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EVALUATING STEM-BASED REFORM TEACHING OBSERVATION PROTOCOL TO ENHANCE STUDENTS' COMMUNICATION SKILLS IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT GOALS IN SCIENCE LEARNING

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ABSTRACT

STEM-based teaching can be challenging as it requires the integration of science, technology, engineering, and mathematics in one lesson. Selecting an engaging topic involving students' experiences with current issues can be helpful in this regard. The Sustainable Development Goals (SDGs) are a relevant and impactful topic that may facilitate students' communication skills. This research aimed to evaluate the Reform Teaching Observation Protocol (RTOP) using a STEM approach to address SDGs and to improve students' communication skills. This research employed quantitative approach to measure an instrument for teaching STEM through the lens of SDG-related issues in the science learning. The process included creating the items, reviewing the RTOP, and testing these items with participants who are the representatives of the intended users. Exploratory Factor Analysis (EFA) was used to measure the structural correlations among items and topics and assess their internal reliability. The results identified five factors in the RTOP evaluation: developing scientific topics (8 items), skills in conveying specific examples (5 items), use of scientific language terms (2 items), representative forms of scientific evidence (2 items), and involving the STEM approach (2 items). The reliability of the RTOP, as indicated by Cronbach's Alpha, was 0.818. Based on these findings, the research concludes that the RTOP is both valid and reliable, and can be implemented in the classroom to teach STEM and SDGs, thereby improving students' communication skills.

Keywords: communication skills; STEM; RTOP; science learning; SDGs

INTRODUCTION

Recently, science education has evolved to incorporate teaching approaches that involve real-world phenomena. These approaches are implemented because teaching science is not only about transferring knowledge but also about engaging students in solving problems relevant to human life (Chaigneau et al., 2019; NGSS, 2013). Students are facilitated to develop evidence and construct arguments to demonstrate the reliability of scientific knowledge (Putra et al., 2024). By using approaches that align with students' needs, there is an opportunity for students to connect scientific knowledge with global phenomena, such as global warming. Furthermore, through developing skills to gather evidence from scientific activities, students can communicate scientific concepts effectively and accurately.

Communication plays a crucial role in the development of scientific knowledge (Bautista et al., 2022; Contera, 2021). Scientists use effective communication to disseminate their findings and gain societal acceptance for their discoveries (Beardsworth, 2020). In science education, it is essential to develop students' communication

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skills so they can share their ideas and knowledge, particularly in scientific concepts (Yustika et al., 2023). By honing these communication skills, students have the opportunity to promote their findings during scientific activities such as experiments, investigations, and fieldwork (Thiel et al., 2023). After discovering new concepts, they can share their insights with others to receive suggestions and feedback, thereby enhancing their understanding of scientific knowledge.

However, students' communication skills have been reported to be low in science education. Studies on communication skills, particularly scientific communication, indicate that junior high school students struggle to effectively communicate their ideas (Khasanah et al., 2023). Additionally, observations of students' collaborative activities reveal that their ability to communicate scientifically about science concepts is also lacking (Putra et al., 2023). Furthermore, a survey developed in previous research highlighted that effective communication remains a significant challenge to be improved in science education, especially among junior high school students (Fatihah et al., 2022).

Globally, previous research has specifically investigated scientific communication skills among students. Shivni et al. (2021) reported that 40% of junior high school students demonstrated a low level of communication skills. Similarly, other researchers have found that students' communication skills in biology education averaged 43.3 out of 100 (Mataniari et al., 2020), indicating a need for improvement in this area. Furthermore, Yildiz & Guler Yildiz (2021) reported that students scored only 57.3% in presenting scientific ideas, further highlighting the deficiency in communication skills related to science learning. These findings underscore the urgent need to enhance scientific communication skills among junior high school students.

Research on communication skills has been conducted by several researchers to improve students' ability to communicate their ideas. Previous studies indicate that the key indicators of communication in science education are the ability to argue, fluency, understanding of science concepts, and the ability to respond to opinions (Siregar & Siregar, 2022). Furthermore, communication skills have been developed through both oral and written communication in various studies (Mercer-Mapstone & Kuchel, 2015; Mercer-Mapstone & Matthews, 2017). However, previous research has not focused specifically on the science concepts themselves as indicators of communication skills. There is a need for more research on how well students grasp and communicate scientific concepts within science education.

Kulgemeyer (2018) criticized the approach to scientific communication skills among science students, arguing that these skills must be differentiated. The focus of scientific communication should be on the relationship with specific topics and mastery within science education. In science education, effective scientific communication emphasizes integrating these skills into learning and using performance tasks to assess the quality of scientific content (Shivni et al., 2021). Nevertheless, the indicator on the specific in scientific communication skills was lack to be explored. Additionally, teachers also have difficulty to train students in communication scientifically (Cian & Cook, 2020).

To train communication skills in science education, students should be engaged in learning processes that involve scientific activities to solve real-world problems (Elmer, 2024). One effective approach that integrates real-world problems is STEM education. STEM is a learning approach that combines science, technology, engineering, and mathematics (Hudson et al., 2015; Moore et al., 2014). STEM education provides students with the opportunity to develop solutions to real-world problems scientifically (Roehrig et al., 2021). Furthermore, STEM education allows students to express their ideas based on their experiences, collect scientific evidence, and present their ideas to be accepted by other students.

Bringing STEM education into the classroom requires careful selection of topics, which becomes a crucial issue for teachers. The topics must connect with problems that students experience, be viewed from multiple disciplines, and motivate students to learn science intensively (Clark et al., 2022). However, selecting STEM topics in the classroom can be challenging for teachers due to the difficulty of integrating different disciplines (Nagdi et al., 2018). Additionally, the novelty of the problems presented to students is an important consideration. When teachers focus too much on the problem, students may lose sight of the underlying science concepts (Putra & Kumano, 2018). Conversely, when teachers emphasize science concepts, students may miss out on the engineering and design context (Sulaeman et al., 2021). This balance is essential for effective STEM education.

Integrating the issue of globalization across disciplines is necessary to introduce to students (Rotger et al., 2019). The Sustainable Development Goals (SDGs) are supported by many countries to ensure a high quality of life in the future (Zabaniotou, 2020). Incorporating the SDGs into science education is relevant to addressing biosphere issues and mitigating global warming. Introducing SDGs to students will also raise their awareness of the importance of maintaining a stable and better environment (Clark et al., 2022).

To facilitate the implementation of STEM teaching, there is an urgent need to develop a teaching protocol that integrates the STEM approach with SDGs issues (Ong et al., 2024). This teaching protocol is designed for use in teaching practices, specifically to teach STEM using SDGs issues to improve scientific literacy (Albareda-Tiana et al., 2024). The protocol should help pre-service science teachers teach science content effectively. The Reform Teaching Observation Protocol (RTOP) in STEM using SDGs issues is one tool to aid pre-service science teachers in teaching STEM in the context of SDGs, thereby improving students' communication skills effectively (Martín-Sánchez et al., 2022). The organization of the RTOP is based on the characteristics of STEM so that SDGs issues can be taught to enhance scientific communication skills.

This research aims to evaluate the Reform Teaching Observation Protocol (RTOP) within the framework of the STEM approach, specifically addressing Sustainable Development Goal (SDG) issues. The primary objective of implementing RTOP is to enhance students' scientific communication skills, particularly in the context of SDG number 14, which pertains to life below water and encompasses relevant scientific concepts (Jongwon et al., 2014). The study explores two key research questions: How was expert validation conducted for developing the RTOP based on integrating SDGs and STEM to improve students' communication skills? Additionally, how was the validation and reliability of the RTOP assessed in the context of integrating SDGs and STEM to enhance students' communication skills?

Roehrig et al. (2021) integrated STEM characteristics into the RTOP to effectively teach STEM in the classroom. Additionally, (Becerra et al., 2023) developed the RTOP to evaluate teachers' practices in mastering science within STEM subjects. However, the integration of the RTOP in STEM education using specific topics such as SDGs has not been widely implemented in the classroom. This research presents a novel approach by developing an RTOP that not only focuses on STEM activities but also incorporates specific topics to support the SDGs. The ultimate goal of using this RTOP is to improve students' scientific communication skills. This study aims to bridge the gap by integrating SDG issues into STEM education through a validated and reliable RTOP, thereby enhancing the overall teaching and learning experience and contributing to the development of students' communication skills in scientific contexts.

METHODS

This research employed a quantitative approach, focusing on measuring the teaching observation protocol. The methodology followed the Benson & Clark (1982) model. This model was selected because it is suitable for measure the instruments to evaluate the RTOP to be valid and reliable. The process was divided into two stages: identification and testing. During the identification stage, a draft of the RTOP was created, consisting of various items reviewed by experts. The testing stage involved piloting the RTOP with participants to assess its effectiveness and gather results.

Identifying the RTOP involved ensuring it aligned with its intended purposes and its application in teaching implementation. The RTOP was developed based on the STEM education framework and the SDGs program, both related to science content. Furthermore, the RTOP also focuses on improving students' scientific communication skills specifically. Therefore, the hypothesis of the RTOP was developed based on the concept of integrating STEM and SDGs issue to improve students' communication skills. The hypothesis of the items was developed based on the representation of five factors and 39 items.

Once the RTOP was developed, its items were evaluated by five experts in the STEM and SDGs areas. The evaluation criteria covered science content, language, and item usability. This stage aimed to ensure that the instrument accurately reflected the integration of SDGs and STEM and was clear and practical for teaching purposes. This evaluation also helped address the first research question regarding the expert and construct validity of the instrument for assessing scientific communication skills of pre-service science teachers in the context of climate change.

To answer the second research question, this study employed an exploratory design aimed at developing a measurement tool to assess the ability of pre-service science teachers to teach science using the STEM-SDGs approach. The goal was to enhance the scientific communication skills of junior high school students. Exploratory research involves investigating a topic to generate insights and hypotheses.

The selection of participants was based on two universities in Indonesia, using purposive sampling. The criteria focused on students in their third or fourth year of a bachelor's degree program, primarily in science-related fields. The total sample included 400 pre-service science teachers, following the recommendation by Goretzko et al. (2021) that suggests a minimum sample size for conducting exploratory analysis. Detailed demographics of the participants are provided in Table 1. This comprehensive approach ensured a robust evaluation of the instrument's effectiveness across different educational contexts.

Table 1. The demography of participants

PSTs Background	N participants
Physics Education	100
Biology Education	100
Chemistry Education	100
Science Education	100
N participants total	400

The instrument developed for this study was the Research Teaching Observation Protocol (RTOP), which was crafted based on the STEM-SDGs framework (see appendix A). The characteristics of the STEM and SDGs issue framework were derived from five key topics. These topics and their corresponding items are detailed in Table 2. (Items described in the appendix A in detail)

Table 2. Topic N-items in the RTOP STEM-SDGs to improve students scientific communication skills.

Factor	N items
Developing scientific topics based on the conditions of SDGs goal 14	9
Skills in conveying specific examples of natural phenomena	8
Use of scientific language terms in the field of science	8
Representative forms of scientific evidence findings in science studies	7
Involve STEM approach to solve the real-world problem	7
Total of Nitems	39

Data were collected using survey methods. In the expert validation phase, five experts completed a survey form based on four criteria, rated on a Likert scale from 1 (not valid) to 5 (strongly valid). This approach provided a systematic evaluation of the RTOP's content validity, ensuring that the instrument effectively integrated SDGs and STEM elements to enhance scientific communication skills. For the second research question, pre-service science teachers watched three videos, each 20 minutes long. After viewing each video, they completed a form based on the developed RTOP. This data collection process was conducted over a period of three weeks.

Once the data were collected; it was analyzed using Exploratory Factor Analysis (EFA) to measure the structural correlations among items and topics and to evaluate the internal reliability of these items. The indicators from the EFA process are detailed in Table 3. These indicators were used to compare the results and ensure that the RTOP is both valid and reliable (Bazan, 2023; Finch, 2023).

Table 3. The criteria for analyzing of EFA based on the RTOP developed

Indicator	Decision to be accepted
Sample Size	Min 400
Kaiser Mayor Olkine Measure	Should be > 0.5
Batlett's test of sphericity	Significant ($p < 0.05$)
Eigenvalue	Should be > 1
Screen Plot	Express the number of factors
Factor Loadings	Should be > 0.4
Total variance explained	Percentage factors more than 60%
Internal Consistency	More than 0.7

RESULTS AND DISCUSSION

The purpose of this research was to develop the RTOP, integrating SDGs issues with a STEM approach to improve students' communication skills. The validation process covered two types: expert validation and construct validation. The final stage in the development process involved evaluating the RTOP's reliability, demonstrating that the RTOP is consistent and suitable for general use in teaching SDGs through the STEM approach to enhance students' communication skills.

The expert validation demonstrated the accuracy of the content, language, SDGs issues, and STEM activities in the RTOP. The results indicated that the RTOP is suitable for proceeding to construct validation.

Table 4. The result of experts' validation

Criteria	x	Decision
Content	89	Strongly valid
Language	82	Valid
SDGs issue	95	Strongly valid
STEM activity	94	Strongly valid
Total	90	Strongly valid

Table 4 explains the level of validation for the developed RTOP. The RTOP aligns with the characteristics of both the SDGs and STEM educational approaches. Furthermore, the content areas in the RTOP focus on improving students' scientific communication skills. According to Table 5, language received the lowest score in expert validation. Based on these suggestions, the items were evaluated and the language was revised to be easier to understand and read.

Based on the expert validation results, the RTOP received a total score of 90 in the "strongly agree" category. This indicates that the RTOP can proceed to the construct validity process. The RTOP was evaluated using Exploratory Factor Analysis (EFA) to assess its consistency in the learning process. The adequacy of the data sample was evaluated through the KMO and Bartlett's tests. The results of these tests are presented in Table 6.

Table 5. KMO and Batlet test results

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure (KMO) of Sampling Adequacy.		.809
Bartlett's Test of Sphericity	*Approx. Chi-Square*	2317.723
	df	741
	Sig.	.000

The Kaiser-Meyer-Olkin (KMO) measure yielded a value of .809, which is close to 1. This suggests that the sample size was sufficient for conducting EFA. Additionally, the significance level of Bartlett's test of Sphericity was less than 0.005. This indicates that the correlation matrix produced significant results and was not an identity matrix, thereby supporting the suitability of the data for factor analysis.

Figure 1 illustrates the eigenvalue plot, which depicts the factor topics recommended based on the data. Points above the value of 1 on the plot indicate the number of factor recommendations. Total number of the

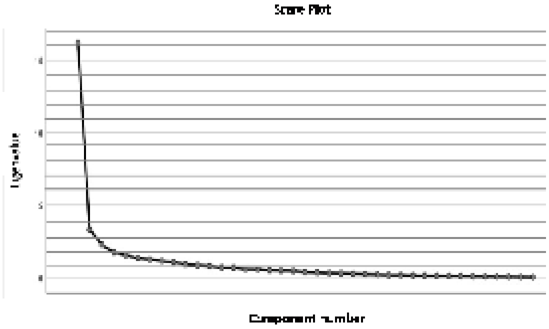

Figure 1. The scare plot of component number in the RTOP items.

Based on Figure 1, the factor plots initially recommended nine factors. However, to test the hypothesis that developing the RTOP for teaching SDGs issues using the STEM approach involves five factors. A confirmation of the hypothesis is needed to assess the reliability of these factors. This hypothesis is grounded in the theoretical framework of the STEM and SDGs project.

Before testing the reliability of the RTOP, the factor loadings for each item were examined to assess the correlation between the items and their respective factors. This evaluation, detailed in Table 6, serves as a matrix recommending the factors.

Table 6. The factor rotation of items in the RTOP

Factor	No item	Factor Loading
1	1	.867
	2	.845
	3	.834
	4	.826
	5	.790
	6	.776
	7	.775
	8	.699
	9	.687
2	10	.699
	11	.818
	12	.778
	13	.778
3	16	.713
	17	.783
4	20	.760
	27	.754

Factor	No item	Factor Loading
5	30	.753
	25	.689
Total Variance explain		76.153%

Table 6 indicates that there were five factors that can enhance students' communication skills using STEM in relation to SDG issues. The total variance explained in table 7 showed an agreement of 76.153%, suggesting that the model is suitable for improving students' scientific communication skills. To evaluate the consistency of the items in the RTOP, Cronbach's alpha was used to investigate internal reliability. The results of the internal reliability analysis are shown in Table 7.

Table 7. The internal reliability in the evaluation using Cronbach's Alpha

Factor	N items	Cronbach's Alpha (α)	Decision
1	8	.944	Reliable
2	5	.890	Reliable
3	2	.787	Reliable
4	1	Error	Not reliable
5	1	Error	Not reliable
6	2	.673	Reliable
7	2	.795	Reliable
8	1	Error	Not reliable
9	1	Error	Not reliable

Based on the evaluation of the items and their alignment with the factors, it is recommended that the items be organized according to the five identified factors. The average reliability score using Cronbach's Alpha (α) is ($\bar{x}$ α=0.818). The comparison between the hypothesized items and the results is presented in Table 8.

Table 8. The comparation items between the hypothesis and result

Factors	N hypothesis	N result
1	9	8
2	8	5
3	8	2
4	7	2
5	7	2

The RTOP was evaluated using two ways of validation. The experts' validation showed that the RTOP was strongly valid and can be used in piloting project to explore the correlation between items and factors developed in the framework of RTOP based on the SDGs issue and STEM approach to improve students' communication skills. The RTOP followed the theoretical framework for developing instruments, consistent with previous research on creating research instruments. Pérez-Rivas et al. (2023) explained that the expert's validation was crucial steps to develop an instrument before the instruments ready to used mainly in education field. Furthermore, the expert's validation also including language, content, and agreement between items and the purpose (Putra et al., 2023). The strong validity demonstrated by the RTOP indicates that it is ready for the next step, which involves piloting the instrument in the field to teach SDGs issues using the STEM approach (Waltner et al., 2019). Expert validation also confirmed that the RTOP is credible and effective for implementation in construct validity (Reis et al., 2024)

Evaluation of the RTOP using Exploratory Factor Analysis (EFA) demonstrated effective measurement with a sample of more than 400 participants (Goretzko et al., 2021). The purpose of using EFA was to estimate the number of factors that influence teachers' ability to teach using SDGs issues in the classroom and to assess students' ability to solve problems using the STEM approach (Haslbeck & van Bork, 2022). The EFA evaluated the RTOP through component validation (Diemer et al., 2017), identification of latent dimensions (Carragher et al., 2016), and data summarization (Watson, 2017). This approach ensured that the RTOP effectively evaluates teachers' ability to teach science using SDGs issues and the STEM approach. Through EFA, evaluation items were refined, making the construct of the RTOP robust and effective (Izadi-Avanji et al., 2024).

The development of the teaching observation protocol has been arranged based on the STEM characteristic that developed by Roehrig et al. (2021). The SDGs was issue that interconnected with the recent phenomena in the world. Mainly in Science learning SDGs was also include the biosphere problem in the climate change so that in the RTOP supposed to interconnected with the SDGs issue. The RTOP demonstrated teachers' ability to teach science using SDGs issues that support climate change education. This approach helps both teachers and students understand the goals of sustainable development in addressing climate change (Ong et al., 2024; Scharfenberg & Bogner, 2019). These results are supported by previous research, which emphasizes the importance of education in promoting human sustainability in the context of climate change (Walsh et al., 2021).

The SDGs play a crucial role in integrating real-world challenges into learning strategies in science education (Martín-Sánchez et al., 2022). The RTOP was developed to provide opportunities for students to explore problems within the biosphere, specifically targeting SDG number 14. In line with these goals, the RTOP encourages students to become more aware of and actively solve problems related to SDG issues (Zwolińska et al., 2022). The results indicated that integrating SDG issues serves as a bridge for teachers to connect science concepts with STEM activities (Guo et al., 2024). The factor recommendations based on the EFA suggested nine factors; however, only five were found to be valid and reliable. These factors focused on the hypothesis that teaching using a combination of SDGs issues and the STEM approach improves scientific communication. The hypothesis was proven, indicating that incorporating SDGs into the learning process is effectively supported by using learning approaches such as STEM education (AlAli et al., 2023).

Based on the SDGs problems, students were given the opportunity to solve these issues using a STEM education approach. Through STEM education, learning begins with students gaining experience in scientific concepts and engineering processes (Lin et al., 2021). The RTOP integrates SDGs issues to address real-world problems, using STEM as a guide for problem-solving in the learning process. Additionally, STEM activities provide students with opportunities to explore scientific concepts and design solutions that support SDG programs. This approach not only enhances students' problem-solving skills but also raises their awareness of societal and environmental issues, encouraging them to contribute to a well-conditioned society and environment (Islam & Jirattikorn, 2024; Ramos-Gavilán et al., 2024).

Additionally, the development of the RTOP involves the engineering process. This process helps students take steps to gather scientific evidence and provide reasons to communicate their arguments scientifically (Putra et al., 2024). Engineering emphasizes collaboration, encouraging students to work together to solve problems and share their ideas (Putra et al., 2023). Moreover, through the RTOP, teachers facilitate experiences where students design, test, and decide on solutions that align with and support the SDGs program (Putra et al., 2023; Sulaeman et al., 2021).

The implementation of RTOP in the science classroom provides evidence that it has shifted traditional teaching methods (Großmann & Krüger, 2024; Walker et al., 2024). The RTOP has proven to be a valid and reliable tool for teaching SDGs issues using a STEM education approach. The construct validation of the RTOP supports the idea that it enables students to communicate their ideas scientifically. Students form arguments based on their experiences and use evidence to directly support their ideas (Yustika et al., 2023). In the communication, RTOP follow the concept of scientific communication that develop by Kulgemeyer (2018). Scientific communication shows the students ability to support the solution that support by data and evidence that match with the RTOP that students give a performance to use integration of STEM concept to support the SDGs program.

The development of RTOP using STEM and SDGs is still in the piloting and modeling stages to teach the STEM approach. However, using this RTOP can strongly suggest that teachers incorporate novel issues in the SDGs program, helping students become communicators who can reason scientifically (Jongwon et al., 2014). In future research, this RTOP needs to be implemented for pre-service science teachers to practice delivering science concepts using the STEM and SDGs approach. After several pre-service science teachers use this RTOP, the Cronbach's kappa (κ) will need to be evaluated for interrater reliability (Becerra et al., 2023).

CONCLUSION

The aim of this study was to evaluate the RTOP for STEM education using SDG issues to improve students' communication skills. The results indicated that the RTOP was valid in terms of content, language, SDG issues, and STEM activities. Furthermore, the RTOP highlighted five key factors in its construction: development of scientific topics in SDGs, skills in conveying specific examples of natural phenomena, use of scientific language terms, representative forms of scientific evidence, and involvement the STEM approach. The RTOP was found to be valid and reliable ($\alpha = 0.818$), consisting of a total of 19 items.

The research highlights the impact of using the RTOP as an effective tool for evaluating pre-service science teachers when teaching science in the classroom. Teachers and pre-service science teachers should connect real-world problems to the application of science concepts, helping students understand the relevance of science in everyday life. Furthermore, incorporating scientific communication in science lessons allows students to organize and present their ideas clearly and logically, ensuring that their message is understood by the audience.

This study contributesin these two areas. First, for educators involved in STEM education in the science learning, the development of STEM learning is crucial to help students engage with real-world contexts. Integrating issues related to SDGs offers students the opportunity to become more aware of the global challenges. Second, for policymakers, the RTOP can be applied to evaluate both in-service and preservice science teachers, enabling them to effectively disseminate global issues to students.

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