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Enhancing Students' Conceptual Understanding and Sustainability Awareness through Fishbone-Oriented Instruction in Science Learning to Support Sustainable Development Goals (SDGs)

Wafa P. Cali, Hannah P. Abdulmalik*

Mindanao State University, Philippines

*Correspondence: E-mail: wafa.cali@msumain.edu.ph

ABSTRACT

This study examines the effectiveness of Fishbone-Oriented Instruction (FOI) in enhancing students' conceptual understanding and sustainability awareness in science learning. Using a mixed-method approach with a one-group pretest-posttest design, the study involved secondary school students. Quantitative data from a conceptual understanding test were analyzed using normalized gain scores, while qualitative data were collected through observations, reflective journals, and interviews. The findings show a moderate improvement in students' conceptual understanding, particularly in identifying causal relationships and explaining scientific phenomena. FOI promotes active participation, structured reasoning, collaborative discussion, and connections between scientific concepts and real-world sustainability issues. The study suggests that this strategy supports conceptual learning and sustainability-oriented thinking in science education.

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1. INTRODUCTION

Conceptual understanding is a fundamental goal of science education because it enables students to explain scientific phenomena, identify causal relationships, and apply knowledge meaningfully in real-world contexts. However, science learning in secondary schools often emphasizes factual recall and procedural problem-solving rather than deep conceptual reasoning. As a result, students may develop fragmented understanding and experience difficulty transferring scientific knowledge to complex situations (Chi, 2009). This challenge becomes more evident when students are required to analyze problems involving multiple causes and consequences, particularly those related to environmental and sustainability issues. In recent years, science education has increasingly emphasized instructional approaches that support higher-order thinking, structured reasoning, and active student engagement. Learning strategies that encourage students to analyze problems systematically and visualize causal relationships can improve conceptual understanding and scientific reasoning skills (Hmelo-Silver *et al.*, 2007). At the same time, integrating sustainability issues into science learning has become an important educational priority, in line with the Sustainable Development Goals (SDGs), particularly SDG 4 on quality education and SDG 12 on responsible consumption and production. Therefore, science classrooms should not only develop students' conceptual knowledge but also foster their awareness of sustainability challenges and their ability to analyze socio-environmental problems critically.

Fishbone-Oriented Instruction (FOI) offers a pedagogical framework that supports structured problem analysis through the identification of causes and effects using visual representations. Derived from the fishbone diagram, FOI can be adapted in educational contexts to help students organize ideas, examine relationships among variables, and construct coherent scientific explanations (Dogru, 2008). Visual and cause-and-effect-based instructional strategies are also considered useful for enhancing conceptual understanding because they make abstract relationships more explicit and cognitively accessible (Ainsworth, 2006). Nevertheless, empirical evidence regarding the effectiveness of FOI in science learning, particularly in relation to sustainability awareness, remains limited.

Previous studies in science education have mainly focused on inquiry-based learning, problem-based learning, and concept mapping as strategies for promoting conceptual change and reasoning skills (Chi, 2009; Hmelo-Silver *et al.*, 2007). Comparatively fewer studies have examined fishbone-based instructional approaches as structured reasoning tools in science classrooms. Moreover, the integration of FOI with sustainability-oriented science content has not been sufficiently explored. This gap indicates the need to examine how FOI can simultaneously support students' conceptual understanding and sustainability awareness.

Addressing this gap, the present study investigated the effectiveness of FOI in enhancing students' conceptual understanding and sustainability awareness in science learning. Specifically, this study examined changes in students' conceptual understanding before and after the implementation of FOI and explores students' learning experiences during the instructional process. By integrating structured reasoning with sustainability-oriented science content, this study contributes to the development of pedagogical strategies that support meaningful learning and align science education with global sustainability goals.

2. METHODS

This study employed a mixed-method approach with a one-group pretest-posttest design to examine the effectiveness of FOI in enhancing students' conceptual understanding and sustainability awareness in science learning. The quantitative component measured changes in students' conceptual understanding before and after the instructional intervention, while the qualitative component explored students' learning experiences and perceptions during the implementation of FOI. This approach enabled the integration of learning outcome data with descriptive classroom evidence, providing a comprehensive understanding of the instructional impact.

The participants were secondary school students enrolled in a science course. The intervention was conducted during regular classroom sessions as part of the existing curriculum. All participants received the same instructional treatment, and no control group was involved. Before the intervention, students had limited experience with structured problem-analysis strategies using visual representations such as fishbone diagrams. Participation in the study was voluntary, and students were informed about the purpose of the research.

The instructional procedure began with the administration of a pretest to assess students' initial conceptual understanding. During the learning process, FOI was implemented over several instructional sessions. Students were introduced to the fishbone diagram as a visual tool for analyzing scientific problems by identifying central issues and organizing possible causes into related categories. Guided by the teacher, students worked individually and in small groups to construct fishbone diagrams based on science topics related to sustainability issues. The learning activities emphasized the identification of cause-and-effect relationships, discussion of alternative explanations, and connection of scientific concepts to real-world contexts. At the end of the instructional sequence, a posttest was administered to measure changes in students' conceptual understanding.

Quantitative data were collected using a conceptual understanding test designed to assess students' ability to explain scientific concepts, identify causal relationships, and apply knowledge to problem situations. The test items were reviewed to ensure content validity, and the reliability of the instrument was examined using internal consistency analysis. Qualitative data were obtained through classroom observations, students' reflective journals, and semi-structured interviews. Observations focused on student engagement and interaction during FOI activities, while reflective journals and interviews provided insights into students' reasoning processes and perceptions of the instructional approach.

Quantitative data from the pretest and posttest were analyzed using normalized gain scores to determine the level of improvement in students' conceptual understanding. The gain scores were interpreted using established criteria to categorize learning improvement levels. Qualitative data were analyzed thematically by identifying recurring patterns related to students' engagement, reasoning, and learning experiences. The integration of quantitative and qualitative findings was used to strengthen the interpretation of the results.

Ethical considerations were addressed by informing participants about the study objectives and ensuring the confidentiality of student responses. The instructional activities were conducted as part of normal classroom practice and did not interfere with students' academic evaluation.

3. RESULTS AND DISCUSSION

3.1. Normalized gain of students' conceptual understanding after the intervention

This section presents the quantitative results of students' conceptual understanding after the implementation of FOI. The results are supported by qualitative data from interviews, reflective journals, and classroom observations to explain how FOI contributed to students' learning improvement. Students' conceptual understanding was measured using a researcher-developed Conceptual Understanding Test, and the improvement was analyzed using normalized gain scores based on the classification (Hake, 1998). The analysis involved two Grade 9 sections, namely Nuh and Yunos. The distribution of students' normalized gain scores is presented in **Table 1**. Both sections achieved medium normalized gains. Section Nuh obtained an average N-gain of 0.61, while Section Yunos achieved a slightly higher average N-gain of 0.64. The overall N-gain of 0.62 indicates a medium level of conceptual improvement after the FOI intervention. Importantly, no student was classified in the low-gain category, suggesting that all participants experienced measurable improvement in conceptual understanding. FOI supported students in achieving a substantial portion of the possible learning improvement. This result suggests that the use of fishbone diagrams helped students reorganize prior knowledge, identify relationships among concepts, and explain scientific phenomena through structured cause-and-effect reasoning. The presence of students in the high-gain category, particularly in Section Yunos, further indicates that FOI may be especially beneficial for learners who respond well to visual, structured, and inquiry-oriented learning environments.

Table 1. Normalized gain, average gain, overall normalized gain, and interpretation of students' conceptual understanding in science after intervention.

SECTIONS	LOW GAIN	MEDIUM GAIN	HIGH GAIN	AVE. GAIN	OVERALL N-GAIN	INTERPRETATION
Nuh	0	31	6	0.61	0.62	Medium gain
Yunos	0	20	11	0.64		Medium gain
Total	0	51	17			Medium gain

Note: Normalized gain (g): $g > 0.70$ = high gain; $0.30 < g < 0.70$ = medium gain; $g < 0.30$ = low gain. Adapted from reference (Hake, 1998).

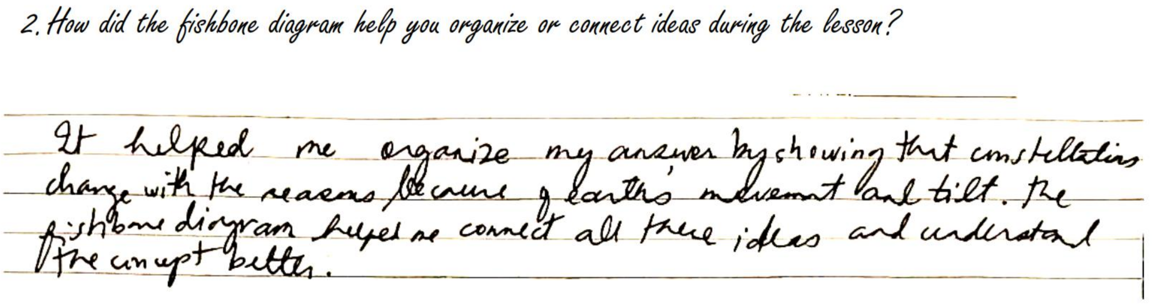
The absence of low-gain outcomes is also notable. FOI provided learning scaffolds that supported students with different levels of prior understanding. By breaking down complex scientific issues into main problems, causes, sub-causes, and effects, students were guided to analyze concepts more systematically rather than relying on memorization alone. This finding is consistent with previous studies showing that visual mapping and fishbone-based strategies can improve students' analytical and problem-solving skills in science learning (Hidayat and Rohman, 2019; Suryani and Hendri, 2019).

The quantitative findings are supported by students' interview responses. Fishbone diagrams helped them understand lessons more clearly, remember key concepts, and connect ideas logically. One student stated that FOI enabled the group to work together and share ideas, while another explained that the strategy helped them remember the key concepts being studied. Students' improvement was not only reflected in test scores but also in their perceived understanding and engagement during learning.

Students also reported that FOI helped them identify causes and sub-causes of a main issue. For example, one student explained that the fishbone diagram made it easier to identify the causes and sub-causes of a problem, while another stated that the diagram helped connect ideas and understand the lesson better. These responses show that FOI encouraged students to move beyond recalling information and toward analyzing conceptual relationships. This finding is consistent with studies indicating that fishbone diagrams and visual reasoning strategies can enhance students' analytical thinking, engagement, and conceptual learning in science education (Latha and Prasad, 2019; Patel and Pradhan, 2018).

Students' reflective journals provide further evidence of this process. As shown in **Figure 1**, one student explained that the fishbone diagram helped organize ideas about how Earth's movement and tilt influence the seasonal appearance of constellations. Similarly, **Figure 2** shows how another student used the fishbone diagram to analyze pollution by identifying the main problem, its causes, and its effects. The journal entries in **Figures 1 and 2** indicate that students were able to construct scientifically meaningful explanations through visual organization. The fishbone diagram helped students transform abstract scientific ideas into structured representations, supporting their ability to identify causal relationships and explain concepts more coherently. This finding is consistent with studies on visual learning strategies, which show that visual representations can reduce cognitive load and support conceptual understanding (Chang *et al.*, 2019; Wang *et al.*, 2018).

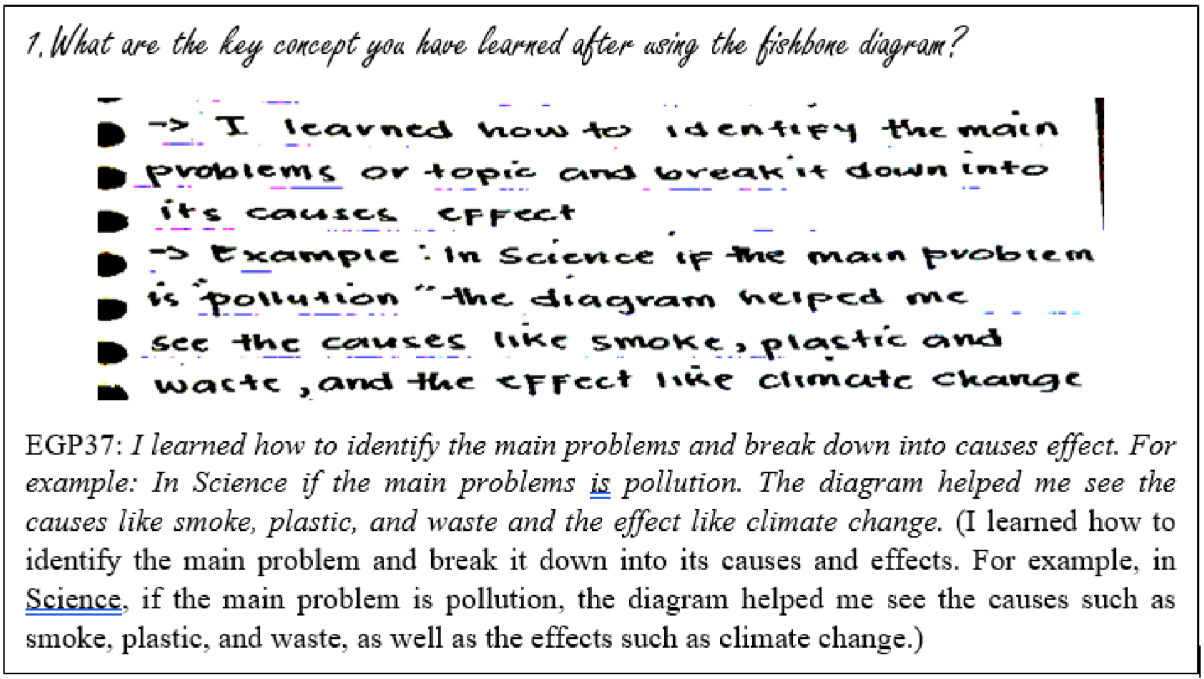
Additional interviews and journal data further show that FOI encouraged responsibility, confidence, and active participation. One student stated that the strategy encouraged them to complete assignments and gain confidence in presenting group outputs. Another student explained that the diagram showed how different causes were connected to a central problem, such as biodiversity. These findings indicate that FOI supported not only cognitive development but also students' confidence and participation in science learning.


2. How did the fishbone diagram help you organize or connect ideas during the lesson?

It helped me organize my answer by showing that constellations change with the seasons because of earth's movement and tilt. The fishbone diagram helped me connect all these ideas and understand the concept better.

EGP66: *It helped me organize my answer by showing that constellations change with the seasons because of earth's movement and tilt. The fishbone diagram helped me connect all these ideas and understand the concept better.* (It helped me organize my answer by showing that constellations change with the seasons because of the Earth's movement and tilt. The fishbone diagram also helped me connect these ideas and understand the concept better.)

Figure 1. Journal entry of EGP66 dated October 15, 2025.



1. What are the key concept you have learned after using the fishbone diagram?

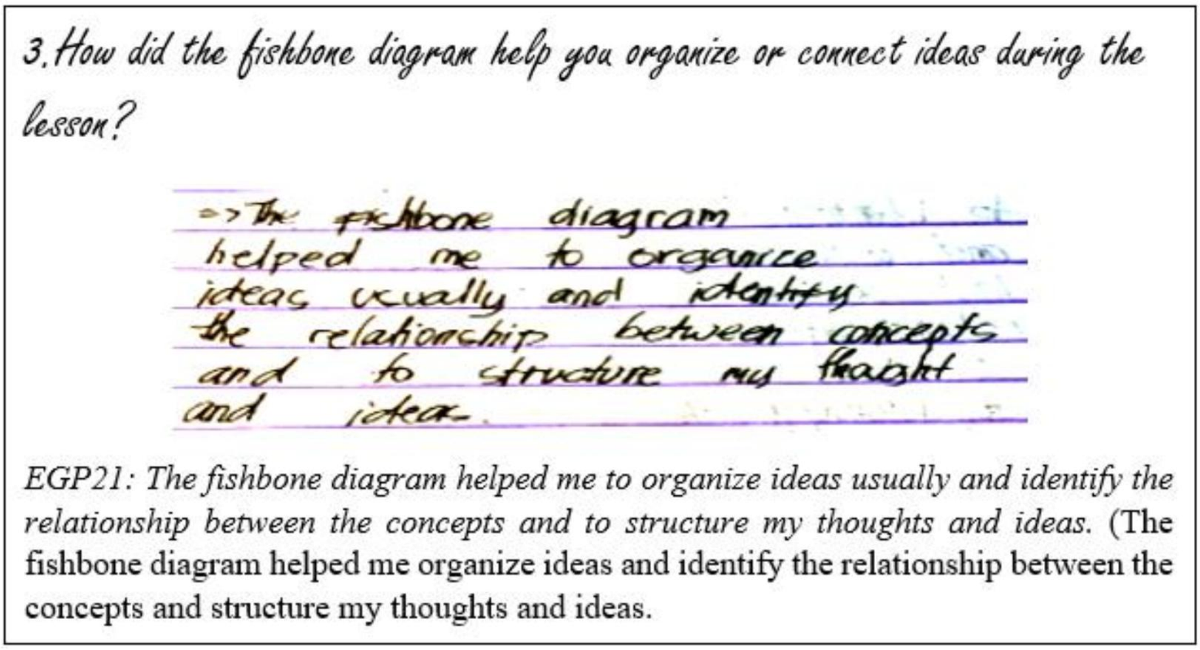
-> I learned how to identify the main problems or topic and break it down into its causes effect

-> Example : In Science if the main problem is pollution "the diagram helped me see the causes like smoke, plastic and waste, and the effect like climate change

EGP37: *I learned how to identify the main problems and break down into causes effect. For example: In Science if the main problems is pollution. The diagram helped me see the causes like smoke, plastic, and waste and the effect like climate change.* (I learned how to identify the main problem and break it down into its causes and effects. For example, in Science, if the main problem is pollution, the diagram helped me see the causes such as smoke, plastic, and waste, as well as the effects such as climate change.)

Figure 2. Journal entry of EGP37 dated October 6, 2025.

This interpretation is reinforced by **Figures 3 and 4**. **Figure 3** shows a student's reflection on how the fishbone diagram helped organize ideas and identify relationships among concepts. **Figure 4** shows another student's reflection on how the diagram provided a visual framework for breaking down complex problems into categorized causes. Students perceived the fishbone diagram as a tool for organizing and connecting ideas. These reflections suggest that FOI supported students' cognitive organization by allowing them to externalize their thinking, categorize information, and identify relationships among scientific concepts. Such processes are important for conceptual change because students need to reorganize fragmented knowledge into more coherent conceptual structures.



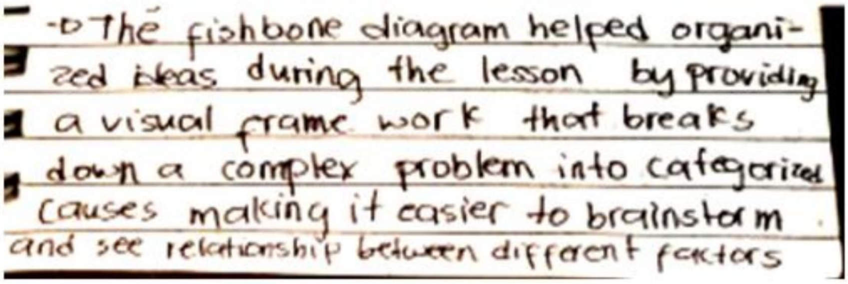
3. How did the fishbone diagram help you organize or connect ideas during the lesson?

=> The fishbone diagram helped me to organize ideas usually and identify the relationship between concepts and to structure my thought and idea.

EGP21: The fishbone diagram helped me to organize ideas usually and identify the relationship between the concepts and to structure my thoughts and ideas. (The fishbone diagram helped me organize ideas and identify the relationship between the concepts and structure my thoughts and ideas.

Figure 3. Journal entry of EGP21 dated September 3, 2025.

3. *How did the fishbone diagram help you organize or connect ideas during the lesson?*

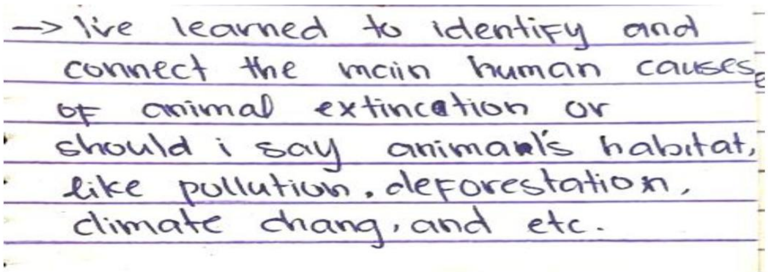

-> The fishbone diagram helped organi-
zed ideas during the lesson by providing
a visual frame work that breaks
down a complex problem into categorized
causes making it easier to brainstorm
and see relationship between different factors

EGP 32: The fishbone diagram helped organized ideas during the lesson by providing a visual framework that breaks down a complex problem into categorized caused making it easier to brainstorm and see the relationship between different factors. (The fishbone diagram helped me organized ideas during the lesson by providing a visual framework that breaks down a complex problem into categorized caused making it easier to brainstorm and see the relationship between different factors.)

Figure 4. Journal entry of EGP32 dated September 17, 2025.

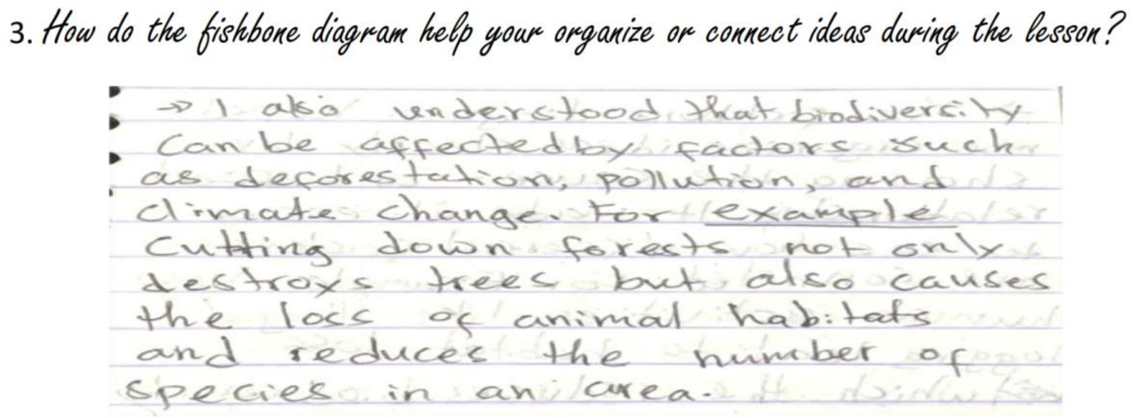
Beyond conceptual understanding, students also demonstrated the ability to connect science learning with real-world environmental issues. As shown in **Figure 5**, one student identified pollution, deforestation, and climate change as human-related causes of animal extinction and habitat loss. Similarly, **Figure 6** shows another student's reflection on how biodiversity is affected by deforestation, pollution, and climate change.

2. *How do the fishbone diagram help your organize or connect ideas during the lesson?*


-> I've learned to identify and
connect the main human causes
of animal extincation or
should i say animal's habitat,
like pollution, deforestation,
climate chang, and etc.

EGP43: *I have learned to identify and connect the main human causes of animal extinction, or should I say animals' habitat, like pollution, deforestation, climate change, etc.* (I have learned to identify and connect the main human causes of animal extinction which are pollution, deforestation, climate change, and etc.)

Figure 5. Journal entry of EGP43 dated September 3, 2025.


3. How do the fishbone diagram help your organize or connect ideas during the lesson?

→ I also understood that biodiversity can be affected by factors such as deforestation, pollution, and climate change. For example cutting down forests not only destroys trees but also causes the loss of animal habitats and reduces the number of species in an area.

EGP 24: I also understood that biodiversity can be affected by factors such as deforestation, pollution, and climate change. For example, cutting down forests not only destroys trees but also causes the loss of animal habitats and reduces the number of species in an area. (I also learned that biodiversity can be affected by factors such as deforestation, pollution, and climate change. For example, cutting down forests not only destroys trees but also leads to the loss of animal habitats and a decrease in the number of species in an area.)

Figure 6. Journal entry of EGP24 dated September 3, 2025.

FOI helped students apply scientific concepts to environmental issues. Students were able to connect human activities with ecological consequences, such as habitat destruction and species decline. This connection is relevant to current environmental science discussions, showing that climate change and human-induced environmental pressures influence ecological systems and natural resources (Soren *et al.*, 2023). This ability to relate classroom learning to real-life sustainability issues suggests that FOI supported both conceptual understanding and sustainability awareness.

The results in this subsection show that FOI effectively enhanced students' conceptual understanding in science. The medium overall normalized gain, the absence of low-gain outcomes, and the qualitative evidence from interviews and journals indicate that FOI supported students' ability to organize ideas, analyze causal relationships, explain scientific phenomena, and connect science concepts with real-world sustainability issues.

3.2. Students' perceptions of FOI as a learning strategy in science

This subsection presents students' perceptions of FOI as a learning strategy in science. The analysis is based on student journals, interviews, and field notes. While the previous subsection focused on learning gains, this subsection explains how students experienced FOI in terms of visual organization, causal reasoning, engagement, collaboration, and idea expression. The thematic analysis generated four main themes, as summarized in **Table 2**. Students perceived FOI positively across cognitive, social, and affective dimensions of learning. The themes indicate that FOI functioned not only as a visual aid but also as a structured pedagogical strategy that supported reasoning, collaboration, and active participation. These findings are consistent with previous research showing that fishbone diagrams can support analytical thinking, conceptual clarity, and student engagement in science learning (Clary and Wandersee, 2010; Istikomah, 2017).

Table 2. Generated key themes based on students' perceptions of FOI.

CODES	THEMES
Identifying root causes of problems; understanding relationships among causes; human activities as causes; concept of anthropogenic causes	Visual structuring and connection of ideas
Organization of ideas; visual learning/mapping; categorization/grouping of causes; clarity and structure in thinking; problem-solving and identifying patterns	Understanding cause-and-effect relationships
Increased engagement and interest; hands-on learning; participatory learning; collaboration	Enhanced engagement, interest, collaboration, and participation
Sharing and contributing ideas; brainstorming; role-switching; reflective learning	Valuing idea sharing and student expression

To strengthen the qualitative findings, representative excerpts from students' interviews, journals, and field notes are presented in **Table 3**. The table provides direct evidence of how students experienced FOI in relation to each theme. Students' responses provide qualitative support for the four themes generated in the analysis. The excerpts indicate that students viewed the fishbone diagram as a tool that helped them visualize ideas, understand causal relationships, participate in group activities, and express their thoughts more confidently. These responses also show that FOI encouraged students to connect scientific concepts with real-world environmental issues, including biodiversity, climate change, and environmental protection. The qualitative evidence in **Table 3** complements the quantitative findings reported in the previous subsection. While the normalized gain scores showed measurable improvement in students' conceptual understanding, the interview responses, journals, and field notes explain how this improvement occurred during learning. Students' reflections suggest that FOI provided a visual and collaborative structure that supported reasoning, discussion, and conceptual connection. Therefore, FOI can be understood as a learning strategy that integrates cognitive, social, and affective dimensions of science learning.

Students' perceptions indicate that FOI created a more structured, interactive, and meaningful learning experience. The four themes presented in this subsection provide the basis for the following subsections, which discuss each theme in greater detail: visual structuring and connection of ideas, understanding cause-and-effect relationships, enhanced engagement and collaboration, and valuing idea sharing and student expression.

3.3. Visual structuring and connection of ideas

One of the main themes that emerged from the qualitative data was students' perception that FOI helped them visually structure and connect ideas. Through fishbone diagrams, students were able to organize scientific information systematically, identify key concepts, and recognize relationships among causes related to scientific phenomena.

During interviews, students stated that the fishbone diagram provided a clear visual structure that made science topics easier to understand. One student explained that the diagram organized ideas in a way that made them easier to understand. Another student stated that using the fishbone diagram made science more interesting because it helped them understand topics better and connect ideas within the group. These responses indicate that FOI supported students in integrating information into coherent conceptual frameworks rather than processing concepts as isolated facts.

Table 3. Representative qualitative evidence of students' perceptions of FOI.

THEME	SOURCE/CODE	REPRESENTATIVE EVIDENCE	INTERPRETATION
Visual structuring and connection of ideas	EGP20, interview	*"It gives a clear visual of ideas. It organizes ideas so that they are easier to understand."*	FOI helped students organize scientific information visually and understand concepts more clearly.
Visual structuring and connection of ideas	EGP44, interview	*"Using the fishbone diagram made science interesting for me because I understood the topics better, and we were able to connect each of our ideas."*	The fishbone diagram supported students in connecting individual and group ideas into a clearer conceptual structure.
Understanding cause-and-effect relationships	EGP52, interview	*"I am okay with this kind of teaching that uses a fishbone diagram because we can identify the causes, categories, sub-causes, and sub-categories of a main issue or problem."*	FOI supported causal reasoning by guiding students to identify root causes and sub-causes of scientific problems.
Understanding cause-and-effect relationships	EGP30, interview	*"Through the diagram, the causes are shown to be connected to the main problem or issue, such as biodiversity."*	Students recognized how different causes were connected to a central scientific issue.
Enhanced engagement, interest, collaboration, and participation	EGP44, interview	*"I am happy because we have this new technique of teaching that enables us to work together as a group to share our thoughts and ideas."*	FOI encouraged collaboration, group discussion, and active participation.
Enhanced engagement, interest, collaboration, and participation	EGP67, interview	*"I appreciated the use of the fishbone diagram because I learned the topic very well. It allows us to participate."*	Students perceived FOI as an inclusive strategy that enabled group members to participate in learning activities.
Valuing idea sharing and student expression	EGP67, interview	*"It enables the whole group to participate and share their ideas. It encourages us to think deeply about the factors contributing to a problem."*	FOI promoted idea sharing, deeper thinking, and student expression during group activities.
Valuing idea sharing and student expression	EGP34, journal	*"It encouraged me to participate more by sharing my ideas to my classmates on how to protect the environment and reduce climate change."*	FOI encouraged students to express ideas related to environmental protection and sustainability.
Valuing idea sharing and student expression	Field note, September 4, 2025	*Students listened to both the teacher and their peers and contributed ideas.*	Field observations supported students' reported experiences of active listening, participation, and idea contribution.

This theme is also supported by **Figures 3 and 4**, which show students' reflections on how the fishbone diagram helped them organize ideas, identify relationships among concepts, and break down complex problems into categorized causes. Although these figures were introduced earlier to support the discussion of conceptual gains, they also illustrate students' subjective experiences of FOI as a visual structuring tool.

From a constructivist perspective, these findings suggest that FOI helped students actively construct understanding by organizing information through meaningful visual representations. From a sociocultural perspective, the collaborative construction of fishbone diagrams also supported shared understanding because students had to discuss, negotiate, and connect ideas with their peers.

FOI supported visual structuring and connection of ideas by helping students organize scientific information, identify relationships among concepts, and build more coherent explanations. This theme provides a basis for the next theme, which focuses on students' understanding of cause-and-effect relationships.

3.4. Understanding cause-and-effect relationships

Another central theme was students' improved understanding of cause-and-effect relationships. Students consistently reported that the fishbone diagram helped them identify root causes, categorize contributing factors, and connect these causes to observable effects. This skill is important in science learning because conceptual understanding requires students to reason causally rather than memorize isolated facts (Driver *et al.*, 2000).

During interviews, students explained that the fishbone diagram helped them break down a main issue into smaller and more manageable components. One student stated that FOI helped identify causes, categories, sub-causes, and sub-categories of a main issue or problem. Another student explained that the diagram showed how causes were connected to a main problem, such as biodiversity. These statements suggest that FOI helped students develop structured causal reasoning.

Students' journal entries provide concrete examples of this process. As shown in Figure 5, one student identified pollution, deforestation, and climate change as causes of biodiversity loss and animal extinction. **Figure 6** similarly shows a student's reflection on how deforestation, pollution, and climate change affect biodiversity by causing habitat loss and reducing species populations.

These findings indicate that students were able to transfer classroom learning to authentic environmental contexts. Rather than merely listing causes and effects, students demonstrated an ability to connect human activities with ecological consequences. This shows that FOI supported meaningful learning by helping students analyze real-world problems through a cause-and-effect lens.

The development of causal reasoning observed in this study aligns with previous research showing that visual reasoning strategies, such as fishbone diagrams and concept mapping, can enhance students' ability to analyze relationships among variables and construct scientific explanations (Chang *et al.*, 2019; Patel and Pradhan, 2018; Suryani and Hendri, 2019; Wang *et al.*, 2018). FOI served as a cognitive scaffold that guided students in identifying causes, grouping related factors, and explaining relationships among concepts.

The emphasis on environmental issues also shows the relevance of FOI in supporting education for sustainable development. As students analyzed problems such as pollution, deforestation, climate change, biodiversity loss, and habitat destruction, they developed greater awareness of how human actions affect the environment. This awareness is aligned with science education goals that emphasize responsible decision-making and sustainability-oriented thinking (OECD, 2019).

FOI enhanced students' understanding of cause-and-effect relationships by guiding them to identify root causes, evaluate contributing factors, and connect these factors to observable outcomes. These qualitative findings help explain the quantitative gains reported earlier and support the role of FOI as an instructional strategy for deep conceptual understanding.

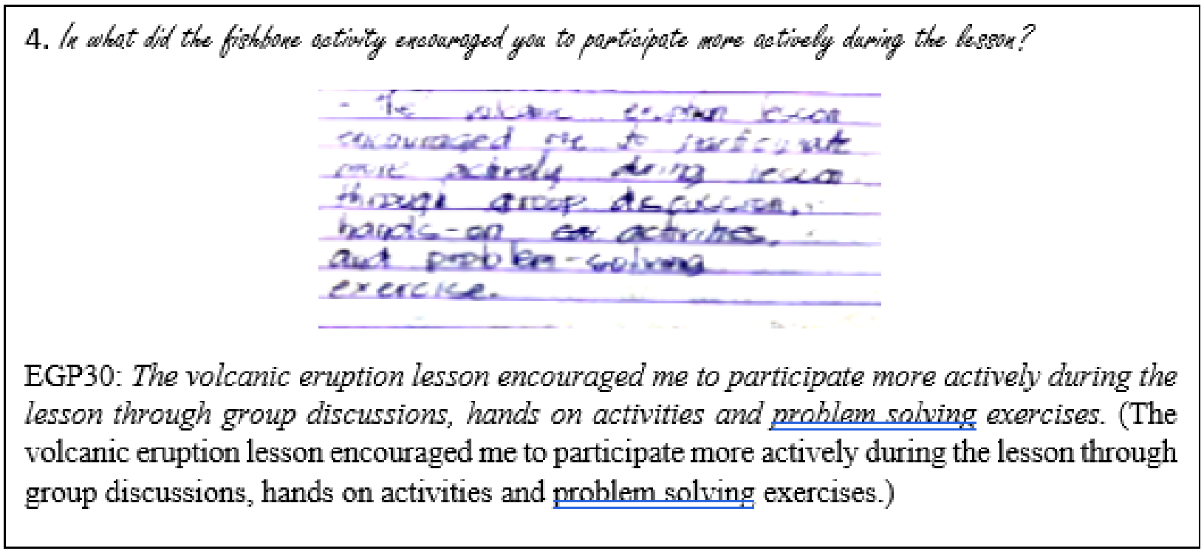
3.5. Enhanced engagement, interest, collaboration, and participation

Another important theme was the enhancement of students' engagement, interest, collaboration, and participation during science lessons. Students reported that learning activities became more engaging when they actively constructed fishbone diagrams, discussed ideas with peers, and collaboratively analyzed scientific problems.

Interview data show that students responded positively to FOI because it encouraged teamwork and active participation. One student explained that the strategy enabled the group to work together and share thoughts and ideas. Another student stated that the fishbone diagram allowed group members to participate and helped them learn the topic better. These responses indicate that FOI created a collaborative learning environment where students felt encouraged to contribute.

Students also reported that FOI made learning more interesting by transforming science topics into interactive and hands-on activities. One student explained that each group member was able to use their own ideas based on the assigned topic, work together, and present the group output. This suggests that FOI connected individual preparation with group collaboration, thereby supporting both responsibility and participation.

Students' journal entries further support this theme. As shown in **Figure 7**, one student reflected that the fishbone activity encouraged active participation through group discussion, hands-on activities, and problem-solving exercises. **Figure 8** shows another student's reflection that the fishbone diagram made learning more engaging and interesting because it provided a visual and interactive way to analyze complex problems.



4. *In what did the fishbone activity encouraged you to participate more actively during the lesson?*

EGP30: *The volcanic eruption lesson encouraged me to participate more actively during the lesson through group discussions, hands on activities and problem solving exercises.* (The volcanic eruption lesson encouraged me to participate more actively during the lesson through group discussions, hands on activities and problem solving exercises.)

Figure 7. Journal entry of EGP30 dated September 18, 2025.

3. *Did using Fishbone activity make learning engaging or interesting for you? Why or why not?*

5) Using the fishbone diagram made learning science more engaging and interesting for me because it provide a visual and interactive way to analyze complex problems. Identify relationship between variables and think critically about cause and effect, making the learning process more interactive fun

EGP48: *Using the Fishbone diagram made learning Science more engaging and interesting for me because it provide a visual and interactive way to analyze complex problems, identify relationship between variables and think critically about cause and effect, making the learning more interactive and fun.* (Using the Fishbone diagram made learning Science more engaging and interesting for me because it provide a visual and interactive way to analyze complex problems, identify relationship between variables and think critically about cause and effect, making the learning more interactive and fun.)

Figure 8. Journal entry of EGP48 dated September 18, 2025.

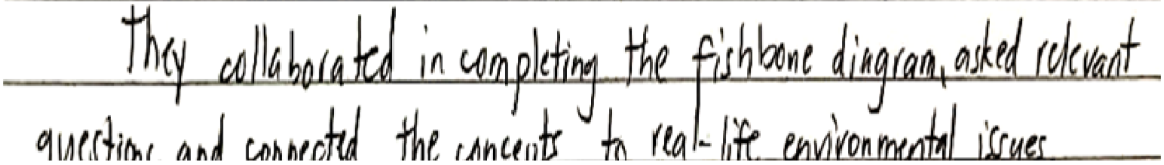
FOI created a learning environment characterized by active involvement and shared responsibility. The hands-on and interactive nature of FOI helped transform students from passive recipients of information into active participants in the learning process. This finding is consistent with research showing that participatory and cooperative learning strategies can improve students' interest and motivation in science education (Sangchan and Boonma, 2019).

Classroom observations also support this theme. Field notes showed that students actively collaborated with group members, shared ideas, asked questions, and connected scientific concepts to real-life environmental issues. These observations are presented in **Figures 9** and **10**.

The learners actively participated In the activity and collaborated with their group members in sharing ideas.

Field note: *The learners actively participated in the activity and collaborated their group members in sharing ideas.* (The learners actively participated in the activity and collaborated their group members in sharing ideas.)

Figure 9. Excerpt from researcher's field note dated October 9, 2025.


They collaborated in completing the fishbone diagram, asked relevant questions and connected the concepts to real-life environmental issues

Field note: *They collaborated in completing the fishbone diagram, asked relevant questions, and connected the concept to real-life environmental issues.* (They collaborated in completing the fishbone diagram, asked relevant questions, and connected the concept to real-life environmental issues.)

Figure 10. Excerpt from researcher's field note dated October 2, 2025.

Students demonstrated active participation and collaboration during FOI activities. The field notes indicate that students shared ideas, worked together to complete the fishbone diagram, asked relevant questions, and connected lessons to environmental issues. These behaviors reflect deeper engagement because students were cognitively, socially, and emotionally involved in learning. From a sociocultural perspective, FOI provided a structured context for students to interact, exchange ideas, and co-construct understanding. From a constructivist perspective, students learned more effectively because they were actively involved in exploring, discussing, and reflecting on scientific content. Overall, FOI enhanced students' engagement, interest, collaboration, and participation by creating a dynamic and supportive learning environment.

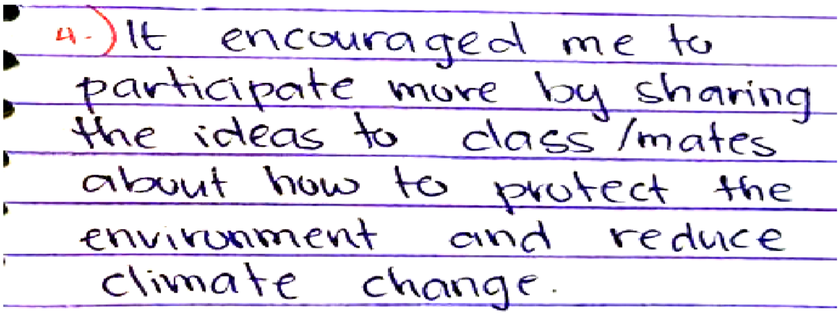
3.6. Valuing idea sharing and student expression

The final theme highlights how FOI encouraged students to value idea sharing and expression. Students reported that FOI created opportunities for them to voice their thoughts, exchange perspectives, and build on each other's ideas in a supportive classroom environment. This theme shows that FOI contributed not only to conceptual understanding but also to students' communication skills, confidence, and sense of ownership in learning.

During interviews, students explained that the fishbone diagram allowed all group members to participate and share ideas. One student stated that the activity encouraged the whole group to think deeply about the factors contributing to a problem. Another student explained that FOI enabled them to read and share what they understood. These responses suggest that FOI transformed the classroom into a dialogic learning space where students were encouraged to express ideas and negotiate meaning with peers.

Students' journal entries also support this theme. As shown in **Figure 11**, one student reflected that the fishbone activity encouraged participation by allowing students to share ideas about protecting the environment and reducing climate change. **Figure 12** shows another student's reflection that FOI allowed them to contribute ideas, work collaboratively, and see connections among different ideas, making them feel more engaged and motivated. FOI supported both cognitive and affective aspects of learning. Students felt that their ideas were valued, which encouraged them to participate more actively and communicate their thoughts. This finding is consistent with research suggesting that student-centered and dialogic strategies can enhance engagement and learning quality (Sangchan and Boonma, 2019).

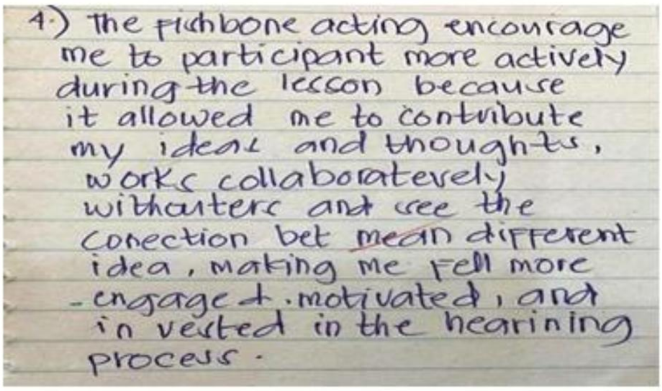
3. *In what did the fishbone activity encourage you participate more actively during the lesson?*


4.) It encouraged me to participate more by sharing the ideas to class/mates about how to protect the environment and reduce climate change.

EGP 34: *It encouraged me to participate more by sharing my ideas to my classmates on how to protect the environment and reduce climate change.* (It encouraged me to participate more by sharing my ideas to my classmates on how to protect the environment and reduce climate change.)

Figure 11. Journal entry of EGP34 dated October 2, 2025.

4. *In what did the fishbone activity encourage you participate more actively during the lesson?*

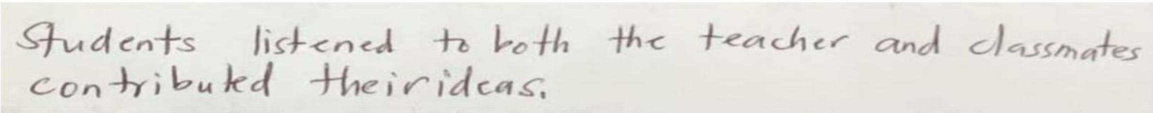

4.) The fichbone acting encourage me to participant more actively during the lesson because it allowed me to contribute my ideas and thoughts, works collaboratevely withoaters and see the conection bet mean different idea, making me fell more engaged, motivated, and in vested in the hearining process.

EGP 55: *The fishbone activity encourage me to participant more actively during the lesson because it allowed me to contribute my ideas and thoughts, works collaboratively with others, and see the connections between different ideas, making me feel more engaged, motivated, and invested.* (The fishbone activity encouraged me to participate more actively during the lesson because it allowed me to contribute my ideas and thoughts, work collaboratively with others, and see the connections between different ideas, making me feel more engaged, motivated, and invested.)

Figure 12. Journal entry of EGP55 dated October 2, 2025.

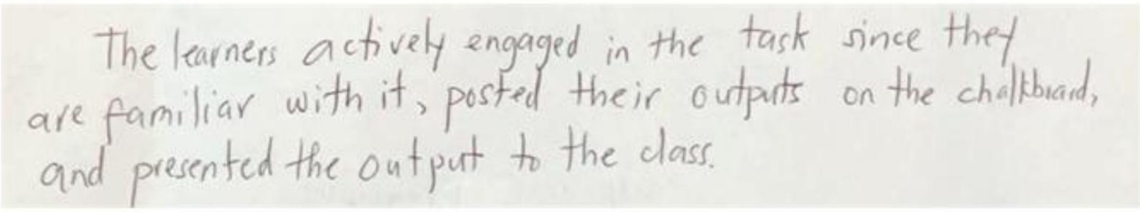
Classroom observations provide additional evidence. Field notes documented that students listened attentively to the teacher and peers, contributed ideas during group discussions, and confidently presented their outputs. These observations are shown in

Figures 13 and 14. FOI encouraged students to listen, contribute ideas, post group outputs, and present their work to the class. These activities helped create a classroom culture that valued expression, collaboration, and shared responsibility. The fishbone diagram functioned as a shared learning artifact that supported discussion and collective reasoning. As a pedagogical tool, the fishbone diagram can facilitate analytical thinking by helping students structure ideas, identify relationships, and communicate their reasoning more clearly (Latha and Prasad, 2019).


Students listened to both the teacher and classmates contributed their ideas.

Field Note: Students listened to both the teacher and their peers and contributed ideas.

Figure 13. Excerpt from field note dated September 4, 2025.


The learners actively engaged in the task since they are familiar with it, posted their outputs on the chalkboard, and presented the output to the class.

Field Note: The learners actively engaged in the task since they are familiar with it, posted their outputs on the chalkboard, and presented the output to the class.

Figure 14. Excerpt from field note dated September 18, 2025.

FOI encouraged students to value idea sharing and expression as integral parts of science learning. By creating structured opportunities for communication and collaboration, FOI helped students develop confidence in expressing scientific understanding. These outcomes complement the conceptual gains and engagement benefits discussed in previous sections.

Taken together, the four themes (visual structuring and connection of ideas, understanding cause-and-effect relationships, enhanced engagement and collaboration, and valuing idea sharing and student expression) show that FOI supported learning across cognitive, social, and affective domains. The qualitative findings explain the quantitative improvement in students' conceptual understanding and demonstrate that FOI is a holistic instructional strategy for science education. By integrating visual organization, causal reasoning, collaboration, and sustainability-oriented content, FOI can support conceptual learning and sustainability awareness among secondary school students.

4. CONCLUSION

This study examined the effectiveness of FOI in enhancing students' conceptual understanding and sustainability awareness in science learning. The findings showed that FOI produced a medium level of improvement in students' conceptual understanding, as indicated by the overall normalized gain score. This improvement suggests that the use of fishbone diagrams helped students organize ideas, identify causal relationships, and explain scientific phenomena more coherently. The qualitative findings further demonstrated that FOI supported students' learning experiences across cognitive, social, and affective domains. Students perceived the fishbone diagram as a useful visual tool for structuring ideas, understanding cause-and-effect relationships, engaging in collaborative learning, and expressing their thoughts during science activities. The reflective journals, interviews, and field notes also showed that students were able to connect scientific concepts with real-world environmental and sustainability issues. FOI can be considered an effective instructional strategy for promoting conceptual learning and sustainability-oriented thinking in science education. The findings imply that science teachers may use fishbone diagrams to support structured reasoning, active participation, and meaningful discussion, particularly when teaching topics that involve complex causes and consequences. Future studies may apply FOI in broader classroom contexts or compare it with other instructional strategies to further examine its effectiveness.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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