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# Science Writing Heuristics Improve Pre-University Students' Understanding of Energy Transfer in an Ecosystem and Argumentation Ability

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**ABSTRACT**
The study using quasi experimental design involving 160 pre-university students, randomly assigned into experimental (n=80) and control groups (n=80), revealed science writing heuristics approach improved pre-university students' understanding of energy transfer in ecosystems and ability to produce quality arguments. After controlling the pretest scores, the one-way ANCOVA analysis indicates a significant difference between the experimental group's posttest scores taught using science writing heuristics approach, and the control group's posttest scores taught using a teacher-centered approach, in favor of the experimental group. The interview findings denote that the students acquired a comprehensive understanding of energy transfer as they provided holistic explanations describing the energy transfer. The science writing heuristics approach also enabled students to produce quality arguments. The study indicates that the science writing heuristics approach is a viable strategy to facilitate teaching and learning abstract concepts such as energy transfer in ecosystems that fundamentally require students to argue to connect and relate compartmentalized ideas to form holistic views.

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## Introduction

Energy transfer (ET) in an ecosystem refers to the transfer of energy from the sun until it reaches the final consumers in an ecosystem (Chabalengula et al., 2012). ET involves transfer via producers and food chains, interception of biogeochemical cycles that function in sustaining the flow of nutrients that affects the energy pathways, and other external human-induced factors affecting the ET (Lin & Hu, 2003). Simplistic ET presentation using teacher-centered pedagogy impedes students from viewing the interdependence and relationships between energy transfer from the sun, food chain, energy transfer between trophic levels, biogeochemical cycles, and factors affecting the ET in ecosystems (Wyner & Blatt, 2019). Superficially knowing the sun's functions, food chain, and energy transfer, ignoring the interdependence and relationships between livings and non-living in the ecosystem results in a poor understanding of the concepts related to energy flow among fourth and eighth grades students (Arkwright, 2014; Khozali & Karpudewan, 2020). Chabalengula et al. (2012) reviewed several past studies on energy inan ecosystem. They documented that students at all levels (primary to tertiary) lack an understanding of how energy is transferred in the ecosystem. Jordan et al. (2014) recorded similar findings in a study involving seventh-grade students. Several other studies revealed students poorly understood energy (Opitz et al., 2017) respiration, photosynthesis (Akçay, 2017; Haslam & Treagust, 1987), and ecosystems (Grotzer & Basca, 2003).

The lecturing method often inhibits students from participating in argumentation inquiry to critique, argue, reason, negotiate, and justify claims to construct knowledge (Erduran et al., 2004). The argumentation skills are innate to understand complex and abstract concepts such as ET in ecosystems (Erduran et al., 2004). Argumentation is instrumental for students to understand science concepts accurately (Toulmin, 1958). Subsequent to this, remarkable evidence was found associating the ability to produce quality arguments with understanding science concepts (Chen et al., 2016; Garcia-Mila et al., 2013; Karpudewan et al., 2016). Despite the significant importance of argumentation, students across primary to tertiary lack the ability to produce quality arguments (Chen et al., 2016; Karpudewan et al., 2016; Sampson et al., 2011; Yaman, 2018).

A wealth of literature documented less effective strategies employed in the classroom contributed to the poor understanding of ET in the ecosystems and limited ability to produce quality arguments among students across primary to tertiary levels. The literature also reveals that a specific pedagogical strategy is essential to encourage students to produce quality arguments and improve understanding. Science writing heuristic (SWH) is an argument-based strategy that facilitates students learning of abstract science concepts and argumentation skills using student and teacher templates (Keys et al., 1999). The approach constitutes brainstorming, and a series activity engages students in negotiation and reflection, comparing their understanding with peers. During the negotiation, students participate in argumentation, developing arguments to justify the claims. Available studies reported on the effectiveness of the SWH approach in improving understanding and developing arguments distinctively. For instance, the SWH approach improved understanding of electricity (Nam et al., 2011); chemistry concept (Kingir et al., 2012), and biology concepts such as cell biology (Hohenshell & Hand, 2006) and pre-service teachers' achievement in biology (Cronje et al., 2013). The SWH approach also improved students' ability to produce quality arguments (Chen et al., 2016; Yaman, 2018). In a different study computational modeling of the effects of the SWH improved students' critical thinking in science (Lamb et al., 2021). The SWH approach is also used to support NGSS-aligned instruction (Hike & Hughes-Phelan, 2020) and environmental literacy (Shamuganathan & Karpudewan, 2017).

## Aıms and Research Questıons

SWH is an argument-based pedagogy (Keys et al., 1999). The strategy has been widely used in teaching several biology concepts. To enable students to understand the complexity of energy transfer in ecosystems requires learning the concepts in an argumentative manner. However, no study was found using the SWH approach in teaching ET in ecosystems to the authors' knowledge. To bridge the gap, this study aimed to introduce the ET concepts using the SWH approach and measure the effectiveness of the approach in enhancing understanding and argumentation practiced during ET lessons. The following research questions guided the study:

1. What is the effectiveness of the SWH approach in promoting pre-university students' understanding of ET in ecosystems?
2. What is the effectiveness of the approach in promoting the ability of the students to produce quality arguments?

## Background of the Study

### *Energy Transfer in the Ecosystem*

In biological sciences, ET is used to describe the transfer of energy from the sun to other organisms at different trophic levels in ecosystems via feeding relationships (Chabalengula et al., 2012). Green plants (producers) capture energy from the sun through photosynthesis to convert it into chemical energy to form carbohydrates at the first trophic level. The biomass's chemical energy nourishes the herbivores that consume the plants at the second trophic level and carnivores at the third trophic level consuming the herbivores. Through the feeding process, energy in the biomass is transferred from lower to higher trophic levels. The ecosystems obey the first and second laws of thermodynamics. On average, 10% of the energy produced at one trophic level is transferred to another level. The majority of the energy is consumed for naturally occurring processes such as respiration, growth and reproduction, defecation. Studying ET in the ecosystem is regarded as a holistic understanding of the food chains and the natural processes that occur in ecosystems. However, contemporary studies have neglected the notion living world is an organized hierarchical complex structure in which entities at one level are interrelated with entities at the next level (Arkwright, 2014; Jordan et al., 2014; Lin & Hu, 2003). The compartmentalization of the hierarchy is notable when energy (Opitz et al., 2017), respiration, photosynthesis (Akçay, 2017; Haslam & Treagust, 1987), and ecosystems were investigated distinctively.

Lin and Hu (2003) documented that 7th-grade students produced distinctive concept maps describing food chains, photosynthesis, and respiration, ignoring decomposers and energy transfer. The linear form of maps was reproduced exactly from the textbook. Jordan et al. (2014), in a different study, reported that the conceptual representation framework resulted in the middle school students describing the living and processes in the ecosystem in isolation. The study by Arkwright (2014) indicates that fourth-grade students' understanding of concepts related to energy transfer in an ecosystem is not on par with the level dictated by national science education standards. The studies above suggest that traditional instruction often stresses the recall of definitions or descriptions of the concepts in isolation found in the textbook. The findings imply the need to have an instruction that emphasizes the inter-relationship between an ecosystem's components.

## *Argumentations*

Students' ability to produce a quality argument is closely associated with understanding science concepts (Choi et al., 2013). For this reason, many studies in the past two decades have documented the significant role of argumentation in science education (Chen et al., 2016; Erduran et al., 2004; Jiménez-Aleixandre & Erduran, 2007; Osborne et al., 2004; Osborne & Patterson, 2011). The descriptions of quality arguments vary across many studies. The quality is mainly reflected in the component of arguments included in the argumentation. Sampson et al. (2011) asserted that a quality argument includes a claim statement that denotes the conclusion for the problem and evidence explaining the solution to the problem. Sandoval and Millwood (2005) indicated coordinating how well a claim and evidence address a question that determines the argument's quality. Choi et al. (2013) included questions, claims, questions-claims relationship, evidence, claims-evidence relationship, multiple modal representations, and reflection as a component of the argument. In studies conducted by (Erduran et al., 2004; Osborne et al., 2004), and (Garcia et al., 2013), arguments are presented according to Toulmin's Argument Patterns (TAP) proposed by Toulmin et al. (1984). In TAP structure of the argument is explained using five elements: claim, data, warrants, backings, and rebuttal. Using TAP, Erduran et al. (2004) proposed a framework for assessing the quality of argumentation and categorized the arguments into five levels, with level 1 indicating the weakest and level 5 highest argumentation level.

Engaging students in productive argumentation always has been a difficult task (Chen et al., 2016). A specific pedagogical strategy is essential to encourage students to produce quality arguments (Sampson et al., 2011; Osborne et al., 2004). Engaging students in the negotiation process should be central to the argument-driven pedagogy. Simultaneously the pedagogy should allow students to understand the argument structure and employ the components of an argument in formulating the arguments during negotiation. Literature depicts the SWH approach as an argument-driven approach (Chen et al., 2016; Choi et al., 2013; Yaman, 2018).

### *Swh and Teaching of Energy Transfer*

SWH approach evident closes the achievement gap by promoting understanding and argumentation skills (Akkus et al., 2007). Grounded in the constructivist philosophy, the approach executed using student and teacher templates prompt the students to work collaboratively in groups negotiating, making meaning through argumentation, and constructing knowledge. The student template is formulated based on the structure of argumentation that engages the student in identifying beginning questions, testing the questions, making claims based on the evidence, and reflecting on their actions throughout the activity. The argumentation structure encouraged students to talk about and negotiate their understanding and build argumentation. On the other hand, the teacher template includes a series of activities for the teacher to facilitate negotiation among students (Keys et al., 1999). Both teacher and student templates consist of four stages of learning. The four stages include brainstorming, negotiation phase 1, negotiation phase II and negation phase III. Brainstorming aims to explore students' understanding of the concepts. In negotiation phase 1, students discuss in groups to identify questions and write the topic's understanding. Negotiation phase 2 involves presenting the outcome to others (sharing and comparing with other groups), and negotiation phase 3 entails comparing the ideas to textbooks and other resources.

The four phases of learning encompass student and teacher templates in the SWH approach appropriate to teach and learn the energy transfer that occurs in the ecosystem for understanding the interdependence and relationships between the living and non-living in the ecosystem. The brainstorming phase engages students in the activities set by the teacher to decide on the beginning questions related to ET. The prompting questions such as 'what is the role of the sun?' 'how to relate the living and non-living in the ecosystem?' and 'how energy is transferred between trophic levels?' trigger students' thinking. Negotiation phase 1, discussing to perform laboratory experiment investigating energy transfer and transformation to answer the beginning questions, demands connecting living at different trophic levels through the food chain. Presenting the observations and data during negotiation phase 2 simultaneously advances argument relating evidence from the experiment with the claim. Connecting evidence and claim allows explicit viewing of the interconnection between different tropic levels exhibited through an energy transfer within the food chain. In phase 3, negotiating the observations and data with other established sources such as textbooks enabled students to confirm their understanding acquired from the activity.

The student template guided the experimental group students in providing a logical conclusion about the data and included appropriate evidence to support the conclusion, resulting in the students understanding ecology and evolution (Cronje et al., 2013). The student-student and student-teacher interactions central to the SWH approach facilitated students' understanding of chemical change and mixture concepts (Kingir et al., 2012). Students individually and in small groups engaged in argumentation tested their questions, performed the experiments, negotiated and discussed the ideas during the interaction. While discussing, students demonstrated argumentation skills by making claims and justifying the claims with evidence. In a different study, the SWH approach provided students with opportunities to negotiate the questions, claims actively, and evidence within and among groups that enabled them to elaborate their thinking and construct an understanding of electricity (Nam et al., 2011). Hohenshell and Hand (2006) asserted that students could construct a richer conceptual framework on cell biology as the SWH approach allowed them to connect, justify, and consolidate knowledge claims from the six laboratory inquiries. Choi et al. (2013) indicated that argument scores were positively correlated with achievement.

## Methods

The study employed a quasi-experimental design following Cook et al.'s (2002) recommendation that the design is appropriate to measure the effect of treatment. Qualitative data was included to strengthen the quantitative findings and better understand the research problems (Creswell, 2021). In week 1, pretest measures comprising of ET concept test and argumentation test were administered. In week 7, the same instruments were administered as a posttest. Additionally, interviews were performed at week seven after the posttest to obtain insights into the ET concept test's quantitative findings. Between weeks 2 to 6, the five lessons on ET in ecosystems were taught using the SWH approach for the experimental students and a more traditional approach for the control group.

## Sample

The school that offers a pre-university program conveniently accessible to the researchers participated in the study. A total of 160 students with an average age of 18 years enrolled in the pre-university program at the school engaged in the study. At the time of the study, the participating samples were in semester 2, and biology is the compulsory subject. The samples were randomly assigned to a control and an experimental group using the students' school enrolment numbers. The odd numbers were assigned to the control (N=80), and the even numbers were assigned to the experimental group (N=80). The students' usual biology teacher conducted the teaching. The teacher with 20 years of experience teaching biology at the pre-university level was trained to use the SWH approach during training sessions before the study. The training sessions were conducted after the official school hours for three days. Both researchers and the teacher meet for three hours for each meeting. During the first meeting the researchers introduced the SWH approach. They explained about the student and teacher templates used in the SWH approach and the eight steps. In the next meeting, the researchers shared the lesson plans to the teacher. The researchers explained to the teacher on how to execute the lessons according to the lesson plan. In the last meeting, the lesson plans were again meticulously explained to the teacher and the researchers answered all the questions from the teacher.

## Data Sources

### *Energy Transfer Concept Test (ETCT)*

ETCT was used to measure the understanding of ET in ecosystems. ETCT consisted of 30 multiple-choice test items. The 30 multiple-choice items were prepared based on the biology curriculum guide provided by the (Ministry of Education Malaysia (MOE), 2005) The questions measured students understanding of feeding relationships, energy transfer, the role of decomposers associated with the nutrient flow, and biogeochemical cycles, and external factors that affect the ET in ecosystems. For each correct response, 1 point was given. An incorrect response was allotted with 0 points. The maximum total score for ETCT is 30 points. A pilot study involving 60 pre-university students and two biology teachers with 15 years of teaching experience from a different school not participating in the real research revealed that students needed around 40 minutes to complete the ETCT. The KR-20 value of .87 indicates that ETCT is a reliable test to be used. The pilot study also revealed that ETCT covered the content, as indicated in the syllabus. The items were presented in a way the students were able to understand the intention of the questions.

### *Argumentation Test (AT)*

AT was a written test used to measure students' ability to present their arguments on scientific issues on ET in ecosystems. The question *'Describe the energy transfer in ecosystems. Include the feeding relationships in the description and illustrate the interconnectedness between organisms living at different trophic levels. The information on the role of decomposer and biogeochemical cycles and the external factors that influence the energy path is necessary'* was included in AT. There is no straightforward answer to the question. The question in AT was piloted for the appropriateness of the content validity in terms of whether the students were able to include argumentation according to Toulmin's argumentation pattern. The pilot findings reflected that student were able to organize claims, evidence and data while responding to the question. Pilot study findings also revealed the question was easily understandable and presented in a way that students had to include argumentation in responding to the question as the it was open ended.

Profoundly, the search for answers demands constructing claims with data and supported with the evidence. To a greater extent, in justifying the ideas, warrant/backings and rebuttals are instrumental. The argumentation skills or the quality of the arguments were determined based on a scheme proposed by Erduran et al. (2004), as presented in Table 1 below. Responses to the questions which contain only a claim (stance on the issues) had been classified as Level 1 of argumentation. Statements had been categorized as Level 2 of argumentation if the arguments contained claims supported by data, warrant, or backing but do not include a rebuttal. Level 3 of argument includes claims supported by data, warrant, or backing with an occasional weak rebuttal. Statements in the written responses categorized in Level 4 of argumentation include clear rebuttals (specify the conditions for when the claim will not be true). Finally, Level 5 argumentation statements contained extended rebuttals.

**Table 1**

*Classification of the Responses to AT According to the TAP Framework*

| Level | Descriptions | Sample answers |
|---|---|---|
| 1 | Simple claim. | *Energy flows from the sun to plants [claim]*<br>*Energy is transferred from producer to consumer. [claim]*<br>*Nutrient flows through biogeochemical cycles. [claim]* |
| 2 | Claim with data but no warrants or backing and rebuttals. | *Energy flows from the sun to plants [claim] make food through photosynthesis [data] process simultaneously, e*nergy is transferred to consumers when they consume producers. |
| 3 | Series of claims with warrants, or backing | *Energy flows from the sun to plants [claim]. The plants consume energy from the sun for photosynthesis [data]. The energy in plants is stored as chemical energy [warrant]. During photosynthesis, biomass with carbohydrates is formed. The energy in the biomass is chemical energy [backing].* |
| 4 | A claim with warrants, or backing, rebuttals and qualifiers. | *Energy is transferred when herbivores at second trophic levels consume the plants and carnivores at third trophic levels consumers herbivores [claim and data]. The energy is transferred in the form of chemical energy stored in biomass (carbohydrates) [warrant]. The food consumed is converted into biomass [backings]. However, only 10% of the energy is transferred to the higher trophic in the feeding relationship [rebuttal]. 90% of the energy at each trophic level is used for naturally occurring processes such as respiration, defecation, and reproduction [qualifier].* |
| 5 | An extended argument with one or more rebuttal. | *Energy transfer is affected by external factors such as human-induced activities, environmental pollution, and natural disasters [rebuttal].* |

*Note.* (Erduran et al., 2004)

### *Focus Group Interview*

Pre- and post-interviews have been conducted in groups with the control and experimental students to explore the understanding. The interview began by illustrating, "You may hear things like: 'The larger animals eat smaller animals' and 'Smaller animals cannot eat things that are bigger than themselves. The biggest animals are at the top of the food web (or food chain)'". Based on the given illustration, the question *"Are there any huge animals that do not eat other animals? If so, what are some of them? What do you know about these animals and how they spend much of their time? Why might they spend their time this way?"* was asked to gauge the students' understanding of ET in ecosystems. The students' responses were recorded and analyzed in entity according to the thematic analysis framework suggested by Braun and Clarke (2006). Table 2 below shows the themes and corresponding codes that emerged from the analysis.

**Table 2**

*Themes and Corresponding Codes Emerged From the Analysis of the İnterview Responses*

| Themes | Codes |
|---|---|
| Feeding relationship | The bigger animal eats the smaller animal.<br>Plants are a consumer at the first trophic level.<br>Herbivore eats plants (second trophic level)<br>Carnivore eat herbivores (third trophic level) |
| Energy Transfer | From the sun to producers<br>Eat to meet energy needs.<br>Energy from producer to consumers<br>Lowest trophic to highest trophic<br>Law of thermodynamics |
| Role of decomposer | Decomposer eats the bigger animals.<br>Decompose dead animals, release heat during decomposition and return nutrients through biogeochemical cycles to ecosystems.<br>Sustaining the nutrient flow in cycles<br>Biogeochemical cycles such as carbon and water cycle. |
| External factors affect the feeding relationships and energy flow. | Environmental pollution<br>Human activities<br>Pollution of the ecosystem<br>Natural disasters |

Understanding ET was reflected when students were able to use the codes to describe the themes. Subsequently, connect the themes describing energy transfer in ecosystems. For instance, energy flows from the sun to consumers when plants perform photosynthesis. The energy is transferred when animals from higher trophic levels consume animals at the lower trophic level. A total of 10% of energy (law of thermodynamics) is transferred via feeding relationships from the biomass (e.g., carbohydrate and protein) formed in plants during photosynthesis to other animals that consume plants. Bigger animals consume smaller animals to meet energy needs. The rest of the energy is lost due to naturally occurring processes such as respiration and defecation. Simultaneously, the decomposers decompose the larger dead animals, return the nutrients to the ecosystems via biogeochemical cycles, and the energy transfer is affected by pollution, human activities, and natural disasters.

### *Treatment*

The main concepts that embody ET in ecosystems were taught in five lessons (week 2 to 6). In lesson 1, the concept of energy transfer was introduced. In lesson 2, students investigated energy transfer during photosynthesis and storing energy in leaves. In lesson 3 chemical energy in biomass was explored using the apple battery. In lesson 4, students investigated abiotic factors that affect the energy transfer and thermodynamic laws to explain the ET in an ecosystem. For the experimental group, the five lessons were performed using the SWH approach. Meanwhile, for the control group, the teacher-centered approach was used.

### *SWH Approach-Treatment for the Experimental Group*

The lessons were executed in eight steps (Hand et al., 2004). Step 1 focused on retrieving students' prior knowledge on the topic studied through group discussions. For lesson 1, students in groups engaged in brainstorming, discussing answers to the teacher's questions such as *'What is energy? Where do plants obtain energy? How do you think the energy in the plants transformed and used by other livings?'* Step 1 was performed similarly for the remaining four lessons focusing on the specific topic of the lessons. Students engaged in pre-laboratory activities in step 2, discussing and preparing beginning questions. For lesson 1, the teacher-facilitated small group discussion and guided in formulating the questions such as *'What do you have to investigate to figure out about energy transformation? What do you have to investigate to figure out about energy transfer? What would be the main question that will guide the investigation?'* The responses to the questions were discussed and proceeded with testing the answers in step 3.

In step 3, laboratory activity was performed to confirm their ideas (testing the beginning questions) through observations and data collected from the experiments. The students discussed and divided the tasks among their group members, decided on the data collection, and drafted appropriate data compilation tables. In lesson 1, students were provided with match sticks, candles, ethanol, a stopwatch, and weighing scales. Using the materials, students planned an experiment to investigate the ET in ecosystems and the energy transformation that happened during the burning of candles and ethanol. During the activity, they measured the changes in the mass of candles or volume of ethanol before and after burning; the mass of candles and volumes of ethanol used for energy transfer and energy transformation. They noticed that the match holds chemical energy stored until it is converted to heat (thermal energy) and light (radiant energy) when the match burns. An energy flow, energy transfer, and energy transformation chart were used to explain how ET in ecosystems and energy transformation occurs. The students recorded their qualitative and quantitative data using charts and tables.

The negotiating phase (steps 4 to 6) occurred concurrently. After collecting all the data, the students critically evaluated the information on the mass of candles used for burning; volume/mass of ethanol used for burning; time is taken for burning the mass of candles and ethanol to convert to heat energy and light energy, and compared between candle (organic) and ethanol (inorganic) for energy flow. They worked together, negotiated, constructed knowledge, and answered the beginning questions. In seeking answers to the questions, the students discussed and identified the appropriate claim and supporting evidence from the observations. The teacher played the facilitator's role, posing questions such as 'What *can I claim?', 'What is my evidence?'* to guide the negotiation. In answering the question *'What can I claim?'* students' reflected on what has happened during the laboratory and summarized it into one or two sentences as claims. An example of a claim is 'The heat of combustion of candle takes…seconds, and the flame is yellow, and blue reflects the energy transformation (thermodynamic laws) and energy transfer (releasing of energy stored by producers) to the living things in the surroundings (ecosystems). The heat of combustion of the ethanol takes…seconds, and the flame is blue, is clean burning depicts the energy transformation (thermodynamic laws) and energy transfer (releasing of ethanol energy stored by producers) to the living things in the surroundings (ecosystems). In answering the question *'What is my evidence?'* students reviewed and organized their data into an argument and presented it as evidence to support the claim.

Students continuously reflected on the laboratory experiences to produce a warrant for the argumentation. An example of a warrant is 'candles produced a significant amount of organic energy (releasing energy stored in the producers (Green plants-photosynthesis)) to the living things in the surroundings (ecosystems) with a yellow sooty flame.' Upon starting the warrant statement, students used a qualifier to reflect a deeper understanding of the warrant. An example of a qualifier that provides insights into a warrant is 'all candles produced little or no soot in the yellow flame (energy transformation/thermodynamic laws) to end up as heat and light energy. In groups, students continued with negotiation and discussion activities to identify backing statements to support the warrant. The backing statement such as 'it is impossible for quantitative measurement in the burning of candles because according to the laws of thermodynamics energy stored is released to the ecosystems from lower trophic level to higher trophic levels. The statement 'it can only be measured when herbivore eats the plants for biomass gain' is a qualifier statement that denotes a deeper understanding of the backing. Rebuttals are counterarguments or statements indicating circumstances when the general argument does not hold true. For example, human activities, weathering processes, Earth-soil resources from various non-organic (radioactive substances, natural gases, or inorganic matters) or organic energy substances (petrol, coal) can affect the ET in ecosystems during pollution.

During reflection, in step 7, students individually reflected on how the heat of combustion of a candle compared with the combustion of ethanol. The students reflected on the ET in ecosystems and energy transformation (thermodynamic laws) produced from the candle, a renewable resource from plant/animal, to alcohol-based inorganic ethanol and compared the findings of the experiments with findings reported in the textbook. In step 8, students prepared a report using the SWH laboratory report writing format. For the rest of the lessons, similar strategies were executed.

### *Teacher Centered Approach- Treatment for the Control Group*

The teacher-centered approach involved discussing the answers to the specific questions on ET topics in ecosystems from the textbook and providing the answers to the teacher before the class. The students passively participated, listening and taking notes as the teacher lectures on the content. The teacher used a whole class approach explaining ecology and ecosystems. The teacher drew some of the food web and food chain to show the energy transfer. The concepts of energy flow, thermodynamic laws, energy transfer, biogeochemical cycles, ecosystems, and sustainable development are discussed and explained accordingly. The teacher introduces the theory of ET in ecosystems through a question and answers session. The teacher discussed and briefly explained the concept of ET in ecosystems. A brief introduction to the procedure of the experiment was given. The students stayed at their experimental workstations and discussed mainly with their partners to conclude the findings of the experiment. Standard lab-report writing format was used to prepare a laboratory report to document the observations.

## Results

### Understanding on ET

The tests of regression slopes showed that the assumption of equality was not violated. Hence, the ANCOVA with pretest as a covariate was performed. The findings revealed that there is a significant difference ($F(1,157) = 293.35$, $p < 0.05$) between the posttest scores of both groups after controlling the pretest scores. The experimental group ($M_{exp} = 24.21$; $SD_{exp} = 4.46$) outperformed the control group ($M_{con} = 16.56$; $SD_{con} = 4.09$) as measured using ETCT. The maximum possible score for the ETCT is 30. The ANCOVA findings are presented in Table 3. The partial eta squared value of 0.65 indicates that 65.0% of the total variance in the posttest understanding scores is due to the treatment.

The statistically significant difference obtained signifies the advantage of using the SWH approach to improve pre-university students' understanding of ET in ecosystems.

**Table 3**

*One-way ANCOVA Findings on the Understanding of ET in Ecosystems*

| Source | SS | DF | Mean | F | p | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Pretest | 1138.87 | 1 | 1138.87 | 101.93 | 0.00 | 0.39 |
| Group | 3277.70 | 1 | 3277.70 | 293.35 | 0.00 | 0.65 |
| Error | 1754.21 | 157 | 11.17 | | | |
| Total | 71738.00 | 160 | | | | |

The understanding is explicitly notable in the qualitative interview responses. All the control and experimental group students interviewed expressed a good understanding of the feeding relationship between organisms living at the different trophic levels. For instance, CS2 (student 2 from the control group) said *'herbivores grazing grasses, eating shrubs or bushes.* CS6 illustrated *'Bigger animals eat smaller animals in food chains.* ES8 (student 8 from the experimental group) and ES10 viewed *'its law of nature that bigger animals eat smaller animals for food as they are carnivores.'* These responses depict that students knew that the producer is the plant (First trophic level). Herbivores (second trophic level) consume plants, and carnivores (third trophic level) consume herbivores.

The majority of the students from both groups are aware that energy transfers from the sun to the producer. For instance, CS9 said, *'when herbivores eat plants, energy is transferred to other herbivores in the same trophic level'*. Response provided by CS9 indicates that CS9 has an incorrect understanding that while eating grass, energy is released to other herbivores. On the other hand, experimental group students explicitly exhibited that energy is transferred from the lowest trophic to the highest trophic level in their responses. ES2 said, *'The plants are producers, and the energy from these producers would be transferred up to the consumers at higher trophic levels.'*. ES5 indicated *'energy is stored in compounds called carbohydrates in plants. When animals eat green plants, the energy is transferred."*

Control group students also expressed an incomplete understanding of energy transfer. CS3 said, *'Carnivores eat these herbivores to transfer the energy up the trophic level further'*. The answer reflects that CS3 knew the feeding relationship between carnivores and herbivores. However, CS3 was not aware that only 10% of the energy is transferred. In other words, 90% of the energy was used for the naturally occurring process, such as respiration, and defecation was not known to CS3. The responses showed that all control group students were unable to explain the energy transfer following the first and second thermodynamics laws. The experimental group students overtly indicated that the application of the first and second law of thermodynamics. ES2 further said that *'because a lot of the energy is lost as heat during transfer up the higher trophic levels in the ecosystems…. only 10% is transferred into the herbivores when they ingest the plants in the ecosystems.* ES6 said that *'In these feeding relationships, energy can be transferred up the trophic levels, but in doing so, energy is also lost in the form of heat energy.'*

Many of the control group students also exhibited misconceptions on the role of decomposers. CS8 said that *'decomposers ate these bigger dead animals and decomposed them, returning the energy into the ecosystems.* CS8 has provided a partially correct answer that decomposers consume bigger dead animals. The indication of returning the energy into the ecosystem is incorrect. The control group students were unable to associate the product of decomposition with biogeochemical cycles. The experimental group students showed the coherent of decomposition with biogeochemical cycles when ES9 states that *'producers and consumers die, the organic matters can be returned into the soil and water systems (through biogeochemical cycles)' so that the decomposers and detritivores (which are not always included in a food chain or web) can break down these dead organisms.* ES10 expressed that *'through carbon and water cycle, the decomposers in the ecosystems can return the chemical nutrients into the ecosystems.'*. ES4 indicated the phosphorus cycle' *weathering washes away phosphate ions from rock to soil, plants and animals absorb phosphate from the soil, decomposition of dead plants and animals return phosphorus to the soil.'* The experimental group students further expanded their answers, illustrating the nutrient flow, associating with the nutrient produced by the decomposer, and returning through the biogeochemical cycle. The experimental group students highlighted environmental pollution and human activities that affect the energy transfer in the ecosystems as follows. According to ES6 *'haze in the skies-the air pollution…rise in temperature or heat…affected the penetration…flow of the solar energy for photosynthesis in plant…causing the flowering pattern different'*. ES7 said *'human activities such as fossil fuel consumption and deforestation affect the feeding relationships, their survival and subsequently, the population of the ecosystems. Ultimately the energy transfer is disturbed'*.

The qualitative interview responses provided insights into understanding quantitative findings. The quantitative findings account that students from both groups gained an understanding of ET following the treatment. The qualitative interview narrates that the students taught using the SWH approach connected and related all the ideas embody ET in providing a holistic explanation.

## Quality of Argument

To establish the effects on producing quality arguments, transition matrices (Table 4) were tabulated. The matrices show that for the control group, 3 students moved from level 1 to level 2, 44 students stayed at level 2, and 2 students shifted from level 2 to level 3. A total of 29 students stayed at level 3, and one student progressed from level 3 to level 4. For the experimental group, it was notable that five students moved from level 1 to level 5. A total of 28 students progressed to level 4 and 13 students to level 5 from level 2. Five students moved from level 3 to level 4, and 26 shifted from level 3 to level 5. Another 3 students progressed from level 4 to level 5. The results show that the control group students mainly exhibited the ability to produce lower level (level 2 and level 3) arguments. Following the conventional teaching approach, only two students managed to reach level 4 of arguments. The experimental group students during the pretest, most of them are at level 2 and level 3. However, the trend changed following SWH instruction. Whereby many of the students managed to reach levels 4 and 5 of argumentation skills.

**Table 4**

*Transition Matrices on the Quality of Argument*

| Pretest | Posttest L1 | L2 | L3 | L4 | L5 | ∑ |
|---|---|---|---|---|---|---|
| Control | | | | | | |
| L1 | | 3 | | | | 3 |
| L2 | | 44 | 2 | | | 46 |
| L3 | | | 29 | 1 | | 30 |
| L4 | | | | 1 | | 1 |
| ∑ | | 47 | 31 | 2 | | 80 |
| Experimental | | | | | | |
| L1 | | | | | 5 | 5 |
| L2 | | | | 28 | 13 | 41 |
| L3 | | | | 5 | 26 | 31 |
| L4 | | | | | 3 | 3 |
| L5 | | | | | | 0 |
| ∑ | | | | 33 | 47 | 80 |

The control and experimental group students' responses to the pre- and post-argumentation tests provide further insights to the quantitative findings on the transition in the argumentation ability presented in Table 4. For instance, CS1's answer '*energy is transferred from the producer which is plants to other animals in the ecosystem'* implies that CS1's ability to produce level 1 arguments as CS1 has only stated the claims. In the posttest, CS1 said that *'energy is transferred when plants perform photosynthesis*. Comparing the pre- and posttests answers, CS1 has transformed from level 1 to level 2 because of the data included to support the claim. Like CS1, the experimental group (ES3) said that '*energy flows from the sun to plants'* in the pretest. Unlike CS1, ES3 in the posttest said *'energy transfer happens through the food chain when animals from higher trophic levels consume animals or plants at the lower levels. For example, energy is transferred when herbivores at second trophic levels consume the plants and carnivores at third trophic levels consumers herbivores [claim and data]. The energy is transferred in the form of chemical energy stored in biomass (carbohydrates) [warrant]. The food consumed is converted into biomass [backings]. However, not all the energy is transferred to the higher trophic in the feeding relationship [rebuttal]. 90% of the energy at each trophic level is used for naturally occurring processes such as respiration, excretion, and reproduction [qualifier]'*. Comparing the answers provided by CS1 and ES3 in the pre-and posttests depicts that ES3 has a better ability to produce quality arguments than CS1.

## Discussion

Students' responses to multiple-choice questions in ETCT show that the SWH approach effectively improved students understanding of energy transfer. In the interview responses, students exhibited inter-relations, interactions, and interdependences between producers, consumers, and decomposers via the food chain, the role of biogeochemical cycles, and the effects of human activities and pollution on the energy paths. The findings of this study suggest that the SWH approach is a solution to address the difficulties in understanding ET in ecosystems and the thermodynamic laws governing all the processes in the ecosystems that occur due to memorization of compartmentalized knowledge that hinders students from conceptualizing the holistic idea about ET in an ecosystem (Chabalengula et al., 2012; Lin & Hu, 2003; Wyner & Blatt, 2019). The findings echoed several other studies that have employed the SWH approach to improving understanding of science concepts (Kingir et al., 2012; Cronje et al., 2013; Hohenshell & Hand 2006; Nam et al., 2011). Besides improving understanding, the SWH approach used in teaching ET in ecosystems also enhanced students' ability to provide quality arguments to justify their claims. Many experimental group students had attained levels 4, and 5 of TAP in the post-evaluation compare to the control group students. Before the treatment with the ability to provide a simple claim supported with data, most of the students were classified into levels 1 and 2 of argumentation. The experiences encountered during the SWH approach prompted them to use rebuttals and qualifiers in producing quality arguments. The findings are parallel with several other studies that have indicated that SWH approach an argument-driven strategy, successfully engaging students in practicing argumentation (Chen et al., 2016; Yaman 2018).

The negotiation process is central to the SWH approach created a platform for the students to collaborate in negotiating the meaning in reaching a consensus about the understanding (Keys et al., 1999). The teacher template guided the teacher in facilitating the negotiation among students (Cavagnetto et al., 2010). The students' template with eight steps of carefully constructed argument structure necessitated students discussing the idea considering others' views before agreeing (Chen et al., 2016). Notable that the SWH approach prompted the students to establish a connection between beginning questions, observations, data, claims, and evidence. The connections were later presented in an organized pattern to describe understanding. Qualifiers and rebuttals were added to the organized idea to describe the circumstances where the pattern could be contested. The socio-constructivist nature of the approach engaged the students in complex cognitive functions discussing, reflecting, and defending their ideas to understand the complex and abstract concepts such as ET in ecosystems and development of quality arguments.

The SWH approach and findings of the study have several implications. The approach offers an alternative student-centered approach to the lessons on ET. The teachers could be trained on using the SWH approach through in-service professional development courses. The approach also should form the integral component pre-service teacher education curriculum. Pre-service teachers have the opportunity to learn to teach EF using a student-centered approach using the SWH approach. On the other hand, the pretest findings inform the curriculum developers and educators that the existing teaching results in students understanding ET's concepts in a compartmentalized manner. Knowing the concepts distinctively prevents them from relating the concepts to their everyday living (Wyner & Blatt, 2019). The study's positive outcome informs the stakeholders that the interconnectedness could be enhanced using the SWH approach.

## Limitations of the Study

The study assessed the quality of arguments using TAP indicated that the framework uses very general and broad categories to categorize argumentation due to the inconsistent use of the key terms (Duschl, 2007). The vagueness of the key terms to distinctively portray the quality of argument is not pervasive in analyzing individual argument structures (Garcia-Mila et al., 2013) and arguments in small groups (Osborne et al., 2004). Additionally, Erduran and Jiménez-Aleixandrear (2008) further indicated that the limitation of TAP is on how the model is used but not the model itself. Since this study investigated argumentation at individual levels practiced in small groups, TAP is perceived as appropriate. Following Cook et al.'s (2002) claim, despite using a quasi-experimental design to measure the treatment's effect, the current study exhibits several limitations. Most importantly, the findings lack generalization. This is because the samples for this study were from one school, and convenient sampling was used to identify the participating school. Although the external factors such as the curriculum content, learning environment, and teacher's qualification are controlled, the study is recommended to be repeated with students from different schools to improve the generalization. In this study, both experimental and control groups were from the same school. There was a tendency for the diffusion effects when the groups are in a close environment. The diffusion effects were controlled by performing the study at different schools' locations and different timing (Karpudewan et al., 2016).

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