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Lessons in Earth Science Using Digitally Printed Three-Dimensional (3D) Models

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ABSTRACT

This study developed and evaluated lessons in Earth Science using digitally printed three-dimensional (3D) models to enhance Grade 8 students' conceptual understanding, higher-order thinking skills, science process skills, and collaborative skills. The study utilized a Research and Development (R&D) design combined with a quasi-experimental research approach involving control and experimental groups. The developed instructional materials included digitally printed 3D models representing selected Earth Science concepts such as earthquakes, faults, typhoons, comets, meteors, and asteroids. These materials were integrated into lesson plans and collaborative classroom activities aligned with the Most Essential Learning Competencies (MELCs) prescribed by the Department of Education.

The findings revealed that the developed instructional materials were highly acceptable in terms of content accuracy, instructional quality, usability, and alignment with curriculum competencies. Results further showed that students exposed to the 3D model-based instruction demonstrated significantly higher posttest scores in conceptual understanding, higher-order thinking skills, science process skills, and collaborative skills compared to students taught using conventional instructional methods. The use of interactive and manipulative 3D models enhanced students' visualization of abstract Earth Science concepts and promoted active participation, inquiry-based learning, and collaborative engagement in classroom activities.

The study concludes that integrating digitally printed 3D models into Earth Science instruction significantly improves students' academic performance and learning experiences. The findings highlight the effectiveness of technology-enhanced instructional materials in promoting meaningful, learner-centered, and interactive science education.

Keywords: *digitally printed 3D models, Earth Science instruction, conceptual understanding, higher-order thinking skills, science process skills, collaborative skills, science education, educational technology, active learning, Grade 8 students*

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INTRODUCTION

Science education plays a crucial role in developing scientifically literate individuals capable of understanding and addressing real-world challenges through critical thinking, problem-solving, and evidence-based decision-making. As societies continue to evolve due to rapid scientific and technological advancements, science education becomes increasingly important in preparing learners to adapt to changing environments and contribute meaningfully to sustainable development. UNESCO (2023) emphasized that science education broadens individuals' perspectives, enhances their understanding of the world, and contributes significantly to societal advancement through innovation and discovery. In particular, Earth Science education holds substantial importance because it focuses on understanding the Earth's structure, processes, resources, and hazards, all of which directly affect human life and environmental sustainability.

In the Philippine educational system, science education aims to develop scientifically literate learners who can apply scientific knowledge and skills in solving everyday problems and making informed decisions. However, despite the importance of science education, the country continues to face challenges in improving students' academic performance and scientific understanding. The Programme for International Student Assessment (PISA) results in 2018 and 2022 revealed that the Philippines consistently ranked among the lowest-performing countries in science, mathematics, and reading. According to the Organisation for Economic Co-operation and Development (OECD), Filipino students performed significantly below the international average, indicating substantial learning gaps and deficiencies in scientific literacy.

The low academic performance in science is also reflected in local school settings. At Cabangan High School in Albay, the consolidated Mean Performance Level (MPL) of Grade 8 students during the second quarter of the 2023–2024 school year was reported at only 49.72%, indicating low mastery of Earth Science competencies. This result highlights the need for innovative instructional interventions and learning materials capable of improving students' understanding of Earth Science concepts and enhancing their academic performance. Furthermore, the school has limited physical teaching-learning resources that can concretize abstract Earth Science concepts, making it difficult for learners to visualize and understand complex scientific phenomena effectively.

Earth Science is considered one of the most conceptually challenging branches of science because it involves abstract processes, spatial relationships, and dynamic Earth phenomena that are often difficult to observe directly. Topics such as earthquakes, faults, typhoons, and celestial bodies require learners to develop strong visualization and analytical skills to fully understand the concepts being taught. However, traditional teaching approaches commonly rely on textbooks, lectures, and two-dimensional illustrations, which may not sufficiently support conceptual understanding and meaningful learning experiences among students.

To address these challenges, educators are encouraged to integrate innovative instructional materials and active learning approaches into science instruction. One promising innovation is the use of digitally printed three-dimensional (3D) models as instructional tools in teaching Earth Science. Three-dimensional printing, also known as additive manufacturing, enables the creation of physical objects from digital designs by depositing materials layer by layer. This technology allows educators to develop realistic and manipulable instructional materials that can improve students' visualization, engagement, and conceptual understanding. According to Hasiuk et al. (2017), 3D printing enhances communication and understanding in science education by utilizing visual and tactile learning experiences that help students comprehend complex structures and processes.

The use of 3D models in science education also supports active and collaborative learning. Students become more engaged when they can manipulate models, interact with peers, and participate in hands-on activities that connect scientific concepts to real-world situations. Research has shown that active learning strategies significantly improve student performance and conceptual retention compared to traditional lecture-based instruction. Freeman et al. (2014) emphasized that students participating in active learning environments are more likely to develop deeper understanding, critical thinking abilities, and scientific process skills. Likewise, collaborative learning environments promote meaningful interactions among students, fostering communication, teamwork, and cooperative problem-solving skills.

Moreover, the integration of 3D models aligns with the development of higher-order thinking skills (HOTS) and science process skills (SPS), both of which are essential components of science education. Higher-order thinking skills involve analyzing, evaluating, creating, and solving complex problems, while science process skills include observing, measuring, inferring, experimenting, and interpreting data. These competencies are necessary for students to become scientifically literate individuals capable of addressing scientific and societal issues. The integration of interactive and manipulative instructional materials such as 3D models provides opportunities for learners to actively apply these skills during the learning process.

In addition, the development of collaborative skills is increasingly important in modern education. Collaborative learning encourages students to share ideas, communicate effectively, and work together toward common goals. Through group activities involving 3D models, students can engage in meaningful discussions, peer interactions, and cooperative learning experiences that enhance both academic achievement and social development. Collaborative environments also improve motivation and student engagement by creating supportive and interactive classroom settings.

Despite the growing interest in 3D printing technologies and active learning approaches, there remains limited research focusing specifically on the use of digitally printed 3D models in teaching Grade 8 Earth Science concepts in the Philippine context. Existing studies primarily focus on general science instruction or large-scale technological integration, leaving a gap in the literature regarding the effectiveness of 3D models in improving students' understanding of Earth Science concepts, higher-order thinking skills, science process skills, and collaborative skills.

In response to these gaps, the present study aimed to develop lessons in Earth Science using digitally printed three-dimensional (3D) models and determine their effects on Grade 8 students. Specifically, the study focused on the development of 3D models related to earthquakes, faults, typhoons, comets, meteors, and asteroids, and evaluated their effectiveness in enhancing students' conceptual understanding, higher-order thinking skills, science process skills, and collaborative skills. Through this investigation, the study sought to contribute to the advancement of innovative and technology-enhanced science education practices that promote meaningful and engaging learning experiences among learners.

Review of Related Literature

Science Education and Scientific Literacy

Science education plays a significant role in developing scientifically literate individuals capable of understanding natural phenomena, making informed decisions, and addressing societal challenges. Scientific literacy involves the ability to apply scientific knowledge, processes, and critical thinking skills in real-life situations. According to UNESCO (2023), science education contributes to societal development by promoting innovation, environmental awareness, and technological advancement. In educational settings, science instruction is expected to enhance learners' understanding of scientific concepts while also developing analytical and problem-solving skills.

However, many countries continue to experience difficulties in improving students' scientific literacy. The Programme for International Student Assessment (PISA) results consistently reveal gaps in science achievement among learners worldwide. In the Philippines, students continue to perform below international averages in science, highlighting the need for improved instructional approaches and innovative learning materials (OECD, 2023). These findings suggest that traditional teaching methods may not sufficiently address the learning needs of students in science education.

Challenges in Teaching Earth Science

Earth Science is considered one of the most challenging branches of science because it involves abstract concepts, spatial relationships, and dynamic Earth processes that are difficult to visualize directly. Topics such as earthquakes, plate tectonics, typhoons, and celestial bodies require learners to understand complex systems and interactions occurring within and beyond the Earth.

Traditional teaching strategies in Earth Science commonly rely on lectures, textbooks, and two-dimensional diagrams. While these methods provide theoretical information, they may not effectively support conceptual understanding, especially among learners who struggle with abstract visualization. According to Kali and Orion (1996), students often experience misconceptions in Earth Science due to difficulties in understanding spatial and temporal relationships.

Furthermore, Earth Science instruction in many schools is limited by inadequate instructional materials and laboratory resources. The absence of interactive and manipulative learning tools affects students' engagement and reduces opportunities for experiential learning.

Technology Integration in Science Education

The integration of technology in education has transformed teaching and learning processes across different disciplines. In science education, technological tools provide opportunities for interactive, student-centered, and inquiry-based learning experiences. Educational technologies such as simulations, digital visualizations, augmented reality, and 3D printing enhance conceptual understanding by allowing learners to interact with scientific representations in meaningful ways.

According to Mishra and Koehler (2006), effective technology integration supports both pedagogical and content knowledge, enabling teachers to create engaging and effective learning environments. Technology-based instructional materials also improve student motivation and participation because learners become actively involved in the learning process.

The use of digital technologies aligns with constructivist learning principles, which emphasize active participation, exploration, and knowledge construction. Through technology-enhanced learning environments, students can manipulate objects, observe scientific phenomena, and develop deeper conceptual understanding.

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Three-Dimensional (3D) Printing Technology in Education

Three-dimensional (3D) printing, also known as additive manufacturing, is a technology that creates physical objects from digital models by depositing materials layer by layer. Initially developed for industrial and engineering applications, 3D printing has gained increasing attention in education because of its ability to produce interactive and realistic instructional materials.

In science education, 3D printing allows teachers to create manipulable models that represent scientific structures and processes. Hasiuk et al. (2017) explained that 3D printing improves scientific communication and understanding by transforming abstract concepts into tangible learning materials. Students can directly observe, touch, and manipulate models, making complex concepts easier to understand.

The accessibility and affordability of 3D printing technology have also increased its application in schools. Teachers can design customized instructional materials that align with curriculum standards and specific learning objectives.

Use of 3D Models in Earth Science Instruction

The use of 3D models in Earth Science instruction enhances students' visualization and conceptual understanding of geological and astronomical phenomena. Three-dimensional representations provide concrete experiences that help learners understand structures, movements, and relationships that are difficult to observe directly.

Studies have shown that students who use 3D models demonstrate improved comprehension of Earth Science topics compared to those who rely solely on traditional instructional methods. According to Horowitz and Schultz (2014), visual and tactile learning experiences significantly improve students' ability to understand scientific structures and processes.

In Earth Science, 3D models can represent earthquakes, faults, volcanoes, typhoons, comets, meteors, asteroids, and other complex phenomena. By manipulating these models, students gain better understanding of spatial orientation, movement, and interaction among Earth systems.

Furthermore, 3D models encourage active participation and inquiry-based learning, which contribute to higher engagement and retention of scientific concepts.

Active Learning in Science Education

Active learning refers to instructional approaches that require students to actively participate in the learning process through discussion, collaboration, experimentation, and problem-solving activities. Unlike traditional lecture-based instruction, active learning emphasizes student engagement and interaction.

Freeman et al. (2014) found that active learning strategies significantly improve academic performance and reduce failure rates in science, technology, engineering, and mathematics (STEM) courses. Students participating in active learning environments demonstrate better conceptual understanding and critical thinking skills.

The integration of 3D models supports active learning because students become directly involved in manipulating and analyzing instructional materials. Instead of passively receiving information, learners interact with scientific concepts through observation, experimentation, and discussion. Active learning also enhances motivation and encourages learners to explore scientific ideas independently and collaboratively.

Higher-Order Thinking Skills (HOTS)

Higher-order thinking skills involve advanced cognitive processes such as analyzing, evaluating, synthesizing, and creating. These skills are essential in science education because they enable students to solve problems, interpret evidence, and apply scientific knowledge in real-world contexts.

According to Brookhart (2010), higher-order thinking occurs when learners go beyond memorization and engage in meaningful cognitive processing. Science instruction should therefore encourage students to analyze data, interpret observations, and formulate conclusions based on evidence.

The use of 3D models promotes higher-order thinking by allowing students to examine structures, compare relationships, and develop explanations for scientific phenomena. Manipulative learning materials encourage learners to ask questions, test ideas, and explore multiple perspectives.

Through interactive learning activities involving 3D models, students can strengthen their analytical and problem-solving abilities while improving conceptual understanding.

Science Process Skills (SPS)

Science process skills are fundamental abilities used in scientific investigation and inquiry. These skills include observing, classifying, measuring, inferring, predicting, experimenting, and communicating scientific findings.

Science process skills are important because they enable students to understand how scientific knowledge is generated and validated. According to Padilla (1990), science instruction should develop both basic and integrated process skills to promote scientific literacy and inquiry competence.

The integration of 3D models into Earth Science lessons supports the development of science process skills by providing opportunities for observation, experimentation, and interpretation. Students can manipulate models, identify relationships, and analyze scientific phenomena through hands-on learning experiences.

Interactive instructional materials also encourage students to formulate hypotheses, conduct investigations, and communicate their findings effectively.

Collaborative Learning

Collaborative learning is an instructional approach in which students work together to achieve shared learning goals. It promotes communication, teamwork, peer interaction, and cooperative problem-solving.

Johnson and Johnson (2009) emphasized that collaborative learning improves academic achievement, interpersonal relationships, and student motivation. Through collaborative activities, learners exchange ideas, explain concepts, and support one another’s understanding.

The use of 3D models in group-based science activities enhances collaboration because students engage in collective exploration and discussion. Manipulating models together encourages active participation and strengthens communication skills.

Collaborative learning environments also help create positive classroom interactions and improve students' confidence in expressing scientific ideas.

Research Gap

Several studies have explored the integration of technology, active learning, and manipulative instructional materials in science education. Research has also demonstrated the effectiveness of 3D printing technology in improving conceptual understanding and student engagement.

However, limited studies focus specifically on the use of digitally printed three-dimensional (3D) models in teaching Grade 8 Earth Science concepts within the Philippine educational context. Existing studies often focus on higher education, engineering, or general science instruction without examining the effects of 3D models on higher-order thinking skills, science process skills, and collaborative skills among junior high school students.

This study addresses these gaps by developing Earth Science lessons using digitally printed 3D models and evaluating their effectiveness in enhancing students' conceptual understanding, higher-order thinking skills, science process skills, and collaborative skills.

METHODOLOGY

Research Design

This study utilized a Research and Development (R&D) design combined with a quasi-experimental research approach to develop and evaluate lessons in Earth Science using digitally printed three-dimensional (3D) models. The Research and Development method was employed to systematically design, create, validate, and implement the 3D instructional models and accompanying lesson materials. Meanwhile, the quasi-experimental approach was used to determine the effectiveness of the developed instructional materials in enhancing students' conceptual understanding, higher-order thinking skills, science process skills, and collaborative skills.

The study specifically employed a pretest-posttest control group design, wherein two groups of Grade 8 students were involved. One group served as the experimental group exposed to the 3D model-based instruction, while the other group served as the control group taught using conventional instructional methods. This design enabled the researchers to compare learning outcomes and determine the effectiveness of the developed intervention.

Research Locale

The study was conducted at Cabangan High School, located in the Province of Albay, Philippines. The school was selected due to the observed low performance of Grade 8 students in Earth Science competencies, particularly in topics involving abstract and complex scientific concepts such as earthquakes, faults, typhoons, comets, meteors, and asteroids.

The school also experiences limited availability of instructional materials and manipulative learning resources that can support visualization and active learning in science classes. These conditions made the school an appropriate setting for implementing and evaluating innovative instructional interventions using digitally printed 3D models.

Respondents of the Study

The respondents of the study consisted of Grade 8 students enrolled at Cabangan High School during the School Year 2023–2024. Two sections of Grade 8 students were selected as participants in the study.

One section was assigned as the experimental group, which utilized Earth Science lessons integrated with digitally printed 3D models, while the other section served as the control group, which received instruction through conventional teaching methods.

The respondents were selected using purposive sampling based on the similarity of academic performance, class size, and accessibility. The inclusion of both groups allowed the researchers to compare learning outcomes and evaluate the effectiveness of the developed instructional intervention.

Development of the 3D Models and Instructional Materials

The study involved the development of digitally printed three-dimensional (3D) models related to selected Earth Science topics, including:

- Earthquakes
- Faults
- Typhoons
- Comets
- Meteors
- Asteroids

The development process began with conceptualization and digital design using computer-aided design (CAD) software. The researchers created digital prototypes that accurately represented the selected Earth Science concepts and aligned with the Most Essential Learning Competencies (MELCs) prescribed by the Department of Education.

After designing the digital models, the researchers utilized 3D printing technology to produce physical instructional materials. The printed models were evaluated for accuracy, durability, usability, and appropriateness for classroom instruction.

The researchers also developed lesson plans, learning activities, worksheets, and assessment tools integrated with the use of the 3D models to support active and collaborative learning.

Research Instruments

Several research instruments were utilized in gathering data for the study. These included:

- Conceptual Understanding Test

- Higher-Order Thinking Skills (HOTS) Test
- Science Process Skills (SPS) Assessment
- Collaborative Skills Rubric
- Validation Evaluation Forms

The conceptual understanding test measured students' knowledge and comprehension of Earth Science concepts before and after instruction. The HOTS assessment evaluated students' analytical, evaluative, and problem-solving abilities. The Science Process Skills assessment measured learners' abilities in observing, inferring, interpreting, and experimenting.

Meanwhile, the collaborative skills rubric assessed students' communication, participation, teamwork, and cooperation during group learning activities involving the 3D models.

The developed instructional materials and research instruments were validated by experts in science education, instructional materials development, and educational technology to ensure content validity, accuracy, and appropriateness.

Data Gathering Procedure

The researchers first secured approval from the school administration before conducting the study. Consent was also obtained from the participants and their advisers.

The study began with the administration of pretests to both the control and experimental groups to determine their initial level of conceptual understanding, higher-order thinking skills, and science process skills.

After the pretest, the experimental group underwent instruction using Earth Science lessons integrated with digitally printed 3D models, while the control group received conventional classroom instruction using standard teaching materials and methods.

During classroom implementation, students in the experimental group participated in collaborative learning activities involving observation, manipulation, and analysis of the 3D models. The researchers also observed students' collaborative interactions and learning behaviors.

At the end of the intervention period, posttests were administered to both groups to determine changes in learning outcomes. The gathered data were then organized, tabulated, and analyzed.

Validation of Instructional Materials

The developed 3D models and lesson materials underwent validation by selected experts composed of science teachers, educational technology specialists, and curriculum experts.

The validators evaluated the materials based on:

- Accuracy of scientific content
- Alignment with learning competencies
- Visual and physical quality
- Instructional usefulness

- Usability and effectiveness

Comments and recommendations from the validators were incorporated into the revision and improvement of the developed materials prior to implementation.

Statistical Treatment of Data

The collected data were analyzed using appropriate statistical tools and techniques. Frequency counts, percentages, weighted mean, and standard deviation were used to summarize and describe the data gathered from validation and assessment results.

To determine the effectiveness of the developed instructional materials, the researchers utilized:

- Mean gain scores
- Paired sample t-test
- Independent sample t-test

These statistical tools were used to compare the pretest and posttest performances of the control and experimental groups and determine whether significant differences existed between the two groups.

The statistical analyses enabled the researchers to evaluate the impact of digitally printed 3D models on students' conceptual understanding, higher-order thinking skills, science process skills, and collaborative skills.

Ethical Considerations

The researchers ensured that ethical standards were strictly observed throughout the conduct of the study. Participation in the study was voluntary, and all gathered information was treated with confidentiality.

The researchers ensured that the instructional intervention did not cause harm or disadvantage to any participant. The data gathered were used solely for academic and research purposes.

Permission from school authorities and concerned individuals was secured prior to conducting classroom implementation and data collection activities.

RESULTS AND DISCUSSION

This section presents the findings of the study regarding the effectiveness of lessons in Earth Science using digitally printed three-dimensional (3D) models in enhancing Grade 8 students' conceptual understanding, higher-order thinking skills, science process skills, and collaborative skills. The results were obtained from the implementation of the developed instructional materials and the analysis of pretest and posttest performances of the experimental and control groups.

The findings were organized and interpreted according to the objectives of the study. Comparisons were made between the performances of students exposed to 3D model-based instruction and those taught using conventional teaching methods. The discussion also explains how the use of digitally printed 3D models influenced students' learning experiences and academic performance.

Validation of the Developed 3D Models and Instructional Materials

The developed digitally printed 3D models and accompanying lesson materials were evaluated by experts in science education, educational technology, and curriculum development. The validators assessed the materials based on content accuracy, instructional relevance, visual quality, usability, and alignment with the learning competencies prescribed by the Department of Education.

The evaluation results revealed that the developed materials were rated highly acceptable in terms of scientific accuracy and instructional effectiveness. Validators noted that the 3D models effectively represented Earth Science concepts such as earthquakes, faults, typhoons, comets, meteors, and asteroids. The physical and visual characteristics of the models enhanced their suitability for classroom instruction and active learning activities.

The validators also emphasized that the models promoted learner engagement and supported experiential learning. Suggestions provided by the experts were incorporated to improve the clarity, durability, and instructional value of the materials before their actual implementation in the classroom.

These findings indicate that the developed 3D instructional materials were appropriate and effective for use in Earth Science instruction.

Students' Conceptual Understanding

The pretest results showed that both the control and experimental groups initially demonstrated low levels of conceptual understanding in Earth Science topics. Many students had difficulty explaining abstract scientific concepts and interpreting Earth processes using traditional textbook-based approaches.

After the implementation of the lessons, the posttest results revealed a significant improvement in the conceptual understanding of students exposed to the 3D model-based instruction. The experimental group obtained higher mean scores compared to the control group, indicating that the use of digitally printed 3D models enhanced students' understanding of Earth Science concepts.

Students in the experimental group demonstrated better comprehension of the structure and movement of faults, the formation of earthquakes, the development of typhoons, and the characteristics of celestial bodies such as comets, meteors, and asteroids. The ability to manipulate and observe the 3D models enabled learners to visualize concepts more clearly and connect theoretical discussions with concrete representations.

The findings suggest that the integration of 3D models improved students' ability to process abstract scientific information and facilitated meaningful learning experiences.

Higher-Order Thinking Skills (HOTS)

The study also examined the effects of the developed instructional materials on students' higher-order thinking skills. Results indicated that students exposed to the 3D models demonstrated improved abilities in analyzing, evaluating, and solving scientific problems.

During classroom activities, students in the experimental group actively engaged in discussions, interpretation of observations, and collaborative problem-solving tasks involving the models. Learners were able to analyze the causes and effects of geological and atmospheric phenomena, compare scientific processes, and formulate explanations based on evidence gathered from the instructional materials.

The posttest results showed that the experimental group achieved significantly higher HOTS scores than the control group. This indicates that the use of interactive and manipulative instructional materials promoted deeper cognitive processing and analytical thinking.

The findings support the idea that active and experiential learning environments contribute to the development of higher-order cognitive skills among students.

Science Process Skills (SPS)

Science process skills are essential competencies that enable learners to engage in scientific inquiry and investigation. The study assessed students' abilities in observing, inferring, predicting, interpreting, and communicating scientific information.

The results revealed that students exposed to the 3D model-based lessons demonstrated significant improvement in science process skills compared to those taught using conventional methods. The experimental group showed greater proficiency in making observations, identifying relationships among concepts, and interpreting scientific phenomena.

The hands-on nature of the 3D models allowed students to directly interact with instructional materials, encouraging active observation and exploration. Learners were also able to formulate hypotheses, analyze patterns, and communicate their findings during collaborative learning activities.

The improvement in science process skills suggests that the use of 3D instructional models enhanced inquiry-based learning and promoted active scientific investigation among students.

Collaborative Skills

The implementation of collaborative learning activities involving the 3D models positively influenced students' collaborative skills. Students in the experimental group participated in group discussions, cooperative tasks, and peer-assisted learning activities while using the models.

Observations during classroom implementation showed that students demonstrated improved communication, teamwork, and participation. Learners actively exchanged ideas, shared observations, and worked together to solve problems related to Earth Science concepts.

The collaborative use of 3D models encouraged student interaction and increased engagement during classroom activities. Students also displayed greater confidence in expressing their ideas and contributing to group discussions.

The findings indicate that integrating manipulative instructional materials into collaborative learning environments supports both academic and social development among learners.

Comparison Between the Experimental and Control Groups

Comparative analysis between the experimental and control groups revealed that students exposed to the digitally printed 3D models consistently outperformed those taught through conventional instructional methods.

The experimental group obtained higher mean scores in conceptual understanding, higher-order thinking skills, science process skills, and collaborative skills. Statistical analysis further indicated significant differences between the performances of the two groups.

These findings suggest that the developed 3D instructional materials were more effective than traditional teaching approaches in improving learning outcomes among Grade 8 students.

The use of 3D models provided learners with concrete, interactive, and engaging learning experiences that enhanced both cognitive and collaborative competencies.

Discussion of Findings

The findings of the study demonstrate that digitally printed three-dimensional (3D) models significantly improved students' learning experiences and academic performance in Earth Science. The integration of interactive and manipulative instructional materials enhanced conceptual understanding by enabling students to visualize and explore abstract scientific concepts concretely.

The positive effects observed in higher-order thinking skills and science process skills indicate that the use of 3D models promoted inquiry-based and active learning. Students became more engaged in analyzing scientific phenomena, interpreting observations, and solving problems through collaborative activities.

The findings also highlight the importance of collaborative learning environments in science education. Through group interaction and cooperative tasks, students developed communication and teamwork skills that contributed to more meaningful learning experiences.

Overall, the results confirm that the use of digitally printed 3D models is an effective instructional strategy for improving students' conceptual understanding, higher-order thinking skills, science process skills, and collaborative skills in Earth Science.

Conclusion

This study successfully developed and implemented lessons in Earth Science using digitally printed three-dimensional (3D) models for Grade 8 students of Cabangan High School. The findings revealed that the developed instructional materials were highly acceptable in terms of content accuracy, instructional quality, usability, and alignment with curriculum competencies. The digitally printed 3D models effectively represented Earth Science concepts such as earthquakes, faults, typhoons, comets, meteors, and asteroids, making abstract scientific ideas more concrete and understandable for learners.

The study further demonstrated that the use of digitally printed 3D models significantly improved students' conceptual understanding of Earth Science concepts. Students exposed to the 3D model-based instruction achieved higher posttest scores compared to those taught using conventional teaching methods. The interactive and manipulative nature of the models enabled learners to better visualize scientific structures, processes, and relationships, resulting in deeper comprehension and meaningful learning experiences.

In addition, the developed instructional materials positively influenced students' higher-order thinking skills. Learners demonstrated improved abilities in analyzing scientific phenomena, evaluating observations, and solving conceptual problems through active engagement with the 3D models. The study also showed that the integration of hands-on and inquiry-based learning activities enhanced students' science process skills, particularly in observing, inferring, interpreting, and communicating scientific information.

Moreover, the implementation of collaborative learning activities using the 3D models promoted the development of students' collaborative skills. Students became more engaged in group discussions, cooperative tasks, and peer interaction, which improved communication, teamwork, and classroom participation.

The comparative analysis between the experimental and control groups confirmed that students exposed to the digitally printed 3D models consistently outperformed those who received conventional instruction. These findings indicate that the use of digitally printed 3D models is an effective instructional strategy for improving conceptual understanding, higher-order thinking skills, science process skills, and collaborative skills in Earth Science.

Overall, the study concludes that integrating digitally printed 3D models into Earth Science instruction provides meaningful, interactive, and learner-centered educational experiences that significantly enhance students' academic performance and engagement in science learning.

Implications of the Study

The findings of this study have important implications for science education, instructional material development, and educational technology integration.

For science teachers, the study highlights the importance of utilizing innovative and manipulative instructional materials to improve conceptual understanding and student engagement. The use of digitally printed 3D models provides opportunities for more interactive and experiential learning environments that support active participation and inquiry-based learning.

For schools and educational institutions, the study emphasizes the value of integrating technology-enhanced instructional resources into science classrooms. The implementation of 3D printing technology can improve the availability of customized learning materials that address specific learning competencies and student needs.

The study also contributes to curriculum development by demonstrating that interactive instructional approaches can effectively support the development of higher-order thinking skills, science process skills, and collaborative competencies among learners.

From a technological perspective, the study supports the growing role of educational technologies in improving learning outcomes and promoting student-centered instruction. The successful integration of 3D printing technology into classroom instruction demonstrates its potential as a valuable educational tool in science education.

Recommendations

Based on the findings and conclusions of the study, the following recommendations are proposed:

- Science teachers are encouraged to integrate digitally printed 3D models and other manipulative instructional materials into classroom instruction to improve students' conceptual understanding and engagement in science learning.
- Schools and educational institutions may invest in educational technologies such as 3D printing equipment and teacher training programs to support the development of innovative instructional materials aligned with curriculum competencies.
- Teachers should implement more active and collaborative learning activities that encourage students to manipulate instructional materials, participate in group discussions, and engage in inquiry-based learning experiences.
- Future developers of instructional materials may improve the design and functionality of 3D models by incorporating additional interactive features, augmented reality integration, or digital simulations to further enhance student learning experiences.
- Educational administrators may support the adoption of technology-enhanced instructional approaches by providing resources, technical support, and professional development opportunities for teachers.

Future Research Directions

Although the study demonstrated positive results, several areas may still be explored in future research.

Future studies may investigate the long-term effects of digitally printed 3D models on students' retention of scientific concepts and academic performance in other branches of science such as Biology, Chemistry, and Physics.

Researchers may also conduct comparative studies involving different grade levels, school settings, and instructional approaches to further evaluate the effectiveness of 3D model-based instruction across various educational contexts.

Further research may explore the integration of augmented reality, virtual reality, and artificial intelligence technologies with 3D printed instructional materials to create more immersive and interactive science learning environments.

Future studies may also examine the perceptions, attitudes, and experiences of teachers and students regarding the use of 3D printing technology in classroom instruction.

Additionally, cost-effectiveness studies may be conducted to evaluate the practicality and sustainability of implementing 3D printing technologies in public schools and educational institutions with limited resources.

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