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Assessing Chemical Environmental Literacy and Sustainable Self-Awareness among Vocational High School Students

Yashinta Suci Kurniati*, Sri Handayani
Chemistry Education Department, Universitas Negeri Yogyakarta, Indonesia
*Correspondence Email: yashintasuci.2021@student.uny.ac.id

Abstract

This study aims to analyze the level and differences of chemical environmental literacy and sustainable self-awareness among vocational high school students based on grade level and gender. A quantitative descriptive-comparative approach was employed involving 100 students from Grades levels. Data were collected using a chemical environmental literacy test and a sustainable self-awareness questionnaire and analysed through descriptive statistics and the Mann–Whitney test. The results showed that most students demonstrated high levels of chemical environmental literacy and sustainable self-awareness, with no significant differences based on grade level, but a significant gender difference in sustainable self-awareness. The study concluded that the implementation of the Merdeka Curriculum and the Adiwiyata Programme positively contributed to strengthening students' sustainability competencies. The findings imply the need for more reflective and contextual learning strategies to reinforce the affective dimension of sustainability education.
Keywords: *Adiwiyata, Environmental literacy, Sustainable self-awareness*

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INTRODUCTION

Global environmental challenges, including climate change, ecosystem degradation, and the overexploitation of natural resources, have intensified over recent decades, posing critical threats to sustainability (Muhirwa et al., 2025; Rahman, 2023) Education plays a transformative role in addressing these challenges by equipping learners with sustainability competencies (Trevisan et al., 2024; UNESCO, 2020; Nur et al., 2024). Environmental and chemical education have been positioned as strategic instruments for preparing future generations to respond effectively to sustainability challenges (Khalil, 2024).

Empirical evidence indicates that environmental knowledge does not automatically translate into sustainable actions. Fridayani (2024) demonstrated that students' engagement in sustainability-oriented activities is fully mediated by attitudes, underscoring the pivotal role of affective constructs in transforming knowledge into practice. Similarly, Maresi and Basoeki (2024) reported persistent gaps between environmental knowledge and pro-environmental behaviour among students, emphasising the necessity of comprehensive environmental literacy integration within school curricula. Learners' attitudes, emotional engagement, and self-awareness are recognized as mediating factors that transform environmental understanding into responsible behaviour (Murzyn et al., 2025; Soeharso et al., 2023). Handayani and Sulastini (2023) further showed that character education programmes that integrate self-awareness and self-respect are effective not only in improving environmental knowledge but also in fostering sustainable character formation, positioning learners as socially responsible actors. Rahmawati, Yuli et al., (2024) found that incorporating personal reflection into chemistry learning strengthened students' emotional commitment and sense of responsibility toward environmental issues. The integration of ethical dilemmas and value discussions within science curricula has been shown to stimulate deeper engagement and help students bridge cognitive understanding with personal values and ethical decision-making. Research using an ethical-dilemma STEAM teaching model in chemistry demonstrated that reflective learning activities increased students'

awareness of environmental protection and supported the development of collaborative decision-making skills necessary for sustainable action.

Despite growing awareness, students' behavioural transformation remains limited, particularly within the chemical environmental domain. Murphy et al. (2020) identified a consistent discrepancy between cognitive understanding of environmental concepts and actual everyday practices, indicating that knowledge alone is insufficient to cultivate holistic environmental consciousness. Wolff et al. (2022) argued that reflective and metacognitive pedagogical approaches are essential to encourage learners to critically examine and transform their own environmental behaviours. The development of sustainable self-awareness in education is fundamentally supported through experiential engagement, reflective processes, and ethics-oriented pedagogies, which collectively facilitate transformative learning among students. Experiential learning, such as participation in environmental projects or ecopedagogical activities, enables learners to connect theoretical knowledge with real-world sustainability challenges, fostering deeper environmental awareness and a sense of personal responsibility (Sukarmin, Asrowi, & Kartika, 2026; Mulyadiprana, Rahman, Hamdu, & Yulianto, 2023). Reflective pedagogies further enhance this process by providing structured opportunities for learners to critically examine their assumptions, values, and actions, which strengthens both cognitive understanding and ethical decision-making capacities (Ayers, Bryant, & Missimer, 2020). In addition, integrating reflective exercises into science and sustainability curricula has been shown to increase students' emotional commitment and motivation to act sustainably, bridging the gap between knowledge and responsible behavior (Sobari, Hernani, & Ramalis, 2022). Collectively, these pedagogical strategies cultivate learners who are not only informed about sustainability concepts but also capable of translating this knowledge into value-driven, proactive actions that contribute meaningfully to sustainability goals within their communities and beyond.

The construct of sustainable self-awareness has emerged as a critical dimension within sustainability education, extending beyond cognitive mastery toward reflective and ethical self-positioning. Khastini et al. (2025) reported that 11th-grade students demonstrate more mature sustainability reflection compared to 10th-grade , largely due to their exposure to more diverse environmental projects. Munasinghe and Ziebell (2024) also found that the integration of personal reflection into chemistry learning strengthens students' emotional attachment and responsibility toward environmental issues. Oliver and Adkins (2020) emphasised that reflective learning spaces enable students not only to understand sustainability concepts but also to make responsible, value-driven decisions.

Vocational education constitutes a strategic domain for strengthening chemical environmental literacy. Montalva et al., (2025) highlighted that vocational students must understand the interconnectedness between professional practices and environmental consequences. This is particularly relevant given that many vocational graduates directly enter industrial sectors with significant potential for waste production. Recent studies emphasize that vocational education plays a pivotal role in fostering sustainability competencies, as graduates often enter environmentally sensitive industries (Castaño et al., 2025). Embedding green skills and ethical reflection in technical programs has been shown to enhance both environmental literacy and professional responsibility (Kostadinova et al., 2025). Demssie et al., (2023) further argued that competencies such as systems thinking and ethical decision-making are indispensable for addressing complex environmental challenges. Vocational school that implement environmentally oriented programs, such as eco-school initiatives, therefore represent relevant contexts for studying the interaction between chemical environmental literacy and *sustainable self awareness* (Nurwidodo et al., 2020).

Furthermore, the school's status as an eco-school institution reinforces its relevance as a research site. Baga et al. (2022) reported that environmentally oriented school cultures are effective in fostering students' environmental engagement across diverse socio-demographic backgrounds. Iwan Fajria et al., (2024) similarly stressed that environmental education must be systematically embedded within curricula across all educational levels to achieve sustained impact. These findings align with national efforts in Indonesia to promote environmentally friendly schools and learning environments.

Empirical evidence further demonstrates that students in eco-school environments tend to develop higher levels of critical thinking, problem-solving, and collaborative skills when addressing environmental challenges, highlighting the interplay between pedagogical design and environmental culture in promoting effective learning outcomes. These insights are consistent with national initiatives aimed at promoting environmentally friendly schools and learning environments across Indonesian education settings, reflecting a coordinated effort among policymakers, educators, and communities to integrate sustainability into both formal and informal education. Collectively, these observations indicate that eco-school settings function not only as centers for academic learning but also as living laboratories where students internalize environmental values, engage in reflective practice, and translate knowledge into concrete actions that support sustainable development goals.

Green chemistry has been identified as a particularly powerful pedagogical framework for enhancing chemical environmental literacy. Chen et al. (2020) defined green chemistry as a set of principles focusing on waste reduction and the use of environmentally benign substances. Maurer and Bogner (2021) demonstrated that green chemistry–based learning approaches significantly improve students' critical thinking and systems-based reasoning. Consequently, this pedagogical orientation is highly compatible with vocational education contexts where applied chemical knowledge and environmental responsibility must be tightly integrated.

At the national level of education in Indonesia, the implementation of the *Merdeka Curriculum* has further strengthened the relevance of sustainability-oriented learning. Kemendikbudristek (2022) emphasised the importance of the *Profil Pelajar Pancasila*, which includes global citizenship, environmental stewardship, and collaborative problem-solving as core student competencies. This alignment reflects a pedagogical shift toward learner-centered, competency-based education that foregrounds real-world problem framing and interdisciplinary engagement, both of which are considered essential for fostering sustainability literacy. Empirical evidence suggests that the curricular emphasis on project-based sustainability learning has a measurable impact on students' awareness and agency. Wisudariani et al. (2024) reported that the implementation of this curriculum through project-based sustainability learning significantly enhances students' sustainability awareness, positioning the curriculum as an important driver of educational transformation. These findings indicate that the Merdeka Curriculum not only provides structural support for sustainability education but also functions as an important driver of educational transformation, supporting learners in developing the knowledge, skills, and dispositions necessary to address complex socio-ecological challenges. Collectively, these developments underscore the potential of national curriculum policy to cultivate a generation of learners equipped with both the competencies and values required for meaningful participation in sustainable futures. Recent analyses suggest that project-based and contextualized learning under the Merdeka Curriculum supports the development of sustainability-oriented character (Amalia, 2023).

Alongside curricular and pedagogical determinant, demographic factors, including gender and grade level have been consistently as significant contributors to students' environmental literacy and sustainable self-awareness. Dey et al., (2024) noted that differences in age and learning experiences contribute to variations in the depth of students' environmental understanding and reflective capacity. Students at higher grade levels tend to exhibit more advanced reflective and ethical reasoning due to their exposure to more complex learning experiences, suggesting the importance of examining these variables within vocational education contexts.

At the global level, education for sustainable development (ESD) has been positioned as a central strategy for achieving the Sustainable Development Goals. UNESCO (2020) emphasised that SDG 4 requires educational systems to cultivate global citizenship, ecological responsibility, and sustainable lifestyles. Sterling (2011) argued that transforming education toward sustainability requires holistic pedagogical approaches that integrate cognitive, affective, and practical dimensions of learning. Within this framework, chemical environmental literacy can be understood as a critical component of broader sustainability competence.

Although previous studies have explored environmental literacy and sustainability awareness among secondary school

students(Colegado & Colegado, 2026; Sya'ban et al., 2025), limited attention has been given to vocational education contexts that integrate both chemical and reflective dimensions of sustainability learning. Most existing studies focus on either environmental literacy or self-awareness independently, rather than examining the interaction between the two constructs. Furthermore, empirical investigations addressing variations in these competencies based on demographic factors, particularly gender and grade level, remain scarce in the Indonesian context. Addressing these gaps is essential for understanding how cognitive and affective dimensions of sustainability develop among vocational learners who are directly linked to environmentally impactful industrial sectors. Therefore, this study aims to assess the level and differences of chemical environmental literacy and sustainable self-awareness among vocational high school students. By combining a cognitive test and a sustainable self-awareness questionnaire capturing affective and reflective dimensions, this research contributes empirical insights into how sustainability-oriented learning environments relate to the development of sustainability competencies in vocational education. The findings are expected to provide an evidence base aligned with national and global sustainable development agendas.

METHOD

This study employed a quantitative descriptive research design to obtain an objective and systematic overview of students' levels of chemical environmental literacy and sustainable self-awareness. The design was selected to identify patterns and distributions of sustainability-related competencies across grade levels and gender. Rather than focusing on causal relationships, this approach emphasised the empirical mapping of students' cognitive, affective, and reflective characteristics in relation to sustainability-oriented learning.

The study was conducted during the second semester of the 2024/2025 academic year. The school was selected due to its implementation of the Adiwiyata (eco-school) programme and the presence of vocational specialisations closely related to environmental and chemical practices. The institutional context provided a relevant environment for examining the integration of chemical environmental literacy and sustainability-oriented self-awareness among vocational students.

The target population consisted of all 10th-grade and 11th-grade students who were actively involved in school-based environmental programmes or Adiwiyata-related activities. The total accessible population comprised 100 students. A purposive sampling technique was applied to ensure that participants met the following inclusion criteria: enrolment in 10th-grade or 11th-grade, prior participation in school-based environmental activities or intra-/semi-intra school organisations, and willingness to complete all research instruments in full. This sampling strategy was designed to capture students with direct exposure to environmental learning experiences within the school context.

This study examined two categories of variables. The dependent variables were chemical environmental literacy and sustainable self-awareness. The independent variables were grade level (10th-grade and 11th-grade) and gender (male and female). These variables were analysed to explore distributional patterns and potential group differences in sustainability-related competencies.

Chemical environmental literacy was assessed using a 20-item multiple-choice test with five response alternatives (A–E). The test items were developed based on Bloom's cognitive taxonomy (C1–C4) and operationalised across five dimensions of environmental knowledge grounded in environmental literacy theory and green chemistry principles: factual knowledge, conceptual knowledge, procedural knowledge, systemic knowledge, and applicative knowledge. The development of the instrument was informed by established theoretical and empirical frameworks from Chen et al. (2020), Maurer and Bogner (2021), Salta et al. (2022).

Sustainable self-awareness (SSA) was measured through a self-report questionnaire constructed based on key theoretical works (Majolo et al., 2023). The instrument consisted of 10 Likert-scale items representing five core dimensions: (1) self-reflection and emotional awareness, (2) critical reflection on consumerism, (3) ethical and ecosystemic reflection, (4) personal value transformation, and (5) sustainable decision-making. Each dimension was operationalised by two statements. Responses were measured using a five-point Likert scale: strongly agree (5), agree (4), undecided (3), disagree (2), and strongly disagree (1).

Expert validation indicated that all 20 items of the environmental literacy test were aligned with the intended indicators, learning objectives, and green chemistry principles. The items were rated "Very Good" in terms of content, construction, and language quality, including their relevance to daily environmental problems, clarity of formulation, and linguistic appropriateness. Nevertheless, expert reviewers suggested minor refinements to several distractors (items 4, 5, 6, 7, 9, 11, 12, and 13) that were considered overly explicit. These suggestions did not undermine the overall adequacy of the instrument but rather strengthened its objectivity.

Similarly, the sustainable self-awareness (SSA) questionnaire demonstrated strong content validity. All 10 statements were rated "Very Good" across content, construction, and language aspects, confirming their alignment with the measurement indicators, conceptual clarity, and appropriateness of Likert scaling. The instrument was considered adequate for use without revision, indicating that it effectively captured the affective reflective dimensions of sustainability. These instruments were systematically developed based on established frameworks in environmental literacy and sustainability consciousness, including Yang et al., (2023).

Reliability analysis using Cronbach's alpha demonstrated excellent internal consistency for both instruments. The Sustainable Self-Awareness (SSA) questionnaire achieved a Cronbach's alpha coefficient of 0.937 for its 10 items, indicating very high reliability. Meanwhile, the environmental literacy test yielded a Cronbach's alpha value of 0.862 across its 20 items, reflecting reliability. Both coefficients exceeded the minimum threshold of 0.70, confirming the suitability of the instruments for research purposes

Data analysis was conducted in two sequential stages: descriptive and inferential. Descriptive statistics were used to examine central tendency and dispersion, including means, standard deviations, and score distributions. Students' scores were categorised into ideal rating categories to describe general trends in chemical environmental literacy and sustainable self-awareness across grade levels and gender groups. Inferential statistics were applied to examine group differences between independent samples. Before hypothesis testing, assumption tests were conducted, including normality testing using the Shapiro–Wilk tests and homogeneity of variance testing using Levene's test. When the data met parametric assumptions of normality and homogeneity, independent samples *t*-tests were employed to compare mean differences between 10th-grade and 11th-grade students and between male and female students. When these assumptions were not satisfied, the Mann–Whitney U test was used as a non-parametric alternative. Statistical decisions were made based on a significance level of $\alpha = 0.05$.

RESULT AND DISCUSSION

A total of 100 vocational high school students participated in this study. The participants were drawn from 10th-grade and 11th-grade students who had been actively involved in the Adiwiyata school programme and had experienced the implementation of the Merdeka Curriculum. Of the total sample, 57 students (57%) were from 10th-grade, and 43 students (43%) were from 11th-grade, providing a relatively proportional distribution that enabled comparative analysis across educational levels. This composition offered adequate representativeness for evaluating sustainability-oriented competencies in vocational education contexts.

In terms of gender, the sample consisted of 41 male students (41%) and 59 female students (59%). Although the number of female participants was slightly higher, the distribution remained within acceptable bounds for comparative statistical analysis. This composition enabled the exploration of potential gender-based differences in environmental literacy and sustainable self-awareness, particularly regarding patterns of ecological empathy, reflective orientation, and value-based decision-making. A detailed profile of the participants is presented in Table 1.

Table 1. Profile of participants

Grade	Male	Female	Total
10th-grade	22	35	57
11th-grade	19	24	43
Total	41	59	100

Normality was assessed using Shapiro-Wilk tests across grade levels and gender for both sustainable self-awareness and environmental literacy. As presented in Table 2, all subgroups showed significance values below

0.05, indicating that the data were not normally distributed. Based on these results, non-parametric tests were considered appropriate for subsequent analyses. Homogeneity of variance was examined using Levene's test for both variables across grade levels. As shown in Table 3, all significance values exceeded the 0.05 threshold, indicating that the assumption of homogeneity of variance was satisfied for both sustainable self-awareness and environmental literacy.

Table 2. Normality test result

Variable	Group	n	Shapiro–Wilk Statistic	Sig.
Sustainable self-awareness	10th-grade	57	0.841	0.000
	11th-grade	43	0.761	0.000
	Male	41	0.777	0.000
	Female	59	0.78	0.000
Environmental literacy	11th-grade	54	0.853	0.000
	11th-grade	46	0.87	0.000
	Male	38	0.864	0.000
	Female	62	0.863	0.000

Table 3. Homogeneity test result

Variable	Test Method	Levene Statistic	df1	df2	Sig.
Sustainable self-awareness	Based on mean	3.057	1	98	0.084
	Based on median	2.362	1	98	0.128
	Based on median (adjusted df)	2.362	1	79.348	0.128
	Based on trimmed mean	2.444	1	98	0.121
Environmental literacy	Based on mean	2.499	1	98	0.117
	Based on median	1.512	1	98	0.222
	Based on median (adjusted df)	1.512	1	97.19	0.222
	Based on trimmed mean	2.088	1	98	0.152

Mann–Whitney U tests were conducted to examine group differences in sustainable self-awareness across grade levels and gender. As presented in Table 4, no statistically significant difference was observed between 10th-grade and 11th-grade students (Asymp. Sig. = 0.619). In contrast, a significant difference emerged based on gender, Asymp. Sig.= 0.023). Meanwhile, the results for the environmental literacy variable are available in Table 5. As shown in Table 5, no statistically significant differences were identified between 10th-grade and 11th-grade students (Asymp. Sig. = 0.674). Similarly, no significant differences were found between male and female students (Asymp. Sig. = 0.915).

Table 4. Mann–Whitney U test result for sustainable self-awareness by grade and gender

Grouping variable	Group	Mann–Whitney U	Z	Asymp. Sig. (2-tailed)
Grade	10th-grade 11th-grade	1154.5	-0.497	0.619
Gender	Male Female	886.5	-2.277	0.023

Table 5. Mann–Whitney U test result for environmental literacy by grade and gender'

Grouping variable	Group	Mann–Whitney U	Z	Asymp. Sig. (2-tailed)
Grade	10th-grade 11th-grade	1181.5	-0.421	0.674
Gender	Male Female	1163	-0.107	0.915

The Mann–Whitney U test revealed a statistically significant difference in sustainable self-awareness between male and female students (U = 918.0, p = .021). The effect size was r = .24, indicating a small-to-medium magnitude of difference (Cohen, 1988; Field, 2018).

Table 6. Mann–Whitney U test result for sustainable self-awareness by gender

Variable	Group	U	Z	p	r (Effect Size)	Interpretation
Sustainable Self-Awareness	Male Female	918	-2.41	0.021*	0.24	Small–medium

Descriptive analysis demonstrated that the majority of students exhibited high levels of environmental literacy. Of the 100 respondents, 54% were categorised as “Very Good” and 28% as “Good”, indicating that 82% of participants possessed strong environmental literacy. Nevertheless, approximately 18% of students fell into the “Fair”, “Poor”, and “Very Poor” categories, suggesting the presence of persistent gaps that require targeted pedagogical interventions. The full distribution is illustrated in Figure 1.

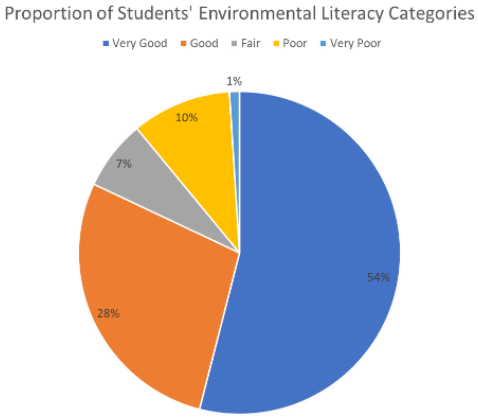

Figure 1. Distribution of environmental literacy categories

A similar pattern was observed for sustainable self-awareness. Most students were classified in the “Very Good” and “Good” categories, indicating a strong foundation of affective and reflective sustainability competencies. However, a smaller group of students remained in lower categories, highlighting the need for differentiated and targeted learning support. The distribution is presented in Figure 2.

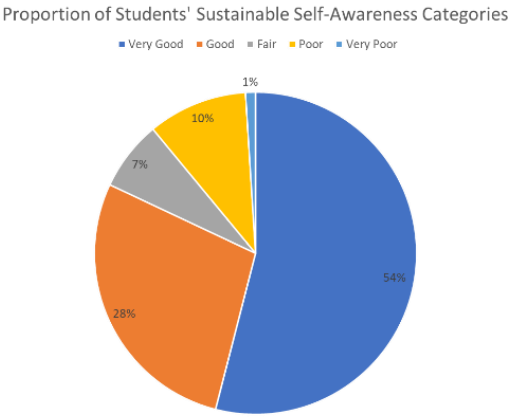

Figure 2. Distribution of sustainable self-awareness categories

Overall, the findings suggest that students demonstrate relatively homogeneous profiles of environmental literacy and sustainable self-awareness across grade levels and gender, except for gender-based differences in sustainable self-awareness. These patterns indicate that institutional factors, particularly the implementation of the Merdeka Curriculum and the Adiwiyata programme, play a more decisive role than demographic factors in shaping sustainability competencies.

These findings are consistent with (Cincera et al., 2025), who argued that environmental literacy is more strongly influenced by systemic educational design than by individual demographic differences. They are also aligned with the findings of Baga et al. (2022), which emphasised that environmentally oriented school cultures foster equitable learning engagement across diverse student backgrounds. Furthermore, the results support Holst et al., (2025) who stressed that sustainability education should be continuous and integrated across all levels of schooling to cultivate deep, reflective learning experiences.

The results have important implications for vocational school teachers. The relatively high levels of environmental literacy and sustainable self-awareness provide a strong foundation for the development of more advanced, reflective, and action-oriented learning strategies. Teachers can use these findings to design contextual, project-based learning activities that integrate chemical and biological concepts with local environmental issues, while simultaneously encouraging personal reflection on lifestyle choices and ecological responsibility.

Given the absence of significant differences between 10th-grade and 11th-grade students, spiral curriculum designs can be effectively implemented, whereby foundational experiences in 10th-grade are deepened through reflective and critical learning activities in 11th-grade. Teachers are also encouraged to facilitate ethical discussions, field-based observations, and reflective practices that are inclusive of all students, regardless of gender. Such approaches would strengthen holistic sustainability education and support the development of environmentally responsible vocational graduates.

CONCLUSION

This study concludes that students generally demonstrate high levels of environmental literacy and sustainable self-awareness, indicating that the implementation of the Merdeka Curriculum and the Adiwiyata programme has been effective in fostering sustainability-oriented competencies, with no meaningful differences observed between grade levels and only limited differences by gender. These findings logically reflect the research objectives and are based on empirical evidence obtained from the data. However, the results should be interpreted cautiously due to the study's limitations, including the restricted sample scope, the focus on limited demographic variables, and the emphasis on cognitive aspects of environmental literacy without in-depth qualitative exploration. Future research is therefore encouraged to involve more diverse school contexts, integrate affective and qualitative dimensions, and examine broader influencing factors such as family and socio-economic background to provide a more comprehensive understanding of sustainable education development.

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BIOGRAPHIES OF AUTHORS

Yashinta Suci Kurniati is a master's student in Chemistry Education at Universitas Negeri Yogyakarta. Her research interests include project-based chemistry learning and chemical entrepreneurship. Her thesis currently focuses on trends in chemical environmental literacy and sustainable self-awareness based on grade level and gender. She can be contacted at the following email address: yashintasuci.2021@student.uny.ac.id

Prof. Dr. Sri Handayani, M.Si., is a professor in the Department of Chemistry Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta. Her research focuses on organic synthesis chemistry. She can be contacted at the following email address: handayani@uny.ac.id