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PjBL-based Green Chemistry Module: Internalizing Creative and Moral Character in the Context of Wetlands

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Creative and moral characters developtment is essential in the industrial Era 4.0, but these characters are less integrated in wetland environment-based learning. This study aims to analyze the feasibility of a green chemistry module based on Project-Based Learning (PjBL) to train creative and moral characters in the context of wetlands. This research uses the ADDIE development model. The validation test involved five experts or practitioners, limited trials, and implementation on groups of 15 and 35 students. Data collection utilized module validation instruments, content readability assessments, learning observations, and student responses. The validation results showed that the module had high validity with a score of 90.00. The readability of the module content was very good, with a score of 90.83. Project-based learning can be effectively carried out in limited trials and implementation. Additionally, expressed positive responses regarding of satisfaction, creativity, and moral character. It was concluded that the PjBL-based green chemistry module was feasible for use in training students to develop creative and moral characters in the context of wetlands.

Keywords: Creative; Green Chemistry; Moral; Project-based Learning; Wetland

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INTRODUCTION

Today, plastic waste is a significant source of environmental pollution, including in wetlands. Plastic waste continues to increase and is difficult to decompose, largely originating from everyday human activities, including those of students at school (Islama et al., 2022). The amount of plastic waste in the school environment suggests a lack of concern or moral character among students in the surrounding environment (Listyowati et al., 2024; Oktaviansyah & Safitri, 2025). After eating or drinking, students still often throw their garbage carelessly, even though teachers frequently remind them to throw trash in its place. Handling plastic waste is a big challenge considering the high level of plastic consumption and the low recycling rate (Song & Park, 2024). Therefore, the habituation of creative and moral characters in the context of wetlands is a significant concern in 21st-century education (Tabiraki et al., 2024).

Development of creative and moral characters in schools plays a vital role in shaping students' awareness and responsibility about the surrounding wetland problems (Balontia, 2024; Gitmiwati & Indrayuda, 2024). One effective educational method is the use of an e-book. This plastic waste processing technique involves filling used plastic bottles with plastic waste until it becomes solid, making it an environmentally friendly construction material (Islama et al., 2022). At the senior high school level, teachers need to encourage the development of students' creative and moral character. Meaningful learning should be contextual or based on the wetland environment (Cardenas Morales et al., 2025; Lusiana et al., 2025). In this case, students are accustomed to recognizing wetland issues around them and creating innovative solutions to overcome the problems they encounter (Almeida et al., 2024; Syahmani et al., 2024).

Various previous studies (Ariyanto et al., 2022; Aziz, 2024; Azzahra et al., 2023; Gitmiwati & Indrayudha, 2024; Hidayat et al., 2024; Kumala et al., 2025) have shown that creative and moral characters in the context of wetlands can be developed through Project-Based Learning (PjBL). Teachers can facilitate meaningful experiences that allow students to engage in contextual learning and perform complex activities (Nugroho et al., 2019). In addition, they are encouraged to be more noble, creative, and collaborative, and to think critically when addressing wetland problems around them (Dinantika et al., 2019). The weakness of these studies is that the principles of green chemistry have not been integrated into PjBL. In addition, the development of creative character and environmentally conscious character discussed is still general in nature and is not linked to the context of green chemistry or project activities oriented towards solving environmental problems. As a result, it is not yet clear how pjbl can effectively foster creative and moral character in the context of wetlands. Therefore, to train innovative and moral characters in the context of wetlands, a PjBL-oriented green chemistry teaching module was developed. The teaching module contains instructions that are specifically and systematically designed to support project activities in the green chemistry learning process, making it enjoyable and engaging for students (Fitri et al., 2024).

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Green Chemistry material was selected because it is one of the new materials for class X (Phase E) at the high school level and equivalent. Green Chemistry is an approach to chemistry that aims to maximize efficiency and minimize harmful effects on human health and the environment, where students play an active role in addressing local and global issues (Okonkwo et al., 2024). Research results (Delaney et al., 2024; Kurul et al., 2025) explain that the most important aspect of Green Chemistry is the concept of design. When designing a process, one cannot rely on chance; instead, the process must be carefully calculated from various aspects. For students to engage in the green chemistry movement, real action is needed to help them understand the concept. This can be achieved by creating a project based on their creative ideas, fostering a love for the surrounding natural environment that can be passed on to their children and grandchildren.

The results of the researcher's initial study showed that teachers often teach green chemistry materials in a manner limited to memorization and practice questions only. Learning becomes less meaningful because students lack an understanding of green chemistry materials, let alone how to apply them in solving wetland problems around them. Students should learn chemistry concepts in a contextualized manner and be actively involved in complex activities to find solutions to surrounding wetland problems (Almeida et al., 2024; Syahmani et al., 2024). Therefore, it is necessary to develop a PjBL-oriented green chemistry module that is feasible to use in learning green chemistry. Through the module, students are actively engaged in contextual, meaningful, fun, and holistic learning. In addition, students can create Green Chemistry products, such as ecobricks, ecoenzymes, plastic bricks, and natural dyes, which can holistically develop creative, critical reasoning, and moral character in the context of wetlands, allowing these values to be embedded within themselves.

Based on the explanation above, this study aims to analyze the feasibility of a PjBL-based green chemistry module to train creative and moral characters in the context of wetlands. The novelty of this module compared to previous modules includes: (1) animation and color composition according to the age of student development; (2) the file size is only 5.84 MB so that it is readily displayed using all types of student gadgets; (3) PjBL-oriented to train creative and moral characters in the context of wetlands, and (4) there are audio-visual material explanations, QR barcodes, daily assessments can be accessed easily using google forms and quizzes. Through the module, teachers are expected to facilitate students in producing green chemistry products in the form of processed products or programs that can be applied in everyday life.

METHOD

This Research and Development method adopts the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). At the analysis stage, the curriculum, student characteristics (creative and moral character), attributes of green chemistry materials, and teaching modules were examined. At the design stage, based on the previous analysis, a teaching module framework was developed, focusing on learning objectives and character grids. During the development stage, carried out: (1) Drafting the PjBL-based Green Chemistry teaching module along with its supporting instruments; (2) Performing an expert validation test by asking three experts and two chemistry learning practitioners to assess the quality and construct of the module content; (3) Conducting a content readability test by asking five students to assess the level of readability, language usage, and suitability for creative and moral character development within the wetland context; and (4) Revising the module based on the results of the expert validation and readability tests, followed by conducting a limited practicality test involving 15 high school students in a wetland environment, during which teachers and students used the PjBL-based Green Chemistry module in three chemistry learning sessions. During the learning process, two observers assessed the implementation of the project-based green chemistry learning stages. At the end of the meeting, students were asked to complete a response questionnaire about the use of green chemistry teaching modules in their classroom learning. During the implementation stage, a practical test of the green chemistry module was conducted in an actual class comprising 35 high school students in a wetland. The implementation of the learning and data collection process was similar to the limited trial.

The data analysis technique employed was a descriptive qualitative approach. The average expert validation scores were grouped into five categories: 3.3-4.0 (highly valid); 2.5-3.2 (valid); 1.7-2.4 (moderately valid); 0.9-1.6 (less valid); and 0.1-0.8 (invalid). Meanwhile, the average value of module practicality (content readability, learning implementation, student response) is classified as follows: 86-100 (very good); 76-85 (good); 66-75 (quite good); 56-65 (less good); and 0-55 (not good). This module is considered feasible if the value of expert validation results is at least in the valid category, as well as the value of content readability, module implementation, and student response is at least in the good category.

RESULT AND DISCUSSION

Green chemistry is not a program to eliminate pollution from the environment. However, green chemistry is a fundamental effort to prevent pollution and its primary sources. Through the PjBL-oriented green chemistry module, students are actively involved in identifying environmental issues around them and creating innovative projects to avoid ecological damage (Syahmani et al., 2020). Therefore, the development of PjBL-oriented green chemistry modules supports 21st-century learning, aligning with the concept of Deep Learning. In Deep Learning (Andayani et al., 2025; Liu et al., 2022), educators complement the learning approach by incorporating characteristics of pedagogical practices, such as practices that foster awareness, where teachers help students develop metacognition to become successful learners. In this teaching module, students develop understanding and are motivated to be active learners in analyzing wetland issues around them and creating innovative solutions to the problems they encounter. The Green Chemistry Module developed consists of a cover page, preface, module introduction, instructions for use, table of contents, learning outcomes, concept map, material content, daily assessment, reflection, glossary, bibliography, and author profile.

[Figure 1 about here.]

The cover page features images related to planting tree seedlings and the surrounding area of the school, creating a comfortable environment for learning and discussion. Students (in the picture on the cover) demonstrate their comfort in learning green chemistry, showing that learning that is fun and exhilarating does not have to be confined to the classroom. The image of a hand holding plant seeds (on the cover) illustrates that teachers are obligated to educate the nation towards the formation of Indonesian students as a whole, based on the values of Pancasila. In line with the demands of the independent curriculum (Fauzan et al., 2023; Zainuddin et al.,

2025), learning in schools should focus on essential content, centered on the knowledge and skills most necessary for developing student competence and character. Educators can facilitate deep and meaningful learning (Andayanie et al., 2025). Therefore, the main activities in this module are designed according to PjBL syntax. This module also accommodates the digital learning process, where exercise questions, pre-tests, and post-tests are in the form of barcodes and question links for Google Forms. Barcodes to create presentations using Canva for free using a learning ID account, provided by Kemendikbudristek, specifically for teachers and students. This module product is also equipped with self-reflection and enrichment questions. Self-reflection to get an idea of how far students can understand the material and the actions they should take. For teachers, reflection serves as feedback and an action plan for the learning process, informing future decisions about what to add or subtract in the next lesson. Enrichment to accommodate students who have abilities above the class average, so that the concept of differentiation also applies. Differentiation in this module, among other options, can also be accessed using a cellphone or in both softcopy and hardcopy formats. The presentation used by students can be in a free-form style or adapted to meet student competencies. This is to accommodate regular students with low, medium, or above-average abilities.

Validity of the Green Chemistry Module

The chemistry teaching module is systematically designed according to the stages of PjBL to train students in developing creative and moral characters within the context of wetlands. The developed module must meet quality requirements, one of which is to achieve the quality of content and construct as determined through validation tests conducted by experts and practitioners. The results of the validation of the PjBL-based green chemistry module are presented in Table 1.

[Table 1 about here.]

Based on Table 1, the results of the validation of the PjBL-oriented green chemistry module are in the outstanding category. The cover design is described as the content of the teaching material, including color, font size, and proportions, and obtained an average of 3.6, with very valid criteria. General information has been provided to describe the module according to the PjBL stage, focusing on enhancing creative and moral character in the context of wetlands. It also provides a general description of the target students, clarity on the dimensions of the Pancasila student profile, and details on the infrastructure used. The core component describes the language according to the EYD, the suitability of the material about the objectives/indicators, the consistency of the objectives across the entire module, and the clarity of the presentation of the prerequisite competencies that students are expected to master. The list of meetings clearly outlines the learning steps, from introduction to core to closing, by the PjBL syntax. It includes a list of attachments, evaluation techniques, and the completeness of evaluation instruments, as well as the completeness of material, all presented in a systematic arrangement. Teaching materials describe the suitability of the material in terms of learning objectives, completeness, accuracy of the concept, character indicators, sample questions, a glossary, and a bibliography. The students' worksheet explains how the command sentence does not lead to multiple interpretations. Activities are organized according to the stages of PjBL, learning experiences encourage students to learn creatively, and the suitability of questions and learning objectives is considered. Language is tailored to the level of student development. The module design also demonstrates compliance with the independent curriculum, supports active, meaningful, joyful, and environmentally conscious learning, and utilizes ICT media in the learning process.

Validation of the green chemistry teaching module encompasses aspects such as material selection using standard curriculum book references, content accuracy, currency, and relevance to its educational implementation, systematic organization according to scientific structure, and alignment with the curriculum and school. The content of the module aligns with the learning needs of children, specifically the learning process that involves and provides a fun and meaningful experience. Activities can utilize real learning resources found in the child's environment. Learning resources that are not readily available in real life can be presented with the support of technology, such as children's reading books, or in other forms Kemendikbudristek 2024. Learning is facilitated by incorporating information and communication technology tools to meet the demands of 21st-century learning (Kalyani, 2024; Punggeti et al., 2024). The use of technology in learning facilitates easier access to, finding, and utilizing various types of information (Azis & Kusnafizal, 2024).

The green chemistry module is designed using PjBL activities. Students are facilitated to interact and build their knowledge from various digital sources. In this case, students are encouraged as active, interactive, and independent learners in learning about green chemistry and its applications in addressing environmental problems. PjBL utilizes projects as a medium and produces clear outputs, such as electronic posters and products in the form of waste utilization products (Sinta et al., 2024). Electronic posters can showcase human activities that apply green chemistry principles to mitigate global warming. Electronic posters can be uploaded to digital social media, serving as a means of communicating project results (Pranata & Kusayang, 2024).

The validation of language with the PjBL strategy is also in the very valid category. These results indicate that the language used in the module follows the correct communicative language rules. The language used in the module is tailored to the language commonly used in students' daily lives (Solfitri et al., 2024). The simplicity of the language used makes students interact directly with the teacher through the module. Thus, the green chemistry teaching module is valid for use in school learning. This module supports an active, contextual, and fun learning process for students. In addition, students are familiarized with noble morals about surrounding wetland issues and have a creative spirit in finding solutions to the problems encountered (Fauzan et al., 2023; Zainuddin et al., 2025).

Practicality of Green Chemistry Module

The practicality of the green chemistry module refers to the ease with which it can be applied in the classroom learning process. In this study, the practicality of the green chemistry module was reviewed based on aspects of content readability, module implementation, and student responses. The readability of the module content refers to the ability of the module to be understood and followed by students (Putri et al., 2024). In this study, the readability of the green chemistry module was emphasized in terms of linguistic aspects, as well as its compatibility with creative and moral characters in the context of wetlands. The results of the module content readability test are presented in Table 2.

[Table 2 about here.]

Based on Table 2, the results of the content readability in all aspects of the green chemistry teaching modules assessment are excellent. The language and readability of the module obtained the best score. This indicates that the language used is easily comprehensible to students. Habituation of morality or care for the environment has obtained perfect criteria. This highlights the importance of students being aware of and friendly to the environment by incorporating environmentally friendly activities into their everyday lives. The suitability of creative characters with values is also excellent, as students can generate new ideas in creating innovative projects. The readability of the module content is reinforced by the results of analyzing the module's implementation in classroom learning.

The module applicability describes the level of teachers' ability to use the green chemistry module in classroom learning (Burhanuddin et al., 2025; Wilda et al., 2024). The results of the module applicability analysis in the limited trial and implementation are presented in Table 3.

[Table 3 about here.]

Table 3 shows that the green chemistry module can be effectively utilized in both limited and implementation tests. This means that the module components are easy to understand and can be effectively used in classroom learning. The main activities of the green chemistry module are oriented towards the stages of PjBL. This activity begins with fundamental questions. The teacher can present fundamental questions in the form of infographics regarding various chemical reaction events in everyday life (Meeting 1), the impact of climate change (Meeting 2), and waste problems in wetlands (Meeting 3). Then, participants are asked to answer fundamental questions in the LKPD. During project planning, teachers facilitate group discussions to identify the concept of applying green chemistry (Meeting 1), human activities that contribute to ozone destruction and global warming (Meeting 2), and solutions to overcome waste problems (Meeting 3). At this stage, the teacher accommodates students' plans by utilizing any media that aligns with their competencies. Teachers can direct students to analyze data and draw conclusions from the activities they engage in. Students are also asked to read various literature (books, articles, YouTube, Google, and others) to complete their project plans. Project making involves the teacher checking the information obtained by students in the form of electronic posters about various human activities that apply the principles of green chemistry to overcome problems in the wetland environment. Among them can be in the form of goods resulting from the utilization of waste or a program. Presentation of project results, Students present the results of their work in front of the class (Aziz, 2024; Hidayat et al., 2024). Additionally, students upload their work through social media, tagging their friends (Sinta et al., 2024), and provide comments on their friends' work uploads. For groups that have not presented in class, they can share their presentation online by recording a video and then sending it to their chemistry classroom's drive link (Pranata & Kusayang, 2024). Furthermore, students evaluate the results and reflection of project activities carried out, and then draw conclusions about their learning (Ariyanto et al., 2022; Hidayat et al., 2024; Kumala et al., 2025). The success of teachers in utilizing modules in the learning process is supported by students' positive responses to the learning experience (Alyusfitri et al., 2024).

Student Response refers to the feedback or comments provided by students after they have attempted and utilized the green chemistry module. Student responses on the limited test and implementation are presented in Table 4.

[Table 4 about here.]

Table 4 shows that students gave positive responses to the use of green chemistry modules in limited tests and classroom implementation. Students were delighted with the presentation of the green chemistry teaching module used. Students want to be encouraged to think creatively and develop a noble character, as well as care about the surrounding environment (Rebecchi et al., 2024). In this case, students demonstrate creative and noble character by identifying wetland issues and finding innovative solutions to overcome the problems encountered (Fauzan et al., 2023; Zainuddin et al., 2025).

Based on the findings of this study (Tables 1 – 4), it can be concluded that experts and practitioners agree that the developed green chemistry module is valid in terms of content and construct. In addition, the teaching module also fulfills the aspects of readability, can be applied effectively in learning, and elicits positive student responses to the module. Thus, the developed PjBL-oriented green chemistry teaching module is feasible for use in training students to develop creative and moral characters in the context of wetlands at school. This module can serve as an alternative to create innovative and God-fearing characters, as well as to motivate students to appreciate chemistry subjects and find solutions to environmental problems.

This study has limitations because the green chemistry module was tested on a limited number of students, in the context of schools in wetland environments, and only three meetings, so generalizing the findings to a broader context still requires further testing. Nevertheless, this study makes a fundamental contribution to the world of education through the development of a green chemistry module that can be used to foster students' creative and environmentally conscious characters through contextual projects. This module also strengthens the integration of green chemistry principles in chemistry learning and offers an innovative learning model that can be used as a reference for teachers, curriculum developers, and further research related to sustainable chemistry education.

CONCLUSION

The PjBL-based green chemistry module is feasible for teachers to use in support of deep learning. Through this module, students are familiarized with creative and noble character in recognizing wetland issues around them and creating innovative work to find solutions to the problems encountered. Further research is needed to evaluate the effectiveness of green chemistry modules in chemistry education on a large scale across various levels of education.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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TABLE 1 / Validity of the Green Chemistry Module

	Assessment Aspects	Value	Category
Cover design	The module cover illustration depicts the content/teaching material of green chemistry, the PjBL model, and creative and environmentally conscious characters.	3.8	Very valid
	Do not use too many font combinations.	3.6	Very valid
	The color of the module title contrasts with the background color	3.6	Very valid
	The font size of the title. subtitle. and supporting text is more dominant and professional than the size of the module and author's name.	3.4	Valid
General information	The teaching module enhances students' creative and ethical character.	3.8	Very valid
	The teaching module is designed in accordance with the PjBL stages.	3.6	Very valid
	The general description of the teaching module is presented clearly.	3.6	Very valid
	Clarity of creative character and moral conduct towards nature	3.4	Valid
	Clarity of the necessary infrastructure, consisting of equipment for the entire learning process.	3.6	Very valid
	Clarity of student targets.	3.6	Very valid
	PjBL steps are able to create an active learning atmosphere for students, can help students practice their knowledge and character, and are in accordance with student characteristics.	3.6	Very valid
Core components	Use of language in accordance with EYD (Standard Indonesian Spelling).	3.4	Valid
	Suitability of module material with learning indicators/objectives.	3.8	Very valid
	Consistency of learning objectives from the entire teaching module.	3.4	Valid
	Clarity of presentation of the expected competency prerequisites that students must have before learning begins	3.4	Valid
Core components	Learning steps are carried out through preliminary, core, and closing stages with a clear allocation of time for each stage in accordance with PjBL to enhance creative and ethical character in wetlands	3.6	Very valid
	Details of each stage of the learning activity in accordance with the PjBL syntax to enhance creative and ethical character in the context of wetlands	3.6	Very valid
	List of supporting material attachments as references for attachments in the supporting material section	3	Valid
	Appropriateness of evaluation techniques to learning objectives	3.6	Very valid
	Completeness of evaluation instruments (questions, answer keys, scoring guidelines)	3.2	Valid
Appendix 1 Teaching Materials	Appropriateness of green chemistry teaching materials to PjBL-oriented learning objectives	3.8	Very valid
	Completeness of teaching materials with a systematic sequence and structure in accordance with learning objectives	3.6	Very valid
	Accuracy of concepts in accordance with PjBL-oriented information listed in the teaching module	3.6	Very valid
	Indicators of creative and environmentally conscious character in the scenario	3.4	Valid
	Examples of questions and assessments are compiled in accordance with learning objectives	3.8	Very valid
	There is a glossary and summary covering the material presented	3.8	Very valid
	The glossary is presented clearly	3.8	Very valid
	Instructions do not lead to multiple interpretations	3.4	Valid
Appendix 2 LKPD	Student activities are in line with PjBL stages to develop creative and environmentally conscious character traits	3.6	Very valid
	The learning experience encourages students to learn creatively and independently	3.4	Valid
	Questions are in line with learning objectives	3.4	Valid
	Instructions do not lead to multiple interpretations	3.8	Very valid

TABLE 2 / Readability of the Green Chemistry Module Content

	Statement	Students' score					Value	Category
		1	2	3	4	5		
Language and readability	The language in the module is easy to understand.	4	4	4	4	4	100	Sangat baik
	The sentences in the module are not ambiguous or biased.	4	3	3	4	4	90	Sangat baik
	Chemical terms are explained clearly and in context.	4	4	4	3	3	90	Sangat baik
	Activity instructions are easy to understand and follow.	3	3	4	4	4	90	Sangat baik
Compatibility with creative character	The module encourages individuals to generate new ideas in completing projects.	3	3	4	4	4	90	Sangat baik
	Freedom to try different ways of solving problems.	4	4	3	3	3	85	Sangat baik
	Activities in the module challenge original thinking.	4	4	4	3	3	90	Sangat baik
	Facilitates the development of innovative products/solutions.	4	4	4	3	3	90	Sangat baik
Fostering environmental awareness	The material in the module raises awareness of the importance of protecting the environment.	4	4	4	3	3	90	Sangat baik
	The projects in the module encourage the application of environmentally friendly principles.	4	3	3	3	4	85	Sangat baik
	The module presents real-life examples of the application of green chemistry.	4	4	4	4	4	100	Sangat baik
	Studying this module motivates participants to take part in protecting the environment.	4	4	4	3	3	90	Sangat baik

TABLE 3 / Implementation of Green Chemistry Teaching Module

Trial	Observation Aspects	Implementation of Modules at Meetings ...					
		1		2		3	
Limited	Basic questions	93.3	Very good	98.3	Very good	100	Very good
	Project planning and scheduling	86.6	Very good	84.7	Very good	93.5	Very good
	Project creation	83.3	Very good	100.0	Very good	91.7	Very good
	Presentation of project results	83.3	Very good	100.0	Very good	75.0	Good
	Evaluation of learning experiences	98.3	Very good	100.0	Very good	100.0	Very good
Field	Basic questions	95.0	Very good	96.7	Very good	95.8	Very good
	Project planning and scheduling	83.3	Very good	90.3	Very good	97.2	Very good
	Project creation	91.7	Very good	100.0	Very good	75.0	Good
	Presentation of project results	91.7	Very good	100.0	Very good	91.7	Very good
	Evaluation of learning experiences	90.0	Very good	93.3	Very good	96.7	Very good

TABLE 4 / Student Response

Trial	Review Aspects	Response Result	
		Value	Category
Limited	Student satisfaction	84.52	Very good
	Suitability with creative character	85.42	Very good
	Habituation of moral behavior in the context of wetlands	77.08	Good
Field	Student satisfaction	69.42	Good
	Suitability with creative character	78.32	Good
	Habituation of moral behavior in the context of wetlands	82.82	Very good

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FIGURE 1 / Green Chemistry Module Section