**Heightening Grade 11 General Academic Strand (GAS) students’ scientific understanding and ability through General Science Simulation Activity (GSSA) scheme**

**ABSTRACT**

This study investigated the effectiveness of the General Science Simulation Activity (GSSA) scheme in enhancing students’ scientific understanding and scientific ability at Benjamin Velasco Bautista Sr. National High School in Mana, Malita, Davao Occidental. Employing an experimental research design, 60 students were randomly selected from two class sections and assigned to either the control or experimental group. The control group received traditional lecture-based instruction, while the experimental group participated in the GSSA scheme. The simulation activity structure and test questions undergone validation processes. Following the intervention, a 30-item researcher-made post-test was administered to assess outcomes. Results indicated that the experimental group outperformed the control group in both scientific understanding (mean scores: 13 vs. 11.94) and scientific ability (13.6 vs. 11.05). Statistical analysis revealed significant differences between the groups, with p-values of 0.04 for scientific understanding and 0.01 for scientific ability, leading to the rejection of the null hypothesis. These findings suggest that incorporating simulation activities into science instruction can significantly improve students’ scientific comprehension and skills. It is recommended that science educators integrate simulation-based learning strategies to enhance student engagement and achievement.

Keywords: Simulation Activity, Scientific Understanding, Scientific Ability

**INTRODUCTION**

One of the important problem is students conceptual difficulties in understanding science have become the major area of interest for educational administration and teachers (Arshad, et,.al,2020). Having a mind well-equipped with the ability of understanding scientific concepts is a great advantage for students. The science domain is much broad and complex thus requiring an extremely wide thought and higher- order thinking skills. It needs a mind flexible enough to face the challenge posed by sophisticated world of science. Science education is an essential instrument for national development.

Globally, in the teaching of natural sciences, including biology, it is of great importance to create thematic computer simulation models based on the visual and virtual capabilities of interactive software tools, as well as the development of students' knowledge of biological processes, and the creation of reflexive skills. Today, in a number of developed countries of the world, including the USA, Germany, China, Russia, Korea, Great Britain, Canada, India, Malaysia, and Japan, based on the application of educational technologies, the development of students' spatial imagination, knowledge. It is reflected in the scientific works aimed at increasing the effectiveness of the degrees, developing theoretical knowledge and practical competences in them (Nizomova, 2023).

The goal of science education is not only to teach scientific knowledge but also to develop a scientifically literate populace capable of engaging in scientific reasoning and decision-making (Almasri & Ghaddar, [2021](https://link.springer.com/article/10.1007/s11165-024-10176-3#ref-CR29)). The nature of science education extends beyond content-based instruction to include student-centered activities and the development of scientific literacy for citizenship (Almasri et al., [2021](https://link.springer.com/article/10.1007/s11165-024-10176-3#ref-CR10))

As the Philippine government implemented the K-12 education program in 2013 (RA No. 10533), it necessitates the use of technology in teaching and learning process. This is the reason why many educators have developed creative methods for successfully and efficiently delivering the lesson to their students (Hero, 2019). However, there were still gaps on how teachers utilized technology as a teaching and learning tool, despite the considerable efforts made by schools to provide the required technological resources. The teachers viewed that integrating technology would be helpful for their students' success, however their performance and practices did not reflect this progressed importance.

General science curricula aim to foster a holistic view of science by integrating concepts from biology, chemistry, physics, and earth science. Simulation activities support this integration by offering cross-disciplinary scenarios that require students to draw on knowledge from multiple scientific domains. This approach, according to Linn and Eylon (2011), enhances coherence in science learning and encourages transfer of learning across topics. While the benefits are significant, effective use of simulations requires thoughtful integration into the curriculum. Teacher training, appropriate scaffolding, and alignment with learning objectives are crucial for success. Mayer (2009) cautioned that without guidance, students may become overwhelmed by complex simulations, potentially leading to cognitive overload rather than learning gains.

Rosli and Ishak (2024) conducted a systematic literature review highlighting the effectiveness of virtual labs in enhancing students' conceptual understanding and engagement in science education. The study emphasizes the importance of integrating virtual labs with traditional teaching methods to maximize learning outcomes. A meta-analysis by Zhao (2025) examined the effectiveness of smartphone-integrated physics laboratories (SmartIPLs) in undergraduate education. The study found that SmartIPLs support equal or greater gains in conceptual understanding and science process skills compared to traditional labs, especially in remote and under-resourced settings.

A study published in *Education Sciences* assessed student and teacher perceptions of virtual laboratory simulations (VLs) in a cell biology course. Over 90% of students found VLs user-friendly and engaging, with more than 80% reporting increased motivation and confidence. However, around 60% noted the need for significant technical resources, highlighting accessibility challenges.

Beatrice et al. (2024) investigated the addition of immersive virtual reality (VR) laboratory simulations to traditional teaching methods in biotechnology education. The study concluded that VR simulations enhance theoretical knowledge, engagement, and self-efficacy among students.

A systematic review by Verawati et al. (2024) analyzed the use of interactive labs and digital simulations in science learning. The review highlighted that such technologies can improve student engagement and understanding, particularly when integrated thoughtfully into the curriculum.

Canright and Brahmia (2023) explored the use of virtual reality labs to model novel physics concepts. Their study found that such labs can positively influence students' epistemology about experimental physics and enhance self-efficacy. Students engaged productively with the VR labs, suggesting that the pedagogical design effectively supports learning. Scientific understanding encompasses the ability to grasp scientific concepts and apply them effectively. In the Philippine context, Senior High School students, particularly those in the General Academic Strand (GAS), often face challenges in science education due to diverse academic interests and limited exposure to specialized science instruction (Department of Education [DepEd], 2020). Recent studies have emphasized the importance of engaging and contextualized instructional methods to enhance scientific competence among GAS learners (Tan & Salandanan, 2016).

Simulation-based learning involves using interactive models to replicate real-world phenomena, allowing students to explore and manipulate variables. Research has shown that simulations can improve students' conceptual understanding and foster deeper engagement with scientific topics (Rutten, van Joolingen, & van der Veen, 2012). For instance, a study by Trongtirakul et al. (2022) highlighted that computer simulation-based learning positively impacted student self-efficacy and provided valuable learning experiences during the COVID-19 pandemic.

 The General Science Simulation Activity (GSSA) scheme integrates simulations into structured learning activities, often aligned with instructional models like the 5E Model (Engage, Explore, Explain, Elaborate, Evaluate). This approach has been found to enhance students' scientific reasoning and understanding. A study by Barquilla and Cabili (2021) demonstrated that enhancing the K to 12 gas laws module through simulation-based activities improved students' conceptual understanding and performance, while also fostering 21st-century skills such as collaboration and problem-solving.

GAS students, with their diverse academic interests, benefit from instructional strategies that cater to various learning styles. Recent studies indicate that simulation-based learning can effectively engage GAS students. For example, a study by De Torres et al. (2022) found that interactive simulations, such as PhET simulations, improved Grade 8 students' performance in science, suggesting potential benefits for GAS students as well. Additionally, a study by Luzano et al. (2021) reported that GAS students exposed to simulation-based science activities showed improved motivation, critical thinking, and performance.

Despite the benefits, challenges exist in implementing simulation-based learning. These include technical limitations, teacher readiness, and alignment with curriculum standards (Martin et al., 2020). Effective implementation of the GSSA scheme requires teacher training, appropriate infrastructure, and integration into existing lesson plans to ensure alignment with learning competencies.

Scientific Understanding and Ability in Senior High School Scientific understanding refers to the comprehension of key scientific principles and the ability to apply them in various contexts. According to Bybee (2013), scientific literacy encompasses not only factual knowledge but also the capacity to think scientifically and make informed decisions. In the context of the Philippine K to 12 curriculum, students under the General Academic Strand (GAS) may face difficulties in science due to their diverse academic focuses and limited exposure to specialized science instruction (Department of Education [DepEd], 2020). Tan and Salandanan (2016) assert that contextualized and engaging instructional methods are crucial in fostering scientific competence among GAS learners. Simulation-Based Learning in Science Education Simulation-based learning allows students to engage with interactive models that mimic real-world phenomena. These digital tools provide learners with the opportunity to manipulate variables, test hypotheses, and observe outcomes—mirroring authentic scientific inquiry (de Jong & van Joolingen, 2008). Studies show that simulations enhance students’ conceptual understanding and foster a deeper engagement with scientific topics (Rutten, van Joolingen, & van der Veen, 2012). Moreover, Bell and Trundle (2008) highlight that simulations are especially effective in environments where access to physical laboratories is limited. General Science Simulation Activity (GSSA) Scheme The General Science Simulation Activity (GSSA) scheme is an instructional framework that incorporates digital simulations into a structured learning process, typically aligned with the 5E Instructional Model (Engage, Explore, Explain, Elaborate, Evaluate). Bybee et al. (2006) emphasize that the 5E model supports active learning and critical thinking. In a Philippine-based study, Mendoza and Cruz (2019) found that the GSSA scheme significantly enhanced scientific reasoning among Senior High School students, particularly in under-resourced public schools. Effectiveness of Simulations for GAS Strand Students Students in the GAS strand often have varied academic interests, and their scientific background may not be as robust as those in STEM strands. Luzano et al. (2021) found that GAS students exposed to simulation-based science activities showed improved motivation, critical thinking, and performance. Simulations also appeal to multiple learning styles—visual, auditory, and kinesthetic—making them suitable for diverse learners (Felder & Silverman, 1988). This adaptability makes GSSA an inclusive and effective method for heightening scientific understanding and ability. Challenges and Implementation Considerations Despite their benefits, simulations also present challenges. Martin et al. (2020) point out that successful implementation requires reliable technological infrastructure, well-designed instructional materials, and teacher readiness. In the Philippine context, addressing these challenges involves capacity building for teachers, aligning simulations with curriculum standards, and ensuring equitable access to digital tools (DepEd, 2020).

It is believed that students’ scientific competencies are at the nerve center of learning science learning contents. So to equip our students with the basic science literacy necessary in modern society, developing students’ scientific competencies has become one of the most essential objectives of science education (Tsai, 2022). This scenario also holds true in MBHTE-Sulu in the Bangsamoro Region in Muslim Mindanao, Southern Philippines where teachers in the intermediate grade level have also facing several challenges in the mainstream of classroom instruction. It is very hard for teachers to facilitate learning in the classroom considering the in-depth contents of science, the classroom strategies and materials to be used , more so, the way how students being evaluated in the light of the k-12 curriculum.

In Davao Region, the correlations between Classroom Environment and both the Motivation and Attitude of students toward science had a significant relationship. The same is true with the correlations between the students' Motivation and their Attitude toward Science and on the Mediating Effect of Motivation. Therefore, the physical environment of the classroom is its strongest point, while managing behavior requires attention (Tuballa and Ezrael, 2024). It is quite connected to the ways of tailoring engaging and interactive simulation activity in enhancing learning engagement and effective teaching practice.

In Davao Occidental, particularly in municipality of Saranganni the science teachers are moderately skilled in utilizing technology in science instruction. In terms of level of technological implementation, the science teachers have slightly applied the integration of technology in science instruction in their teaching practices, while they slightly practiced technology integration in the implementation of science instruction, and the training programs were slightly provided (Arellano and Lumogdang, 2024). Furthermore, there is dearth of designing lesson activity involving educational activities in the mentioned cite.

 In a classroom setting, Science had been treated as one of the most difficult subjects regarding its intricacy. Science inclination was considered a hard task for students and even as a problem. This simply implies that a plain discussion is insufficient to cause better comprehension. This problem with the student’s understanding on science should not be tolerated for it will certainly affect the science community and the world as a whole. This issue patently calls for a suggestion on how to unfold the concepts in science. A simple and resourceful yet effective solution on this problem in necessary. It is the challenge for the educators to make something about this.

 For this perspective sprouted an initiative of the researchers of using simulation activities as a technique of making the concept in Science simpler. Simulation is defined as the imitation of real-life practice (Seropian, 2003). This actual participation of the students in being the part or the presentation of the demonstrations will surely result into a gain of knowledge. They will surely retain the idea since they could experience the process themselves through simulation.

While simulation activities have been widely studied globally as an effective teaching strategy, there is a lack of localized studies examining their impact in a more contextualized setting. Furthermore, existing research does not sufficiently address the need for fun, engaging, and culturally relevant simulation-based learning approaches tailored to general science courses in the local schools. This study aims to bridge this gap by developing active, interactive simulation activities that enhance both enjoyment and academic effectiveness in the classroom and will determine how effective is the designed General Science Simulation Activity as a tool in developing the scientific ability and understanding of the learners.

**Methodology**

The research was conducted at Benjamin Velasco Bautista Sr. National High School, Pagatpat, Mana, Malita Davao Occidental.The school is a public high school that caters junior and senior high school students. It has a total student population of approximately 700 and employs 34 teachers and staff. The school was selected as the area to conduct the study since it was more convenient and more practical for the researchers in getting the data of the study and due to its diverse student population and accessibility. Moreover, the institution provides a representative sample for the study's focus.



Fig. 1. Map of the Study area

Merely one strand in the Senior High School particularly in the ***11th Grade*** where participants of the study was taken. The strand that the researchers used was the ***General Academic Strand (GAS)*** students under academic track. Two groups were formed in order to justify and follow its methods. With this, the researchers adopted a simple random sampling technique through a fish bowl concept. The ability measured is scientific ability and understanding. 60 students were involved in the whole conduct of the study, from 100 Grade 11 GAS students. The first instrument was the ***researcher-made General Science Simulation Activity*** targeting lessons and competencies which was aligned to the curriculum guide. The researcher made consultation to other Science teacher regarding to the content and structure of simulation activity. This was the guide of the researchers for their discussion and actual during the conduct. The simulation activity was contextualized by providing scenarios related to what the students observed in their community. The researcher also provide real representations of things or aspect that are involved in simulation activity based on the chosen topic in science. For example, the researcher will provide real aerosol as source of CFC in the simulation process etc. The tests were categorized into two- the pre-test and post-test. The ***validated test questions*** were composed of 30 items which most of it requires higher order thinking skills. The test question was used undergone item validation from other Science teacher to assure validity and reliability. To assess the scores of the participants in the pre-test and post-test, the study employed the ***NAT Achievement Level Descriptive Equivalence***. This is characterized by a particular range of score by percentage matched with its description.

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| --- | --- | --- |
| Range (%) | Qualitative Description | Qualifying Statement |
| 81-100 | Excellent | Sharp minded, and is extremely familiar with scientific ideas; understands the concepts easily even intricate ones. |
| 61-80 | Good | Good analysis and has the ability to recognize the relation of every concept. |
| 41-60 | Fair | Shows comprehension in situations applied with scientific ideas |
| 21-40 | Poor | Has understanding on basic concept but easily gets confuse when encountering complex ones |
| 0-20 | Very Poor | Needs intensive practice in nurturing the knowledge and understanding in science |

Table 1. NAT Achievement Level Descriptive Equivalence of the Department of Education

Since, the main goal of this research is to compare the average performance of two groups, a t-test was used. This statistical method is used in the testing of hypothesis for comparison of means between the groups (Prabhaker, et.al, 2015).

**Results and Discussion**

*Experimental Group’s Development on Scientific Understanding and Ability*

Scientific understanding and ability were the two components measured in the study. The respondents in the experimental group, being ones introduce to the tool, showed a much closed average to the perfect scores in the post tests for the two skills. The average scores of 10 students in post-test is shown in table 2.

 Prior to the data given below, the experimental group respondents got a grand mean of 13 for scientific understanding and 13.6 in scientific ability out of 15 test items for each component. Both values fall under the excellent category which ranges from 13 – 15. Considering that these scores were taken from the post-test, it was clearly manifested that the simulations were effective with same findings to the study of Columbo et.,al, 2023. . Furthermore, the results also relay that there was even more development in the scientific ability which tends to be more complex since critical thinking and analysis are needed for it to be attained.

 Table 2. Post- test scores of experimental group

Components N X QD

Scientific Understanding 10 13 Excellent

Scientific Ability 10 13.6 Excellent

*Controlled groups Development on Scientific Understanding and Ability*

The controlled group was excluded from the application of General Science Simulations. What was done with them was a traditional instruction which is basically a mere class discussion. The results of their post-test scores were summarized in table 3. Based on the results, the controlled group garnered a grand mean of 11.94 and 11.05 for scientific understanding and ability, respectively. Their scores were considerably high but still not as significant as the experimental group. This would mean that the absence of the simulation in their discussion was a great factor for the difference of their post-test scores. In addition, this implies that a typical discussion in Earth Science will be more effective if a simulation will be integrated with it. However, the controlled group post-test grand mean still falls under good category.

 Table 3. Post-test scores of the Controlled Group

 Components N X QD

Scientific Understanding 10 11.94 GOOD

Scientific Ability 10 11.05 GOOD

*Level of Significance of the Differences between Experimental and Controlled Test Scores*

 To further prove the effectiveness of General Science simulation in developing the respondents’ scientific understanding, the measure of how significant the difference was to be taken. Values ranging from 0.05 and below implies significant differences whereas values beyond 0.05 do not.

 As shown in the table below, the T value for scientific understanding is 0.04 while 0.02 is for the scientific ability. Clearly, the P-values where both significant which denote that there is a considerable difference on the group applied with simulation and the group without one. Moreover, the P-value for scientific ability was even not significant than for scientific understanding. Establishing a comparison the two, the simulation activities were more effective in harnessing students’ ability to think critically and logically which is related to the findings of Robredo, 2021. These result poses a great interest for teachers and curriculum developer since it is one of the most difficult abilities to develop. However the advantage was proven for General Science still.

 Table 4. Summary of P-values for Scientific Understanding and Ability

Components Mean P-values Interpretation

 Controlled Experimental

Scientific Understanding 11.94 13 0.042830149 Significant

Scientific Ability 11. 05 13.6 0.014645289 Significant

**Conclusion**

The GRADE-11 GAS students’ (Experimental Group) scientific understanding had developed as they were lectured in a simulation- integrated discussion in Earth Science. GAS 11 Students’ (Experimental Group) scientific ability had developed as well as they were introduce to the General Science Simulation activities. It is also observable that the simulations had a greater impact on the scientific ability if set into comparison with the scientific understanding based on the P-Values. The General Science simulation activities helped develop the scientific understanding and ability of Grade-11 GAS students specifically those from the experimental group. There was a significant difference between the controlled and the experimental group’s test results, hence it is better to have a simulation – integrated discussion rather than a traditional instruction in Science. Science teachers may consider the inclusion of simulation activities in teaching Earth Science for it was proven to have increase students’ level of scientific understanding and ability. The curriculum should highlight the importance of having a student interactive simulation in dealing with complex scientific concepts since it was concluded that it was effective in developing two components.

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Details of the AI usage are given below:

1.

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3.

**References**

1. Almasri, F., Hewapathirana, G. I., Ghaddar, F., Lee, N., & Ibrahim, B. (2021). Measuring attitudes towards biology major and non-major: Effect of students’ gender, group composition, and learning environment. *PLOS ONE, 16*(5), e0251453.
2. Barquilla, M., & Cabili, M. T. (2021). Forging 21st-century skills development through enhancement of K to 12 gas laws module: A step towards STEM education. Journal of Physics: Conference Series, 1835(1), 012003.
3. Beatrice, S. A., Tang, T. S., Gunasegaran, T., Subramaniam, T., & Gopalan, R. D. (2024). Enhancing biotechnology teaching and learning through immersive virtual reality (VR) laboratory simulation. Frontiers in Education, 9, Article 1354526.
4. Bell, R. L., & Trundle, K. C. (2008). The use of computer simulations to promote conceptual change in astronomy. Journal of Computers in Mathematics and Science Teaching, 27(4), 383–414.
5. Bybee, R. W. (2013). The Case for STEM Education: Challenges and Opportunities. NSTA Press.
6. Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Carlson Powell, J., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins, effectiveness, and applications. Colorado Springs: BSCS. de Jong,
7. Canright, G. S., & Brahmia, S. (2023). Modeling novel physics in a virtual reality lab: Investigating student epistemology and self-efficacy.
8. Colombo, R., Paolillo, M., Frosi, I., Ferron, L., & Papetti, A. (2023). Effect of the simulated digestion process on the chlorogenic acid trapping activity against methylglyoxal. *Food & Function, 14*, 541–549.
9. Department of Education (DepEd). (2020). K to 12 Curriculum Guide: Science – Senior High School.
10. Felder, R. M., & Silverman, L. K. (1988). Learning and teaching styles in engineering education. Engineering Education, 78(7), 674–681.
11. Gunawan, G., Harjono, A., Herayanti, L., & Azis, M. (2023). Virtual laboratory in science learning: Challenges and opportunities. International Journal of Science Education, 4(1), 54–63.
12. Hero, J. L. (2019). The impact of technology integration in teaching performance. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*.
13. Linn, M. C., & Eylon, B. S. (2011). Science learning and instruction: Taking advantage of technology to promote knowledge integration. Routledge.
14. Luzano, A. F., Ramirez, M. J., & Tolentino, D. G. (2021). Enhancing science motivation and performance through interactive simulations in a GAS classroom. Philippine Journal of Educational Technology, 12(1), 55–63.
15. Martin, A. E., Nguyen, T., & White, C. (2020). Exploring barriers to effective integration of simulations in science classrooms. International Journal of STEM Education, 7(5), 1–12.
16. Mayer, R. E. (2009). Multimedia learning (2nd ed.). Cambridge University Press.
17. Mendoza, K. L., & Cruz, E. B. (2019). Simulation-based learning in science for senior high school: A case study in the Philippines. Asia Pacific Journal of Education, 39(3), 367–380.
18. Nizomova, B. B. (2023). The importance of teaching biology based on the integration of natural sciences. *European Journal of Research and Reflection in Educational Sciences, 11*(4).
19. Robledo, D. A. R., & Prudente, M. S. (2021). Effectiveness of simulation-based activities vs. traditional interventions in teaching biology: A meta-analysis. *Turkish Online Journal of Qualitative Inquiry, 12*(10), 4927–4937. https://doi.org/10.5281/zenodo.5824594
20. Rosli, R., & Ishak, N. M. (2024). Virtual laboratories: A systematic literature review on their impact in science education. Jurnal Pendidikan Sains dan Matematik Malaysia, 14(1), 12–25.
21. Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. Computers & Education, 58(1), 136–153.
22. Sorensen, P., Twidle, J., Childs, A., & Godwin, J. (2007). The use of the Internet in science teaching: A longitudinal study of developments in use by student-teachers in England. *International Journal of Science Education, 29*(13), 1605–1627.
23. Suyumov, J., Lutfillayev, M., Yuldosheva, D., Xasanova, M., & Polvonov, A. (2024). Technology for the formation and application of simulation modeling in the educational process. *E3S Web of Conferences: GreenEnergy 2023, 04008*.
24. T., & van Joolingen, W. R. (2008). Scientific discovery learning with computer simulations of conceptual domains. Review of Educational Research, 68(2), 179–201.
25. Tan, M. S., & Salandanan, G. G. (2016). Teaching Strategies: For the 21st Century Learner. Rex Bookstore.
26. Trongtirakul, T., Pusorn, K., & Peerawanichkul, U. (2022). Computer simulation-based learning: Student self-efficacy during COVID-19 outbreak.
27. Tsai, C. Y. (2022). Improving students’ PISA scientific competencies through online argumentation. *International Journal of Science Education, 37*(2), 321–339.
28. Tuballa, I. D., & Israel, G. F. G. (2024). The mediating effect of motivation on the relationship between classroom environment and students’ attitude towards science. European Journal of Education Studies, 11
29. Verawati, N. N. S., Asih, N. K. I., & Aji, G. S. (2024). The role of interactive labs and simulations in STEM education: A systematic review. International Journal of Education and Curriculum Application, 7(2), 103–114.
30. Wulandari, I., Fauzi, A., & Ramli, R. (2024). Student and teacher perspectives on virtual lab simulations in biology education. Education Sciences, 14(3), 243.
31. Yeo, L. B., & Zhao, Q. (2025). Smartphone-integrated physics laboratories (SmartIPLs)
32. Zamora, R., & Carreon, J. R. (2024). Virtual lab simulations in microbiology education: Perceptions and effectiveness. Journal of Microbiology & Biology Education, 25(1), e00203-24.