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ORIGINAL ARTICLE

SOLO-based Formative Assessments in Teaching and Learning Earthquakes

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ABSTRACT

The study examined how well Structure of the Observed Learning Outcome (SOLO)-based formative evaluations might improve students' comprehension in the context of science education, with an emphasis on seismic events like earthquakes. Using a mixed-method research design, the study assesses students' entry understanding, how they advance through formative assessments, and how they consolidate their knowledge at the exit phase. Study findings revealed a significant difference between students' understanding ($t = 26.128$, $p = 0.000$) and high acceptance of SOLO-based assessments ($\mu = 4.47$, $SD = 0.42$). Simultaneously, qualitative insights shed light on emerging themes, emphasizing students' adoption of particular teaching strategies and cooperative learning approaches. The results highlight the pedagogical benefits of SOLO-based assessments and support their inclusion as a crucial element of contemporary science instruction. In addition, actionable suggestions are outlined for instructors and curriculum developers, focusing on incorporating visual aids and cooperative learning techniques. Although the study provides invaluable insights, it also recognizes its inherent limits and suggests directions for future research to build on and improve upon these findings.

KEY WORDS: Earthquakes; formative assessments; science teaching; SOLO taxonomy

INTRODUCTION

Science education is essential for countries hoping to advance their societies and technologies. Its fundamental ties to industry, technology, and culture highlight how crucial it is to determine a country's future (Department of Science and Technology-Science Education Institute & University of the Philippines National Institute for Science and Mathematics Education Development, 2011). Science education supports individual progress and advances society by fostering critical thinking, objectivity, curiosity, and ethical ideals in pupils. Science education is given top priority by universities all around the world, including those in the Philippines, because of its importance in producing people who can make educated judgments (De La Cruz, 2022). However, new tests, like the Programme for International Student Assessment (2022), show that the Philippines has a long way to go before reaching the levels of science literacy sought, highlighting the need for creative educational strategies.

Formative assessments are essential tools for improving teaching strategies in Earth Sciences. To be more precise, formative evaluations give educators and students quick feedback, which makes it easier to modify teaching strategies and accomplish learning objectives (Schildkamp et al., 2019). The Philippines is prone to natural disasters, particularly earthquakes, in areas such as Luzon, Visayas, and Mindanao; hence, teaching and understanding earthquakes needs to be done with special attention. In addition to enhancing academic understanding, this method equips students with the necessary abilities to handle earthquake situations safely (Subedi et al., 2020).

In light of this, immediate attention is needed to the earthquakes frequently occurring in the Philippines. Although students are familiar with the fundamentals of earthquake activities and preparedness, there needs to be a more thorough comprehension of seismic activity, fault movements, and associated scientific concepts Santini et al. (2018). Improving this knowledge is essential, mainly because nearby towns are at serious risk from earthquakes. As Subedi et al. (2020) pointed out, increasing Filipinos' scientific understanding of earthquakes might reduce the hazards connected to seismic disasters, protecting infrastructure and lives.

Even though science education is considered necessary, especially regarding earthquakes, a significant research gap still needs to be. Conventional teaching approaches provide a basis of information, but novel methods that can improve in-depth learning and overall comprehension still need to be thoroughly investigated. The Structure of the Observed Learning Outcome (SOLO) Model appears as a viable intervention for this gap. The SOLO Model, created by Biggs and Collis (2014), offers learners' replies an organized cognitive framework that divides them into five levels: Pre-structural, unistructural, multi-structural, relational, and

extended abstract. Teachers can acquire sophisticated insights into their student's comprehension levels using the SOLO taxonomy in the context of earthquakes. This allows them to modify their teaching strategies to meet the needs of individual students more effectively.

This study's primary goal is to maximize the use of SOLO formative assessments to improve earthquake-related teaching and learning activities. By concentrating on critical K to 12 curriculum competencies, such as comprehending fault motions, differentiating earthquake parameters, and interpreting seismic waves, this study aims to close current knowledge gaps and advance scientific literacy. This project aims to improve students' comprehension of earthquakes by applying SOLO-based evaluations methodically. This will give students the ability to react appropriately to seismic situations.

This study's importance goes beyond its immediate academic setting, with significant ramifications for science education within and outside the Philippines. Through assessing how well SOLO formative assessments work to teach and learn about earthquakes, this research offers insightful information that might improve pedagogical practices, influence educational policy, and promote a scientifically literate society. Investing in creative educational initiatives becomes essential as countries struggle with complicated issues like natural disasters like earthquakes. Therefore, the results of this study hold the potential to transform paradigms in science education by highlighting the incorporation of evidence-based strategies to foster knowledgeable, resilient, and empowered communities.

LITERATURE REVIEW

Structure of Observed Learning Outcomes

Developed by Biggs and Collis (1982), the Structure of Observed Learning Outcome (SOLO) Model provides a thorough framework for assessing and comprehending student learning in various fields. Fundamentally, the SOLO taxonomy examines the caliber of student answers and groups them into five groups: Pre-structural, relational, multistructural, unistructural, and extended abstract. Agustinsa et al. (2021) conducted a groundbreaking study that demonstrated the SOLO taxonomy's broad application in academic research and emphasized measuring student responses (Pegg, 2018). Similarly, Svensater and Rohlin (2022) revealed the transformative power of formative and summative tests based on the SOLO taxonomy. Their research showed that students' answers followed a developmental trajectory that started at the structural level and moved up to higher cognitive levels, such as the relational level. Furthermore, 86% of students acknowledged formative assessment's helpful role in their learning process.

Mulbar et al. (2017) carefully outlined several indications corresponding to each SOLO level to enhance the SOLO taxonomy's usefulness even more. Their research offered detailed insights into students' talents and cognitive processes, spanning from broad generalizations at the extended abstract level to incorrect conclusions at the pre-structural level. Moreover, the interaction between students' cognitive styles, field dependency, and independence explained different paths within the SOLO taxonomy, which improved its complex applicability even more. Agustinsa et al. (2021) and Mukuka et al. (2020) shed light on the SOLO taxonomy's potential as a diagnostic tool in the field of mathematics education, identifying areas of student difficulty and enabling pedagogical modifications. Their findings supported those of Claudia et al. (2020), highlighting how student responses changed throughout different SOLO levels and shedding light on the complex dynamics of mathematics understanding and problem-solving skills.

Beyond traditional disciplines, Rickles et al. (2013) and Lucander et al. (2010) explored dentistry education and social environments, respectively. Their research revealed the revolutionary effect of the SOLO taxonomy on the growth of critical thinking and involvement in deep learning. In particular, Lucander's et al. (2010) study showed higher learning outcomes due to increased student awareness and comprehension, demonstrating the SOLO framework's cross-disciplinary applicability. Furthermore, Prakash et al. (2010) explored the SOLO taxonomy's metacognitive implications and emphasized how important it is for improving students' cognitive organization and assessment readiness. Their results were in line with a more general agreement among students, who consistently favor the SOLO taxonomy's ability to improve academic achievement in various subject areas.

To synthesize, existing research highlights the SOLO taxonomy's versatile use in various academic domains, including the social sciences, dentistry, and mathematics. Although the current corpus of research provides vital insights into students' metacognitive improvements and developmental trajectories, there is still a noticeable vacuum regarding its applicability in Earth and Space Sciences. However, the currently available research highlights the SOLO taxonomy's revolutionary potential in promoting critical thinking, deep learning, and academic success, which calls for further investigation and incorporation into modern educational frameworks.

Formative Assessments in Education

The transforming impact of formative assessment on student learning and instructional efficacy has attracted significant scholarly attention. Formative assessment is an essential pedagogical strategy in contemporary education. Black and William's (2008) seminal work pioneered formative assessment's theoretical foundations, which conceptualized it as a triadic interplay among peers, teachers, and students. The teacher's deliberate planning of positive interactions in the classroom, which used students' emotional and cognitive frameworks to direct educational paths, was at the center of their discussion. In fostering student-centered learning environments, formative assessment is critical in providing scaffolding for subsequent inquiry tasks.

Irons and Elkington's (2021) later research projects clarified the complex dynamics of formative assessment by classifying its aspects into teacher, student, and peer domains. Their analytical framework, outlined specific roles for each dimension, from defining learning objectives to designing productive educational activities and promoting peer relationships. This distinction provides educators with a thorough road map by highlighting the diverse roles essential to practical formative assessment. In addition, Svensäter and Rohlin (2023) conducted an empirical investigation combining formative and summative assessment models using the SOLO taxonomy. Their study clarified the mutually beneficial relationship between different evaluation modes and their cumulative effect on students' cognitive growth. Their results demonstrated a clear path of improved comprehension, highlighting the critical role of formative assessment in promoting instructional quality and learner-centered outcomes.

Freislich and Bowen-James (2020) added to this empirical effort with a comparison analysis that pitted formative assessment-centric approaches against established summative assessment paradigms. His study uncovered notable differences in learning outcomes between cohorts exposed to dissimilar assessment approaches. In particular, cohorts that benefited from iterations of formative assessment and ongoing feedback systems performed better academically, confirming the transformative potential of formative assessment. Formative assessment effectively boosts academic achievements and promotes metacognitive awareness, as demonstrated by Wafubwa's and Csíkos (2022) paper, which supported these findings. This supporting data highlight the formative assessment's global application and significance as a pedagogical innovation catalyst, echoing previous studies such as Ozan and Kincal (2018). Furthermore, Tavdgiridze et al. (2020) emphasized the importance of careful preparation in formative assessment initiatives, promoting planned approaches catered to student's individual requirements, preferences, and learning styles. Their observations support the adaptive potential of formative assessment, enabling teachers to create engaging learning environments that support students' achievement and overall growth.

The current literature highlights formative assessment's transformative potential and critical role in promoting student-centered learning environments, improving academic achievement, and developing metacognitive awareness. Formative assessment is still essential to evolving pedagogical paradigms because it allows teachers to navigate educational environments skillfully, resulting in the best possible student results and pedagogical excellence.

Teaching and Learning Earthquakes

Because earthquakes dramatically affect infrastructure and populations, understanding them is crucial in earth sciences. Including earthquake studies in the curriculum emphasizes how important it is to promote awareness, readiness, and mitigation techniques. The K–12 curriculum's competencies definition is essential to earthquakes in science education. Three primary competencies are highlighted in the curriculum: Simulating fault movements, defining anatomical features, and explaining the importance of seismic waves. With the help of this systematic approach, students are better equipped to handle the complexity of seismic activities and develop a comprehensive understanding based on theoretical concepts and empirical data.

However, widespread misconceptions frequently obstruct the effectiveness of earthquake education, as shown by Francek (2013). His groundbreaking research exposed widespread myths about Earth's geological layers and earthquake mechanics, covering more than 500 geoscience errors. Specifically, myths linking seismic activity to weather or mythical origins highlight the importance of implementing focused pedagogical interventions. Due to these beliefs, education must move toward experiential learning, which gives students the tools to disprove falsehoods through critical analysis and empirical research. Wu et al. (2022) conducted an empirical investigation to support this academic discourse by examining the disaster awareness and mitigation measures of inhabitants in China's earthquake-prone regions. Their results show a clear relationship between catastrophe awareness and effective disaster preparedness. Significantly, the seismic disaster sparked increased awareness, highlighting the transformative power of hands-on learning and community involvement in building adaptive skills and resilience.

Subedi et al. (2020) conducted a comprehensive educational intervention in Nepalese schools, focusing on community involvement and earthquake preparedness, expanding this discourse to a global setting. Their empirical results highlight the critical role that educational interventions play in promoting community cohesion, increasing seismic awareness, and strengthening adaptive capacities. Still, ongoing danger perceptions demand ongoing educational efforts that support a lifelong learning and readiness process. The exploratory study conducted by Oven and Bankoff clarified the deficiencies in seismic awareness in rural post-Soviet Kazakhstan, highlighting the necessity of focused educational initiatives. Their findings highlight widespread knowledge gaps and fear related to seismic dangers, highlighting the need for extensive educational measures and community outreach programs.

The existing research highlights the variety of opportunities and challenges of teaching about earthquakes. Structured curricula and pedagogical interventions provide a solid foundation, but widespread misunderstandings and knowledge gaps call for focused approaches, community involvement, and experiential learning programs. Since earthquakes are a significant global concern, promoting earthquake awareness, preparedness, and resilience is crucial. This calls for cooperative efforts by community, government, and education stakeholders.

METHODOLOGY

Research Design

This study is used a quasi-experimental research design to evaluate the effect of SOLO-based formative assessment on

students' comprehension of earthquakes. This design aims to enable a systematic comparison to ascertain whether or not SOLO-based approaches notably improve students' understanding. Students' initial and final test scores were compared through statistical procedures to determine how much their knowledge had improved. To supplement the quantitative approach, qualitative procedures entailed interviewing participants to gather their viewpoints and experiences about assessments based on SOLOs. Following transcription, these interviews were subjected to in-depth theme analysis, providing detailed insights into the students' educational experiences.

Research Environment and Respondents

The study occurred in a secondary school located north of Cebu, Central Visayas, Philippines. The school serves 466 junior and senior high school students, creating a conducive learning environment. Interestingly, the junior high school portion is divided into two parts, guaranteeing students specialized and concentrated education.

The study's main participants were 60 Grade 8 pupils from the previously mentioned school. Universal sampling was used to carefully choose these participants, focusing on students present every day from the 1st day of implementation to the end of the study. These 60 respondents were selected from 82 students enrolled for the 2023 – 2024 academic year based on their capacity to participate in various study tools, such as formative assessments, acceptance surveys, post-tests, and pre-tests. The participants include 39 females and 21 males, aged between 13 and 15 years. These demographics ensure a diverse yet focused lens through which the study aims can be comprehensively addressed.

Research Instruments

The study employed three research tools. First and foremost are the 30 multiple-test items comprising the teacher-crafted pre-test and post-test (Appendix A). Based on the desired capabilities, these products appeal to both basic and advanced levels of learning, ranging in complexity. This instrument was validated by three experts in the field, including a college Earth and Space professor, a Science master teacher, and a data analyst. Once validated, the tool was pilot-tested to 30 students in a nearby school. The resulting Cronbach's alpha was 0.78, indicating a good reliability level.

Another tool was the worksheet designed by the teacher for SOLO-based formative assessments. Divided into three separate worksheets, each corresponds to a particular competency, the study has revealed. Every worksheet in this structure has three components: a stem, an illustrative element, and three questions (Appendix B). These questions have a novel design: The first question is meant to provoke a *unistructural response*, requiring a single, precise response. On the other hand, the following question calls for a *multi-structural* approach, requiring a multipronged answer to represent its intrinsic complexity fully. This series ends with a question that requires *relational skills* and asks students to identify and explain relationships between various components. Even though each question has a specific response standard, it is still open-ended, so students may naturally go toward more extended responses that demonstrate more sophisticated thinking than they may have first thought. The same experts validated these SOLO-based formative assessments, and an interrater reliability kappa of 0.70 was obtained. This value meant that the validators had good agreement with their responses on the formative assessments.

Moreover, an acceptability survey has been developed to gather information about students' perceptions and attitudes toward the SOLO-based formative assessment system. A 5-point Likert scale is used in this survey, with 1 signifying the least amount of agreement and 5 the maximum. This survey, which consists of 15 different statements, aims to determine how students feel and what they have experienced regarding the use and effectiveness of SOLO-based formative assessments in the classroom (Appendix C). This tool was validated and pilot-tested to the same class as above, gaining an overall Cronbach's alpha of 0.73. This value signified a good, reliable tool.

Furthermore, the semi-structured interview guide (Appendix D) complemented the structured instruments. The interview followed a set of structured questions to obtain firsthand information from students about their experiences navigating and responding to the formative assessments based on firsthand insights, adding a rich qualitative dimension to the research project. The interview questions were validated by the same experts above.

Data Gathering Procedure

The first step in the data-gathering process for this study was obtaining the required research clearances, ensuring that ethical standards were always maintained. After this initial stage, the pre-test was distributed as part of the research to gauge students' baseline comprehension. This assessment was given to each of the Grade 8 students, allowing for a thorough analysis of the students' preliminary comprehension of earthquake-related competencies. These pre-tests were carefully examined and documented when finished, providing the baseline information needed to determine the students' entry scores.

Following the pre-testing phase, students were placed in an organized learning environment that combined talks and practical exercises focused on the three earthquake-related targeted competencies. Every week for 3 weeks, a whole week was devoted to exploring a particular competency in depth. Using materials from the learners' curriculum, these interactive workshops were enhanced with PowerPoint presentations and valuable exercises. Every instructional week, Fridays were set aside to administer SOLO-based formative assessments. This allowed teachers to continuously assess students' growing comprehension and make necessary adjustments to their instructional strategies. These tests, which consisted of three questions, allowed students to express how their knowledge and understanding changed over time.

Afterward, the research moved into its final data collection phase. The post-test was administered to measure the conceptual growth attained and served as an evaluation tool for student progress and the effectiveness of the SOLO-based formative assessment. Simultaneously, a survey was distributed to students to gather information regarding their perspectives and attitudes to the SOLO-based approach. Moreover, a semi-structured interview was conducted with a chosen group of 10 students to obtain a deeper and more complex insight into the student experience. After receiving the data, the quantitative measurements were subjected to rigorous statistical analyses, and the qualitative insights were carefully examined to identify recurring themes and patterns. This process resulted in a thorough comprehension of the study's findings.

Data Analysis

Initially, the pre-test and post-test datasets and the SOLO acceptability survey were subjected to a Shapiro–Wilk test to check for normality. The obtained p-values of less than 0.05 showed that the data sets had a normal distribution. After normality was confirmed, parametric tests were considered suitable for data analysis. The student's performance and acceptance levels were described and analyzed using descriptive statistics, including means and standard deviations. A comparison analysis of pre-test and post-test scores was conducted through a paired sample t-test. Using this statistical procedure, it was possible to determine whether any variations between the pre-test and post-test scores were statistically significant or just the result of random variation. All statistical analyses were conducted with a 95% confidence level throughout the investigation. Results with p-values less than. 05 were deemed to be statistically significant.

The qualitative data obtained from the interviews held significant value in addition to quantitative analyses. Every interview session was meticulously transcribed to guarantee accuracy. The transcriptions were then subjected to Braun and Clarke's (2006) thematic analysis. This method offered detailed insights into participants' experiences, opinions, and thoughts about the SOLO-based formative assessment strategy, making it easier to find, analyze, and interpret patterns or themes within the qualitative data.

RESULTS AND DISCUSSION

Students' Entry Understanding of Earthquakes

The students' entry-level understanding of earthquakes is presented in Table 1.

Their pre-test results in Table 1 indicated that 94.92% of students started the study with an inadequate understanding of the fundamental abilities associated with earthquakes. With $\mu = 11.22$ and $SD = 4.31$, the student's baseline level of understanding appears to be very low. These results are especially concerning in light of the student's geographic location; despite living in an earthquake-prone area, they lacked basic seismic understanding. This lack of knowledge is consistent with findings by Oven and Bankoff (2020), who discovered unexpected apathy and low awareness among Kazakh citizens living in earthquake-prone areas. Similarly, Subedi's et al. (2020) study in Nepal found that students had an unsettlingly low awareness of the likelihood of earthquakes and the risks accompanying them. Interestingly, Subedi's analysis revealed that, based on myths, 7% of students had misconceptions about earthquake phenomena.

This lack of understanding has implications, including societal and political issues. A lack of basic understanding of earthquakes puts communities and infrastructure at serious risk and endangers people's safety. The results of this study support Oven's and Bankoff (2020) claim that earthquake risk reduction (ERR) education merits serious consideration. Looking more closely, the disruptions brought on by the recent pandemic may be one reason contributing to this educational deficit. Students may have suffered significant learning losses during this time due to the switch to modular learning methodologies and decreased teacher–student interactions, especially in areas like earthquake education. As a result, the study emphasizes how critical it is for nations like the Philippines to implement extensive earthquake education programs. According to Wu et al. (2021), such programs would provide citizens with essential information and allow communities and governmental entities to develop well-informed, long-term plans for risk reduction and catastrophe preparedness.

Formative Changes in the Conceptual Understanding of Earthquakes

Changes in students' levels of understanding occurred during the implementation of SOLO formative assessments. Figure 1

Table 1: Students' entry-level understanding of earthquakes

Level	n (%)	Overall mean (SD), Transmuted score	Overall level
Fairly satisfactory	3 (5.09)	11.22 (4.31), 69.07	Did not meet expectations
Did not meet expectations	56 (94.92)		

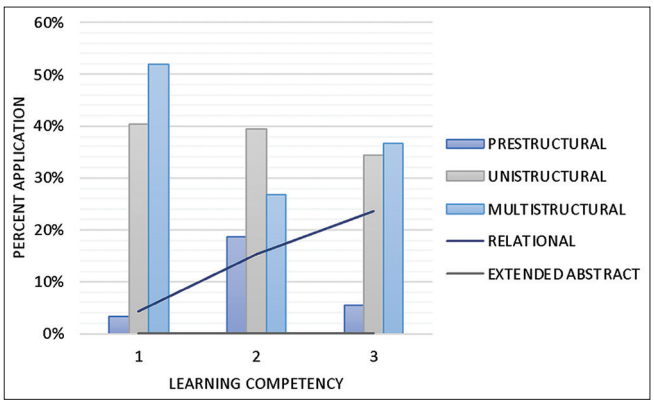

Figure 1: Changes in the levels of understanding according to SOLO taxonomy

shows the percent application of the different levels across the learning competencies.

According to Figure 1, the SOLO taxonomy thoroughly comprehends the student's knowledge about earthquakes. Just 3% of pupils had a pre-structural understanding at the beginning, indicating a minimal or nonexistent understanding of the subject. On the other hand, a significant 40% showed unistructural understanding, and the majority – 52% – showed multistructural understanding. These numbers, especially the pre-structural ones, show that although pupils have advanced past the most basic levels, there is still a sizable knowledge gap in the fundamentals.

Examining the competencies in detail, the responses from students provide light on their cognitive processes. For example, student responses ranged from relational to unistructural in the first competency. Here, students demonstrated a range of talents, from giving isolated facts to making connections between different ideas. These findings are consistent with earlier studies, like those by Ewen (2020), Valeeva et al. (2023), which highlight the value of model-based instruction in improving students' comprehension of scientific ideas. The practical process of building models has enhanced students' understanding during class discussions, which allowed them to envision and process complicated geological processes.

However, in the second competency, an intriguing change was noticed. A discernible rise in pre-structural answers raises the possibility that students have difficulty extracting pertinent information from certain situations. Claudia et al. (2020) confirms this pattern by pointing out that students occasionally tend to reply based on surface-level clues rather than going deeper into the subject's intricacies. Despite this, most demonstrated multistructural comprehension, demonstrating the capacity to recognize and link several earthquake-related ideas. Bein (2019) and Hailikari et al. (2008) emphasize how important it is for students to improve their fundamental knowledge since they recognize that prior information plays a critical role in shaping students' conceptual grasp.

A positive pattern started to develop by the third competency. Pre-structural understanding was significantly reduced, but multistructural and relational understandings increased. These developments highlight the advantages of iterative SOLO-based assessments and discussions, which support students' transition from basic to more complex knowledge structures. This progression toward relational awareness is congruent with studies by Svensäter and Rohlin (2023), highlighting the transforming power of regular participation in SOLO-based tasks. It is remarkable that although students have advanced to relational levels, most of them still struggle to reach the extended abstract level. This is consistent with findings from Agustinsa et al. (2021) and Mulbar et al. (2017), which indicate that achieving the upper levels of the SOLO taxonomy requires a deep dive, incorporating a variety of data formats, real-world applications, and complex conceptual relationships.

In general, although students demonstrated impressive advancements in their grasp of earthquakes, a range of proficiency levels was seen, highlighting the necessity of ongoing instructional approaches that promote more in-depth understanding and integration of information.

Students' Exit Understanding of Earthquakes

After implementing the SOLO formative assessments, the students were given the post-test. Their exit level of understanding of earthquakes is shown in Table 2.

Table 2 makes it clear that the students performed exceptionally well on the post-test; none failed, and a sizable majority showed proficiency ranging from satisfactory to outstanding. This group's proficiency with earthquake comprehension, with $\mu = 23.34$ and SD = 2.68, highlights how effective the SOLO formative evaluations was in improving their understanding. These results are consistent with the claims made by several academic publications, such as Wafubwa and Csíkos (2022), Ozan and Kincal (2018). These studies highlight that using formative assessments, like SOLO-based examinations, can spur considerable improvements in academic performance.

To better understand this accomplishment, look at the study conducted by Ganajová et al. (2021), which emphasizes the importance of formative assessment (FA) as a crucial tool for improving learning. The overall consequence of their study is relevant here, even though its primary focus was on how FA influences students' development of inquiry abilities in topics such as biology, chemistry, and mathematics. Similarly, Svensäter and Rohlin's (2022) study highlights the importance of the SOLO taxonomy by introducing a novel assessment methodology that smoothly combines formative and summative evaluations. Their findings demonstrate that a blended approach enables more nuanced knowledge and allows educators and institutions to modify their teaching strategies better to meet the needs of a wide range of students.

Given the Philippines' location in the Pacific Ring of Fire, an area prone to seismic activity, it is imperative that students have a deeper understanding of earthquakes. Subedi's et al. (2020) research reinforces this viewpoint by stressing the importance of providing kids with a broad education. These students' increased knowledge guarantees that they will be more equipped to create plans that reduce risks, limit damages, and promote community resilience as the keepers of future planning and development. These research findings highlight the revolutionary potential of formative evaluations such as

Table 2: Students' exit level of understanding of earthquakes

Level	n (%)	Overall mean (SD), Transmuted score	Overall level
Outstanding	10 (16.95)	23.34 (2.68), 85.64	Very Satisfactory
Very Satisfactory	30 (50.85)		
Satisfactory	6 (10.17)		
Fairly Satisfactory	13 (22.03)		

SOLO in molding a generation skilled in negotiating and adapting to seismic problems.

Difference between the Entry and Exit Levels of Understanding Earthquakes

The students' entry and exit scores were compared to determine whether there was a significant difference between them after implementing SOLO formative assessments. The results of the comparative analysis, conducted using a *t*-test, are gleaned in Table 3.

Table 3 demonstrates a mean gain of 12.12, a *t*-value of 26.128, and a *p*-value of 0.000, confirming a significant difference between the student's initial and subsequent understanding of earthquakes. The importance of SOLO formative assessments in enhancing students' comprehension of seismic occurrences is highlighted by this empirical data. The observable results are consistent with the studies described by researchers such as Agustinsa et al. (2021), Svensater and Rohlin (2022), and Mukuka et al. (2020). All of this literature support the effectiveness of SOLO examinations in strengthening students' cognitive abilities. In particular, using SOLO-based formative assessments as a teaching method has proven effective for Grade 8 students in this study. Students' understanding of earthquake-related concepts has improved thanks to the combination of the SOLO approach's standardized feedback mechanisms and organized conversations.

Svensater and Rohlin (2022) study highlights frequent feedback's critical role in promoting rich learning experiences, supporting this pedagogical claim. Based on the combination of empirical evidence and academic consensus, it is clear that the deliberate incorporation of SOLO assessments has sparked a revolutionary change in pedagogy by providing students with a thorough and nuanced understanding of earthquakes.

Moreover, the impact of SOLO formative assessments can be visualized using the raincloud plots, as seen in Figure 2.

As shown in Figure 2, a pattern becomes apparent: a densely packed, rising learning cloud representing a continuous progress trajectory. This strong trend highlights the positive effect of SOLO formative assessments within the educational context. In the details of the box plots, there is a higher median and a narrower interquartile range. Taken as a whole, these measures point to a measurable improvement in science, primarily due to the effectiveness of SOLO formative assessments.

In addition, the violin plot illustrates an apparent tilt in the direction of higher developments. These graphical representations demonstrate how applying SOLO approaches has improved students' understanding of earthquake concepts somewhat and considerably. This supporting data resonates with essential studies conducted by eminent scholars, including Svensater and Rohlin (2022), Freislich and Bowen-James (2020), and Mukuka et al. (2020). Their investigations into the SOLO taxonomy highlight its revolutionary potential, especially in fostering a rich feedback-focused learning environment. Therefore, after combining these factual findings with academic support, it is abundantly evident that SOLO formative assessments have become a crucial component in facilitating persistent and significant instructional improvements.

Furthermore, Cohen's *d* was obtained to test how practical the SOLO formative assessments were. The result is presented in Table 4.

Table 4 clearly shows that Cohen's *d* value is 3.402, which indicates a large and strong impact size. This significant value highlights the powerful effect that SOLO formative evaluations have on raising students' comprehension skills. This effect has far-reaching implications: SOLO-focused exercises have led to small but significant improvements in students' understanding of complex scientific phenomena, specifically earthquakes and their underlying ideas.

This transformative teaching method highlights the critical significance of SOLO-based assessments, as supported by the body of existing literature, which includes studies by Svensater (2023), Freislich and Bowen-James (2020), and Mukuka et al. (2020). Such tests catalyze an environment full of iterative feedback and push students toward improved academic achievement. According to Biggs and Collis (2014), a critical aspect of SOLO approaches is their ability to involve students in metacognitive processes. Students are encouraged to reflect and clear up any misunderstandings through this interaction. They also get the ability to define their learning paths, make clear goals, and improve their learning methods.

Because the SOLO taxonomy fosters increased self-awareness and reflective practice, students' performance metrics are

Table 3: Comparison between the students' entry and exit understanding of earthquakes

Aspect	Mean	Mean Gain	*t*-value	*p*-value
Entry	11.22	12.12	26.128*	0.000
Exit	23.34			

*Significant at α=0.05.

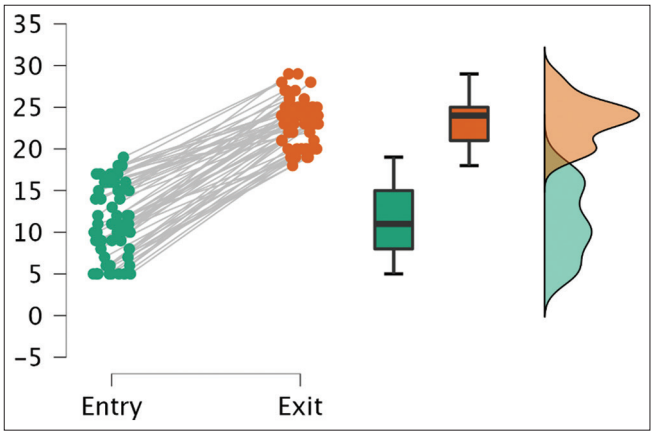

Figure 2: Raincloud plots of the entry and exit

elevated, as demonstrated by their excellent scores in later assessments. Therefore, besides its direct educational benefits, SOLO-based learning promotes a culture of reflection, improvement, and ongoing development, guaranteeing comprehensive academic growth.

Students' Acceptance of the SOLO Assessments

The students' acceptance of the SOLO formative assessments was also explored. The level of acceptance of the said assessments is showcased in Table 5.

Based on Table 5, it can be observed that students demonstrated a strong preference for SOLO formative assessments. They demonstrated a remarkable degree of acceptance of these assessments in various aspects and notably connected with their constructivist nature. Notably, students gave traits such as active involvement and participation ($\mu = 4.58$, $SD = 0.52$), real-world relevance and application ($\mu = 4.50$, $SD = 0.59$), and knowledge construction and integration ($\mu = 4.50$, $SD = 0.57$) the highest acceptance ratings.

The effectiveness and allure of SOLO-based assessments stem from their inherent applicability to actual situations, providing students with a useful framework to negotiate concepts connected to earthquakes. Subedi et al. (2020) emphasizes that this kind of educational method develops a community that is knowledgeable about disaster relief techniques and is ready and able to withstand earthquake activity. Simultaneously, students move up the cognitive ladder from basic comprehension to complex knowledge synthesis when they engage with real-world situations. This cognitive boost is consistent with research by Rickles (2013), which explains that higher SOLO scores are associated with improved critical thinking ability.

Table 4: Effect size of the mean gain provided by SOLO formative assessments

Test	*d* Statistic	Interpretation
Cohen's *d*	3.402	Large Effect

Legend: 0–0.190 (Trivial effect), 0.200–0.490 (Small effect), 0.500–0.790 (Medium effect), Above 0.790 (Large effect)

Table 5: Students' level of acceptance of the SOLO assessments

Aspect	No. of Items	Mean (SD)	Description
Active Engagement and Participation	2	4.58 (0.52)	Very acceptable
Real-world Relevance and Application	3	4.50 (0.59)	Very acceptable
Knowledge Construction and Integration	3	4.50 (0.57)	Very acceptable
Personalized Learning and Reflection	3	4.46 (0.44)	Very acceptable
Collaboration and Peer Interaction	2	4.31 (0.55)	Very acceptable
Overall Level of Acceptance	13	4.47 (0.42)	Very acceptable

Legend: 1.00–1.80 (Not acceptable), 1.81–2.60 (Fairly acceptable), 2.61–3.40 (Moderately acceptable), 3.41–4.20 (Acceptable), 4.21-5.00 (Very acceptable)

In addition, students expressed satisfaction with the customized aspects of SOLO tests, highlighting customized learning and reflective practices ($\mu = 4.50$, $SD = 0.59$) and group projects ($\mu = 4.50$, $SD = 0.59$). This acceptance highlights the SOLO approaches' flexibility, allowing for various learning styles and promoting metacognitive development. In agreement with this, Prakash et al. (2010) proposed that the SOLO taxonomy stimulates students' metacognitive development by helping them identify the best learning approaches based on their preferences. In addition, the cooperative environment created by SOLO evaluations strengthens peer relationships, enhancing group knowledge creation and cooperative problem-solving, as demonstrated by the interactive dynamics seen in brainstorming and group talks.

In summary, the general acceptance expressed by students emphasizes strong support for SOLO formative assessments ($\mu = 4.47$, $SD = 0.42$). This group's affirmation highlights how SOLO approaches may change lives by fostering a comprehensive, nuanced understanding of seismic phenomena that goes beyond simple memorizing. These supporting observations align with important studies by Svensater and Rohlin (2022), Freislich and Bowen-James (2020), Mukuka et al. (2020), and Claudia et al. (2020), which together highlight the critical function of SOLO taxonomy in enhancing students' academic knowledge and developing a strong foundation in conceptual understanding.

Students' Experiences in Using SOLO-based Formative Assessments

This study gathered four themes from the interviews gathered from ten students about their experiences in SOLO-based formative assessments. The themes are grouped into two categories – the positive themes and the challenge themes. Positive themes include (1) Appreciation of Constructing STEM and Diagrams and (2) Effectiveness of Collaborating Critically in Class. Challenge themes include (3) the Challenge of Answering Open-Ended Questions and (4) the Difficulty of Analyzing Relational Questions.

Theme 1: Appreciation of constructing stem diagrams

One common theme expressed by the students interviewed is the significance of including paragraphs and illustrations in the question stem, explaining their strong influence on aiding understanding and directing answers. The students noted that the supplementary paragraphs clarified the main idea and expedited their method of answering later questions. *"Masabtan dayon namo ang topic tungod sa drawing ug ang paragraph nga niexplain ato ng topic,"* for example, was said by a student, highlighting how the use of both visuals and explanatory paragraphs facilitated their learning. This was also expressed by another student, who said, *"Mas nindot gyud siya nga naay paragraph kay igkabasa nimo sa question dali raka maka answer,"* highlighting the effectiveness of this integrated

strategy in promoting straightforward and knowledgeable responses.

Students also emphasized illustrations' critical role in improving their understanding of particular concepts. One student specifically mentioned how the visual aids helped her understand complex ideas like how fault movements cause earthquakes, saying *"Nakatabang sa akoa nga naay drawings kay mas nasabtan nako ang mga faults nga if mulihok maka cause ug earthquake."* This supports the pedagogical effectiveness of visual aids, as demonstrated by Gillies and Rafter (2019) and Lule (2022). Their findings emphasize how effective pictures are as learning catalysts, promoting improved comprehension, memory retention, problem-solving skills, and general learning goals. In essence, these visual components go beyond conventional teaching strategies by fostering critical thinking skills in students, supporting their visual literacy, and creating a rich learning environment that supports comprehensive understanding and knowledge acquisition.

Theme 2: Effectiveness of collaborating critically in class

The interviews yielded a second theme that centers on the evident advantages and efficacy of cooperative learning opportunities in the classroom. During the discussion phase, a noteworthy educational method involved grouping students to enable them to brainstorm collaboratively and explore themes related to subject competency. Although the first round of ideation and analysis of the questions from the SOLO worksheet was done in groups, the second round of writing the answers was done alone.

Several students emphasized the observable benefits of these kinds of group projects. The importance of group participation in activities was expressed by a student, who said, *"Ganahan ko nga naa koy ka grupo sa pagbuhat sa activities kay kung magkalisod ta naa ray mutabang nga ka grupo,"* highlighting the group dynamics' innate capacity for collective problem-solving. *"Sa activities ug sa pagsabot sa mga questions nga g ipabuhat sa amoa nindot nga by group kay magtinabangay rami,"* said a second student, echoing similar feeling and emphasizing the collaborative spirit. Similar highlights the synergistic benefits of collaborative learning. In addition, a different student highlighted the richer nature of the answers that came from group discussions by stating, *"Mas maayo pagka answer ang gibuhat namo tungod kay mag kasagol man ang iya iyang opinion."*

This collaborative instructional technique develops students' sense of shared responsibility in addition to higher-order thinking skills. These observations are consistent with the research conducted by Warsah et al. (2021) and Amalia (2018), which suggests that collaborative learning might foster critical thinking abilities. As a result, this instructional strategy goes beyond simple memory by enabling students to participate more fully in the learning process. These assertions are further supported by Warsha's (2021) research, which shows how collaborative learning approaches strengthen students' motivation, emotional intelligence, cognitive development, and openness to different points of view. Cooperative learning presents itself as a paradigm shift in education that gives students the abilities and attitudes needed for lifetime learning and overall growth.

Theme 3: Challenge of answering open-ended questions

The third theme explores students' complexities and difficulties when completing SOLO-based formative assessments, especially the open-ended questions that require them to generate their answers. According to Gharehbagh (2022), this teaching strategy assigns students responsible for creating responses, which they must do using their knowledge and critical thinking abilities. Three open-ended questions punctuate each competency, demanding students carefully examine the stem and analyze the corresponding visuals before voicing their ideas.

The insights obtained from student interviews clarify the intrinsic complexity of this assessment mode. *"Ang mga question kay lisod answer kay way choices, kinahanglan mi maghunahuna,"* said a student in reaction to the cognitive demands. This highlights the lack of multiple-choice alternatives, which typically scaffold solutions. Another student agreed, considering the questions to be inherently "tough." On the other hand, student S3, who saw the lack of options as beneficial, stated that *"Walay choices ang mga questions, nindot siya para di nami magsalig sa mga choices."* Another student, on the other hand, had a different perspective, believing that the demanding nature of these open-ended questions helped students' progress intellectually. She said, *"Mas ni grabe pa ang akong knowledge kay dapat man jud hunahunaon ug maayo para masakto ang answer."*

There are several reasons why students find it difficult to respond to these open-ended questions; one is the widespread disruptions to learning caused by the pandemic. As Brillianandа and Wibowo (2023) pointed out, the pause brought on by the epidemic has made pupils' deficiencies in reading comprehension worse. This feeling aligns with Hayati's and Puspitaloka (2022) claim that students' struggles with reading comprehension are related to their declining interest in reading and inability to understand English sentences. Hidayati (2018) clarified further that various factors, including grammatical errors, lexical limitations, and a range of extrinsic and inner problems, contribute to these barriers to understanding. As such, the combination of these elements leads students to struggle with the complexities of open-ended questions, underscoring the need for instructional strategies to strengthen understanding and critical thinking skills.

Theme 4: Difficulty of analyzing relational questions

The last theme from the interviews focuses on the intrinsic difficulties students encounter when analyzing relational questions in SOLO-based formative evaluations. Although all students expressed that open-ended questions are challenging, there was a general agreement that the third question presented more challenges than others.

A student explained that the third question was more difficult because it involved more complex scenarios: *"Ang ikatulo nga question kay lisod tungod kay nagka grabi na ang sitwasyon."* Likewise, another student explained that the third question was more difficult because it was multifaceted and required definitions and understanding of fault formations and seismic activities: *"Lisod ang question 3 kay daghan ug gipangita nga depinisyon ug pagsabot pareha sa tulo ka faults ug ang pagkahimo sa linog nga maoy nakahimong mas lisud sa tulo ka pangutana."* Another student's honest admission of their problems, *"Katong ika tulo nga question ma'am wa kaayo ko kasabot nato,"* further emphasized this feeling by highlighting their inability to completely understand the complexities of the extended third question.

Academic literature further supports these problems. The results of this study agreed with Hidayati's (2018) assertion that students frequently struggle with comprehension when faced with long phrases. In addition, the results of Abdullah's (2015) study support these conclusions by indicating that students often struggle to distinguish relationship notions, particularly when required to use higher-order thinking abilities to make connections and synthesize information. To sum up, the four themes that emerged from the interviews provide invaluable insights for future research, especially when identifying areas that require more focus and instructional improvement in SOLO-based formative assessments.

Integration of Quantitative and Qualitative Findings

This study, which integrates quantitative and qualitative findings, highlights the transformative impact of SOLO-based formative assessments in teaching and learning about earthquakes and advancing scientific understanding. Quantitative results demonstrate a substantial improvement in students' comprehension after the intervention, reflecting the effectiveness of the structured approach provided by the SOLO taxonomy. This improvement signifies a progression in students' cognitive abilities, moving from basic recall of isolated facts to an ability to connect and integrate complex ideas related to seismic events.

The qualitative findings provide depth to this analysis by uncovering the mechanisms through which these cognitive gains were achieved. Students consistently acknowledged that the scaffolding inherent in the SOLO framework helped them move through increasingly complex levels of understanding. This approach, which begins with foundational questions and gradually advances to tasks requiring integration and synthesis, was instrumental in fostering their more profound engagement with the material. The iterative nature of the assessments also encouraged sustained focus and critical thinking, enabling students to revisit and refine their understanding over time.

Furthermore, specific aspects of the SOLO-based assessments efficiently enhanced learning. Visual aids were pivotal in clarifying abstract concepts, helping students develop a concrete understanding of processes such as fault movements and seismic wave propagation. Collaborative learning opportunities further enriched this experience, allowing students to engage in dialogue, share diverse perspectives, and address misconceptions in a supportive environment. These instructional strategies reinforced students' grasp of the content and encouraged a culture of inquiry and peer learning, both of which are critical in science education.

The study also revealed that SOLO-based assessments fostered skills beyond earthquake education. The assessments challenged students to think critically and make connections across different scientific concepts by emphasizing open-ended questions and tasks that require relational thinking. This approach cultivated a mindset of exploration and problem-solving, preparing students to apply their knowledge in real-world contexts. While some students found the tasks demanding, these challenges were integral to their intellectual growth, as they prompted deeper reflection and understanding.

The overall acceptance of SOLO-based assessments further underscores their effectiveness. Students recognized the assessments as engaging and meaningful, linking classroom concepts to practical applications. This alignment between the assessments and students' learning experiences created a dynamic and relevant educational environment. Integrating quantitative improvements with qualitative insights demonstrates how the SOLO framework supports academic achievement and the development of critical competencies essential in scientific inquiry.

In summary, combining quantitative and qualitative findings provides a holistic view of the benefits of SOLO-based formative assessments. These assessments improved students' understanding of earthquakes and fostered critical thinking, collaborative learning, and the ability to synthesize complex ideas. This integration underscores the value of evidence-based approaches in promoting more profound, meaningful engagement with scientific concepts.

CONCLUSION AND RECOMMENDATIONS

This study examined the assessment of SOLO-based formative evaluations in the context of scientific teaching, with a special emphasis on seismic phenomena like earthquakes. The thorough examination covered everything from evaluating pupils' basic comprehension at enrollment to their advanced comprehension at the conclusion. Using a thorough analysis of formative evaluations, the study revealed a noteworthy distinction between the baseline knowledge of pupils and their improved comprehension after the intervention. Furthermore, the high levels of student acceptance highlighted the educational significance and usefulness of SOLO-based evaluations in supporting productive learning environments. Furthermore, emerging themes from qualitative insights provided a nuanced viewpoint by highlighting students' appreciation of particular teaching strategies, group projects, and the difficulties posed by particular question types. These findings provide a robust foundation for understanding the multifaceted impact and implications of integrating SOLO-based assessments in contemporary science education settings.

Practically speaking, the study's findings offer valuable suggestions for enhancing the quality and effectiveness of science instruction. Educators and curriculum designers are encouraged to incorporate SOLO-based formative assessments as a fundamental aspect of their instructional practices. They should utilize visual aids, such as annotated fault diagrams, to support pre-structural and multi-structural learning, as students deemed these essential for conceptual clarity. In addition, the integration of collaborative learning tasks, like group discussions on seismic events, was identified by students as effective in boosting comprehension and problem-solving skills. Providing structured guidance for relational questions is essential since students found these particularly challenging during the assessments. Workshops for teachers on designing and grading SOLO-aligned activities are also recommended to ensure successful implementation in the classroom. Educational stakeholders who coordinate their pedagogical methods with evidence-based tactics such as SOLO may create an atmosphere that supports lifelong learners who are prepared to face problems in the real world.

However, it is important to recognize that this study framework has some intrinsic limitations. Although the study provides insightful information, its limitations and context-specific design may only partially capture the influencing elements seen in other educational environments. Therefore, it is essential to exercise caution when extrapolating results since variables related to student demographics, cultural contexts, or other environmental factors may add biases or confounding variables.

Given the study's limitations and complex results, more comprehensive and integrative approaches should be used in future research. Integrating mixed-method research designs can yield a more thorough and intricate comprehension of the effectiveness of SOLO-based assessments across various educational settings and student demographics. Moreover, investigating possible improvements or modifications to the SOLO framework based on actual data and iterative feedback might spark innovative teaching practices. Broadening the scope of the research to include more diverse demographic groups, multidisciplinary topics, or educational levels can enhance the scholarly conversation and promote ongoing improvements in scientific education methods.

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APPENDIXES

Appendix A: Sample Pre-test/Post-test Questions

1. What are the two types of faults according to their activity?
   A. active and inactive faults
   B. active and dormant faults
   C. normal and reverse faults
   D. reverse and strike-slip faults
2. What factor is considered by scientists when categorizing a fault as an active fault?
   A. if the fault is near the ocean
   B. if the fault is near a mountainous area
   C. if the fault has been generating movements for the past 1000 years
   D. If the fault has been generating movements for the past 10,000 years
3. You are currently in the Science laboratory experimenting with photosynthesis; however, you notice that the room moves and realizes an ongoing earthquake. How will you react at this point?
   A. Panic and run outside.
   B. Continue the experiment.
   C. Cover your head and run toward an open area.
   D. Duck, cover, hold, and stay under the sturdy table.
4. Which of the following statements BEST describes the state of earthquake prediction?
   A. Scientists can accurately predict when an earthquake will occur, but not where.
   B. Scientists can accurately predict the time and location of almost all earthquakes.
   C. Scientists can accurately predict the time and location of about 50% of all earthquakes.
   D. Scientists can characterize the seismic risk of an area but have yet to predict more earthquakes accurately.
5. Which of the following statements is FALSE?
   A. Most earthquakes occur at plate boundaries.
   B. The time and location of most major earthquakes can be predicted several days in advance.
   C. Earthquakes can be caused by normal, reverse, and strike-slip faulting.
   D. P waves travel faster than both S waves and surface waves.

Appendix B: Sample SOLO-based Formative Assessments

Q1. What characteristic is considered to determine that a fault is an active fault?
Q2. Where is the focus and epicenter of an earthquake occur?
Q3. How is the magnitude of an earthquake different from its intensity?

Appendix C: Sample Items for the SOLO-based Formative Assessment Acceptance Scale

Q1. *Active Engagement and Participation:*
I actively participated in the SOLO-based formative assessments to understand earthquake concepts.
Q2. *Real-world Relevance and Application*
I could see the real-world relevance of the earthquake concepts addressed in the SOLO assessments.
Q3. *Knowledge Construction and Integration*
The SOLO assessments helped me connect different aspects of earthquake knowledge.
Q4. *Personalized Learning and Reflection*
The SOLO-based assessments allowed me to personalize my learning experience about earthquakes.
Q5. *Collaboration and Peer Interaction*
I found the collaborative aspects of SOLO assessments beneficial for understanding earthquake concepts.

Appendix D: Interview Guide

1. What are your experiences regarding the use of SOLO-based formative assessments in class?
2. What do you think are the advantages of the SOLO-based formative assessments?
3. Did you encounter any challenges during the use of SOLO-based formative assessments? What are these challenges?
4. How about teaching and learning opportunities? What are these opportunities?
5. If given the chance, how do you revise the SOLO-based formative assessments prepared by the teacher?