student teachers to obtain feedback for further improvement. Finally, the lesson plan was applied in two groups of chemistry student teachers who were taking part in an environmental chemistry course.

The research instrument in this study was a questionnaire with five Likert-scale items (5 step). The questionnaire focuses on the student responses to the two main objectives of the lesson plan: (1) Learning chemistry that is connected to an indigenous culture; and (2) Learning about other substances and processes that are adopted from indigenous science as a starting point for understanding green chemistry practices. The questionnaire was administered after the completion of the teaching intervention. The development of the questionnaire took the same steps as the lesson plan development. It was validated by a professor and three expert researchers in the field of chemistry education. After revision, the questionnaire was tested in a small group of student teachers and was then revised. The reliability of the Likert questionnaire was tested by Cronbach's alpha, with a final score of 0.83 (good).

Descriptive statistics were used to analyze the student teachers' responses to the Likert items. The aim of the analysis was to obtain feedback on the learning design and the perceptions of the effects of the teaching intervention. The students' feedback was calculated according to a percentage distribution of the agreement to the statements. It is suggested that this type of analysis is sufficient for research-based design studies, which aim at the cyclical improvement of teaching and learning practices [51].

The teaching intervention and data collection was conducted according to the institution's policy on research regulations and ethics. The permission for exploring and publishing the findings about the ethnoscience in the Baduy indigenous community was obtained from the elders of the Baduy.

4.2. 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 two days long and it focused on the botanical pesticide use by the Baduy Tribe on Java (Banten, Indonesia). On the first day, the students learned independently by using an online learning management system. On the second day, the teacher facilitated the students' learning through Google Meet and the learning management system for 150 min. The Baduy people are an indigenous community that maintains traditional agricultural practices, and that has the philosophy of preserving nature. This includes avoiding potentially harmful synthetic pesticides on their crops [41]. 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 pomelo (scientific name: *Citrus grandis*, or *Citrus maxima*; Indonesian name: Jeruk Bali) manually by hand by 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, and specifically, *Leptocorisa acuta*, *Oseolia orizae*, and *Grylottalpa africana*. All of this information is given to the students in the accompanying teaching materials during the introductory activity (e.g., which covers the worksheet tasks related to the chemical concepts and processes behind the ethnoscience of the Baduy). The tasks include an explanation of the chemistry behind the botanical pesticide activity of pomelo extract, the process of extraction by using fermented sugar palm juice, and an understanding of the bioactivity of the related compounds.

During the lesson, students have to extract the abovementioned information from a text and a video that explain the ethnoscience of the natural pesticide that is 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 pomelo. Pomelo is a local and highly relevant plant from the grapefruit family. It is abundant and widely available in South East Asia, and especially in Indonesia. Pomelo peels contain quite a large amount (>94%) of d-limonene [52], which has been suggested as an eco-friendly biopesticide [35,53]. After receiving this information, the students then take up the role of a chemist who must identify the natural pesticide compound (d-limonene) that is found in the pomelo peels. The selected learning activities have the following objectives for the students: (1) To learn about the context of ethnochemistry in connection with a local indigenous culture; (2) To 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) To analyze the structure of the phytochemical agent; and (4) To analyze and evaluate different extraction methods (Soxhlet extraction with alcohol; steam distillation; and microwave-assisted extraction) on the basis of green chemistry principles.

In order to illustrate green chemistry in practice, we chose a cost-effective method that can also be used in high schools. The experiment consisted of low-cost green microwave-assisted extraction (MAE), which used an unmodified kitchen microwave and very simple lab equipment that was inspired by other MAE experiments [54–56]. The learning approach that was selected involved the participants directly in the application of the green chemistry principles to the laboratory techniques. It forced them to evaluate and compare the levels 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 watts) 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 into small pieces with the help of a grinder. Then, 100 g of the sample were placed in the setup, as is shown in Figure 2. 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, the steam was allowed to condense completely for 5–10 min. The oil was then cooled down and was then separated by decanting and pipette extraction. The identification of the essential oil component was performed by a visual interpretation of the graphic spectrum of the gas chromatography–mass spectrometry (GC-MS). Visual interpretation can be conducted by comparing the retention indices and the mass spectrum to the published data, and then matching the recorded mass spectrum with references in a computer database (e.g., NIST® Database) [57].

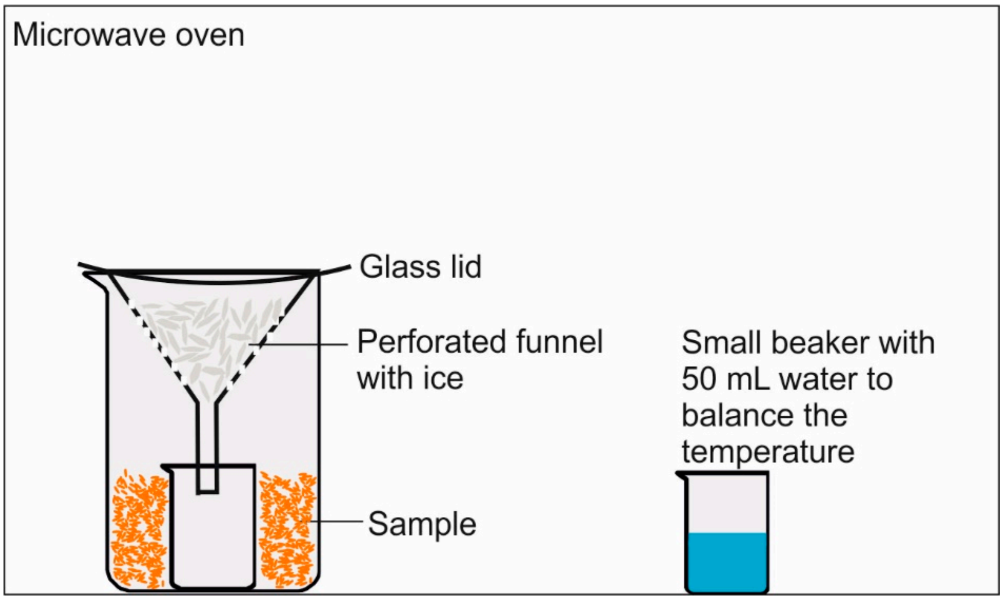


Figure 2. Kitchen microwave extraction setup.

The study was conducted during the COVID-19 pandemic. An online learning management system, SPADA (developed by an Indonesian Higher Education Institution), 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 assessment [58] was used to evaluate the greenness of the extraction methods. These were based on protocols that 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 that are available in the literature [58].

During the intervention, five main activities were assigned to the students via SPADA (Figure 3). The first and second phases were conducted by the students independently through SPADA on the first day, and the other phases were carried out on the second day. The first phase asked the students to locate the initial information with regard to the lesson, which included: (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, durations of analysis, energies, and yields; (c) Finding information about the chemical analysis of phytochemicals; and (d) Searching for information about green chemistry principles.

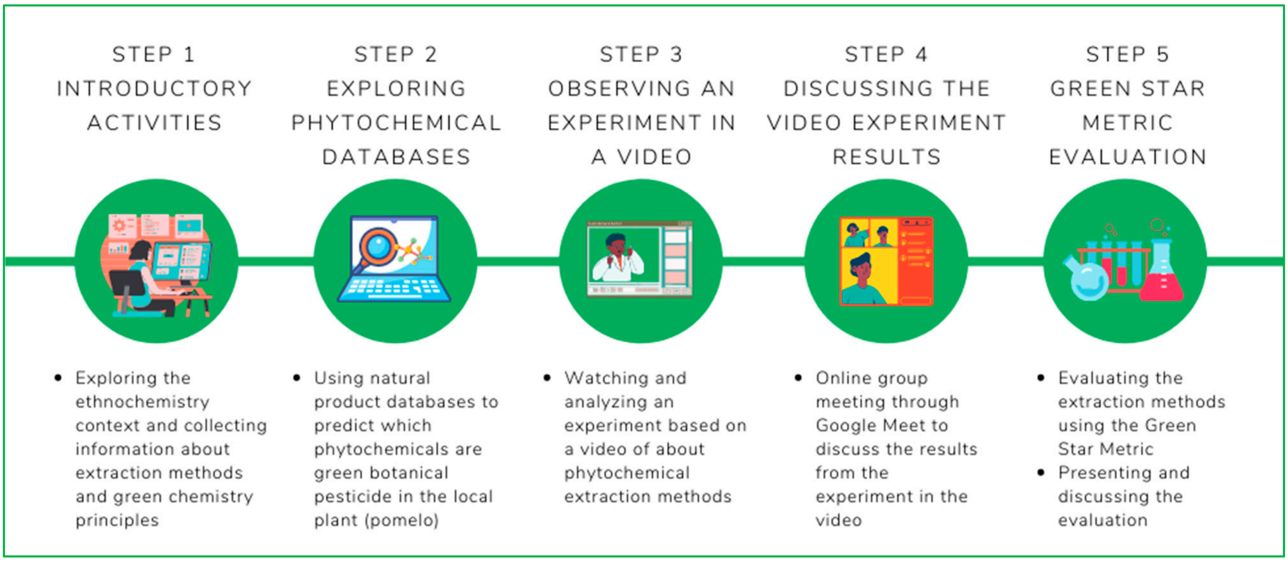


Figure 3. Learning activities in the lesson plan.

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 that was 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 biopesticide use. They examined the corresponding phytochemicals that were found in reliable sources (e.g., research articles), and they used the information to identify the relevant compounds, which could be confirmed by the teacher. The students collected all of their results in the form of a table. The table covered information about the local background of the plant, the available phytochemical compounds and their functional groups, and the related biopesticide activity of the compounds.

In the next step, the students analyzed a video about different extraction methods that was supported by worksheets. On the basis of 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 biopesticide activity.

They compared more conventional extraction methods (Soxhlet and steam distillation) to the MAE. In the video, the teacher gives a general overview of the three extraction methods and conducts an MAE by using an unmodified kitchen microwave (see explanation above). Finally, the teacher then shows a qualitative analysis of the compounds and gives 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 that was related to the experiment. The questionnaire focused on the following tasks: (a) Identifying the chemical functional groups in the pomelo peel extract on the basis of the literature search; (b) Explaining which phytochemical compound is relevant for biopesticide use; (c) Estimating and comparing the total energy consumption of the three extraction methods; and (d) Evaluating the extraction methods in the experiment on the basis of 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 familiarize themselves 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 on the basis of green chemistry became the focus of the discussion at the end of the session. The students discussed how to evaluate the extraction methods on the basis of 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. [58]. It provides a holistic assessment, which is intended to show a systemic metric of the inherent benignancy, or "greenness", of the chemical procedure. At the end of the discussion, the students presented their results from the assessment to the group. They shared their reasons for believing that a certain method falls most in line with green chemistry principles.

5. Results

5.1. Student Feedback on the Lesson Plan

Overall, the feedback from the university students (Figure 4) was very positive with respect to the teaching unit. The majority of the 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 personally motivated them to learn chemistry ideas from an indigenous culture. The lesson also facilitated the students in their own self-awareness and understanding of the chemical phenomena that are related to a specific cultural environment. As is 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 the students' insights into the development of chemistry. They realized that such development comes not only from the sophistication of modern Western technology, but that it can also be inspired by indigenous or traditional knowledge. According to the student feedback, most of the 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 such as indigenous and cultural knowledge.

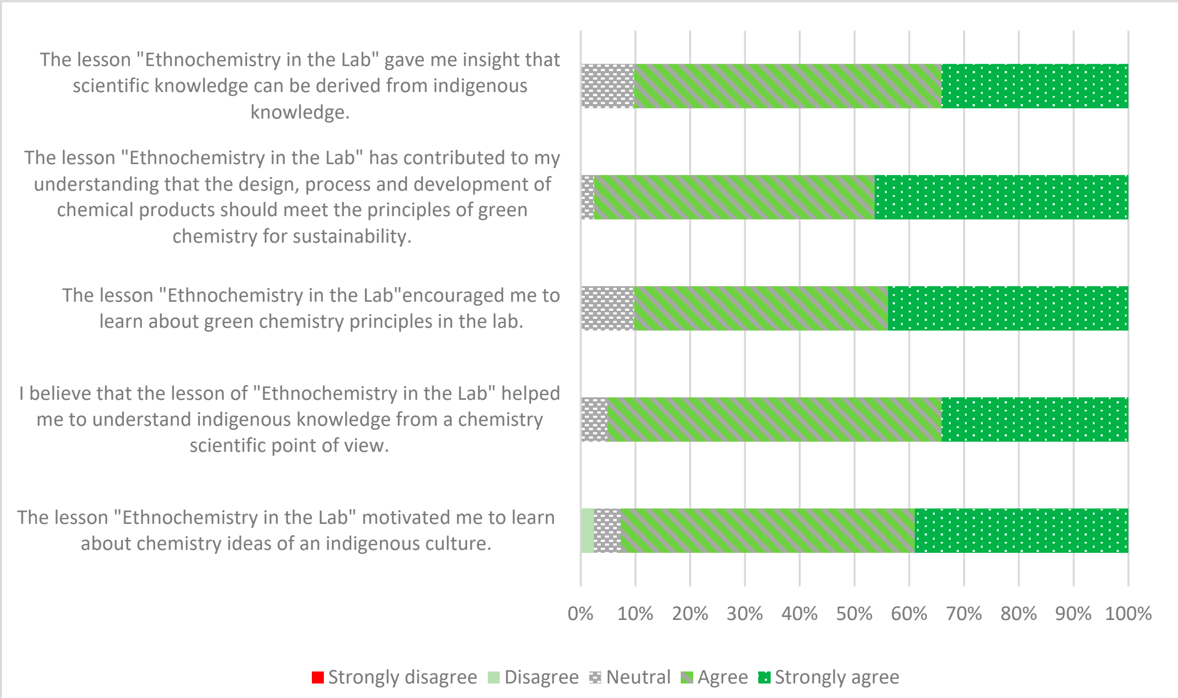


Figure 4. Responses of the students to the feedback questionnaire (N = 41).

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 a green chemistry lab assessment. Accordingly, they gained experience in how to implement green chemistry principles in lab instruction. Most of the student responses (90.2%) stated that the lesson plan had encouraged them to learn and practice greener chemistry. Moreover, almost all of the participants (97.5%) 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.

5.2. Students' Experiences in the Evaluation of the Extraction Methods on the basis of Green Chemistry Principles

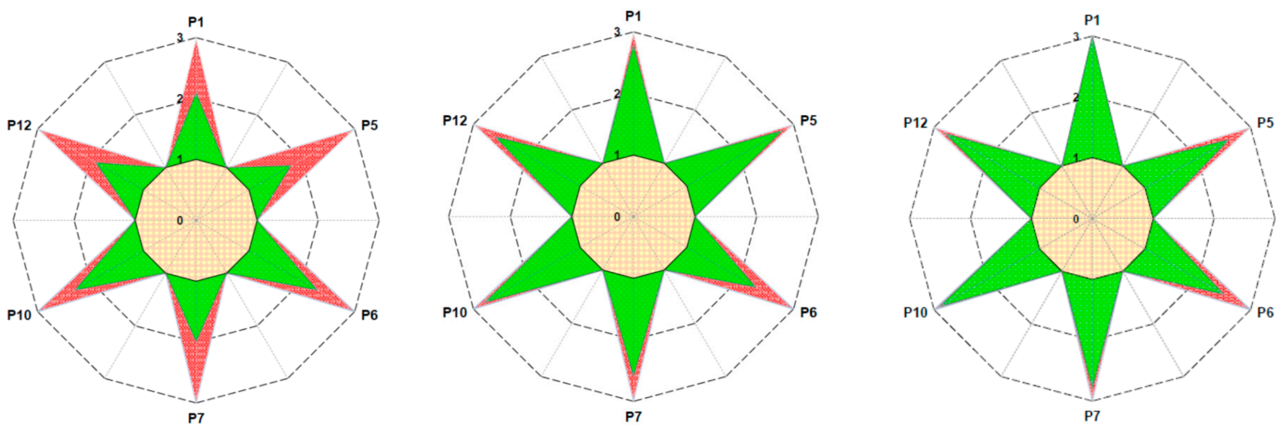
In the teaching intervention, the green star metric was employed to evaluate the greenness of the three extraction methods. In general, the green star metric can encompass any or all of the twelve principles of green chemistry. The green nature of the method is expressed by awarding scores of 1, 2, or 3.54. In this case, which only examined the isolation steps in the procedure, the students only used a total of six principles, which were applicable to the evaluation of the experiment. The descriptions of the six principles that were used as criteria are shown in Table 2.

The results of the groups' green star analysis were generally the same. All of the groups considered steam distillation, and particularly MAE, to be greener than the Soxhlet method (Figure 5). On the basis of 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 being 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, such as 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 because of the use of an organic solvent. 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 2. The principles of green chemistry used to assess the extraction (adopted from Duarte et al. [58]).

Principle	Criteria Description
P1: Prevention	It is better to prevent waste than to treat or clean up waste after it has been created.
P5: Safer solvents and auxiliary substances	The use of auxiliary substances (e.g., solvents, separating agents, etc.) should be made unnecessary wherever possible, and should be made innocuous whenever used.
P6: Increase energy efficiency	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 the ambient temperature and pressure.
P7: Use renewable feed stocks	A raw material or feedstock should come from renewable sources rather than from limited ones whenever technically and economically practicable.
P10: Design for degradation	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.
P12: Safer chemistry for accident prevention	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.

(**a**) (**b**) (**c**)



GSAI = 53.33 GSAI = 82.50 GSAI = 88.33

Figure 5. Mean scores of the students' green star metric assessments of Soxhlet (**a**), Steam Distillation (**b**), MAE (**c**). "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. On the basis of 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 Criterion P6 (increase energy efficiency), the 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". On the basis of the analysis average, the MAE received the highest scores, followed by steam distillation and the Soxhlet method. However, there was only a slight difference between the MAE and steam distillation. This neglected to take into account the necessarily long heating time of several hours that steam distillations regularly require. The students considered the MAE to best represent the ideas of the green chemistry principles.

6. Discussion and Conclusions

The case study that is presented in this paper illustrates that learning about green and sustainable chemistry can be enriched by taking perspectives of chemistry other than modern Western science into account, which, in our case, is the culture of an indigenous community (the Baduy). With this additional perspective, students can learn some important aspects of chemistry, which include: (1) That scientific knowledge is universal and can be inspired from other cultures, such as ethnoscience; (2) That chemistry ideas are not restricted to the perspective of modern Western science and that further views can be found in the students' local cultural environment; and (3) That learning about the concepts and practices of green and sustainable chemistry can even be initiated from the local wisdom that is close to the students' cultural environment.

The case of this study shows that the students mostly perceived the lesson plan to be motivating and inspiring. They acknowledged that learning chemistry can be connected to the knowledge of their local indigenous cultural environment. It is suggested that this has the potential to increase the students' awareness of the knowledge around their cultural environment in order to improve scientific and cultural literacy [59]. With regard to the lesson plan, which was inspired by the context of the ethnoscience of the Baduy community, the students agreed that they learned about the valuable aspects of sustainable chemistry practices with regard to the use of green pesticides from natural product. These aspects include: (1) The use of biodegradable compounds, such as plant-based natural products, to avoid environmental pollution; (2) The traditional processes of pesticide extraction, which avoid abundant chemical waste; (3) The uses of renewable resources from natural products, such as from plants; and (4) To avoid the use of chemical derivates, which have the potential to produce excess waste. The contention with ethnoscience can help to reflect the sustainability concerns of industrialized societies. Most of the students also agreed that lesson plans that are inspired by local wisdom could encourage them to inquire into the chemistry ideas behind ethnoscience that focus on green lab practices and methods. In general, the students developed the ability to evaluate the extraction methods on the basis of green chemistry principles. The participants learned how to compare and evaluate the advantages and disadvantages of different extraction methods. 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 [58]. This activity offers students new forms of laboratory learning. It engages learners to reflect on alternative experimental practices or methods to promote chemical greenness, instead of merely following a prescribed protocol without any deliberation.

The implementation of the learning design in this study has depicted Models 1 and 2 of the ESD-type pedagogies in chemistry education, as suggested by Burmeister et al. [11]. In terms of adopting green chemistry principles into chemistry lab work (Model 1), the lesson plan provides hands-on learning activities to apply green chemistry principles in order to evaluate lab methods, which are used to investigate the phytochemicals behind ethnoscience. The lesson also offers the students the opportunity to learn green and sustainable content (Model 2) that is inspired by ethnoscience, such as the valuable aspects of the sustainability chemistry practices of the Baduy indigenous community with regard to the use of green pesticides from natural products. The implementation and combination of Models 1 and 2 in this learning design can be a promising strategy for achieving a broad range of ESD goals in chemistry education [11]. It can help the students to understand and access the sustainability issues behind chemistry in an everyday-life context.

There is growing interest, which is visible in the international literature, in the integration of ethnoscience into the science curricula in different parts of the world, including Asia, Africa, the Americas, and Australia (e.g., [20,43,60,61]). The case in this study contributes alternative pedagogical approaches and a didactic model for how to design chemistry education for sustainability that takes ethnoscience into consideration. In addition, learning chemistry that is inspired by ethnoscience can encourage modern Western chemistry to more deeply explore the potential of using sustainable and renewable natural products or reagents in order to achieve green and sustainable chemistry [33].

We can conclude that the participants in the study perceived the lesson as very interesting and as personally relevant to them. Learning chemistry in real-life situations that were 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 study. The 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 cultures. 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 the advancement of modern Western science and to the achievement of the 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.

7. Limitations and Outlook

This study necessarily has some limitations, since it is a case from one Indonesian university only, and it focuses on one indigenous community, and on one practice from their ethnoscience. It also only focuses on encouraging students to learn about the green and sustainable chemistry ideas behind ethnoscience as a starting point to better reflect chemistry in terms of sustainability. Further research needs to explore more of the aspects of the students' learning when they are exposed both to ethnoscience in general, and to the practices from ethnoscience in the field of chemistry and agriculture in particular. Moreover, a deeper focus on the learning of the chemistry content that is behind and that is inspired by ethnoscience would be a worthy topic for research (e.g., on natural chemicals as pesticides for the promotion of green and sustainable chemistry). This might also include learning about the formulations of d-limonene pesticide products, their specific modes of effect on certain pests, the safety and health aspects of d-limonene pesticide products, and further sustainable resources for biopesticide mass production.

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