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Developing Students' Reflective Thinking Skills in a Metacognitive and Argument-Driven Learning Environment

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Article Info	Abstract
<p><i>Article History</i></p> <p>Received: 08 April 2020</p> <p>Accepted: 23 June 2020</p> <hr/> <p><i>Keywords</i></p> <p>Metacognition Argument-driven inquiry Biology teaching Reflective thinking Action research</p>	<p>This study designed and examined the effects of Metacognitive and Argument-Driven Learning Environment (MADLE) in cultivating students' reflective thinking skills. The study involved a group of third-year Biological Science Education students (n=23) in a state university in the Philippines. The study employed a mixed-method approach, where both quantitative and qualitative data were collected and analyzed to answer the research question. Specifically, one-group pretest-posttest design was used under the paradigm of pedagogical action research. The quantitative data were obtained from a 16-item pre- and post-Reflective Thinking Questionnaire while qualitative data were culled from classroom observations and focus group discussions. The Wilcoxon Signed Ranks Test was utilized to determine significant changes in students' reflective thinking skills. Findings showed an insignificant difference in students' reflective thinking skills prior to and after their four-week exposure to MADLE. However, the multiple sources of data yielded from students' higher posttest mean scores in each level of reflective thinking skills, classroom observations, and responses in the focus group discussion imply the efficacy of MADLE in stimulating and supporting students' reflective thinking skills. Hence, it is recommended to integrate MADLE in improving instructional practices that will engage students in reflective thinking practices.</p>

Introduction

The world today has been experiencing diverse and dynamic changes, for it has become more complex as information becomes easily available, and people are continually rethinking, changing directions and problem-solving strategies more quickly. In the landscape of education, teachers are constantly called upon to adhere to instructional practices that support students with relevant knowledge and lifelong skills to be able to cope with these complex changes (Jerald, 2009). According to Lai and Viering (2012), these important skills are the 21st-century skills, which include learning and innovation skills (critical thinking, problem-solving, creativity, innovation, communication, and collaboration), information, media and technology literacy skills, and life and career skills (initiative and self-direction) Hence, today's education is challenged to develop these skills among students, especially in higher education.

One of the essential lifelong skills tied to critical thinking is reflective thinking (Akerson, Carter, Park Rogers, & Pongsanon, 2018; Al-Husban, 2020; Murphy, 2014; Naber & Wyatt, 2014; Perdana, Jumadi, & Rosana, 2019; YuekMing & Manaf, 2014). Reflective thinking is the ability to make use of observations and experiences to shape decisions about what happened in the past or is occurring now to direct and control future activities (Pisapia, 2009). It is a way of thinking and contemplation on how one acts on new understandings (Strampel & Oliver, 2007). This involves the stimulation of new understanding, bringing previous experiences, and the consideration of how "old knowledge" affects new situations. It also entails the interpretation and evaluation of one's experience, creating meaning, justifying actions, and solving problems (Syed, Scoular, & Reaney, 2012). According to Strampel and Oliver (2007), developing students' reflective thinking skills can facilitate understanding, support conceptual change, and foster critical evaluation and knowledge transfer. Therefore, designing an effective learning environment that promotes a culture of reflection must be one of the primary goals of teachers, especially in science education. It is a very significant task for teachers to make scientific concepts more authentic, and more reflective of the actual practices of science that may support students' development of reflective thinking skills.

Literature Review

Metacognition

There have been several definitions of metacognition in the literature. It is described as the individual's awareness of knowledge and thought processes regarding his or her learning. It involves active control of one's cognitive processes (Akturk & Sahin, 2011; Kaberman & Dori, 2009). It also refers to how one reflects on and directs thinking (National Research Council, as cited in Seraphin, Philippoff, Kaupp & Vallin, 2012), and is considered as the highest level of thinking (Livingston, 1997). In the field of education, following Bransford, Brown, and Cocking (2000), fostering metacognition is one of the main recommendations in improving teaching and learning, which emerged from numerous researches about effective learning. They maintain that integrating metacognition in teaching improves student achievement and cultivates independent learning among students. Supporting this claim, a number of researches signified the importance of metacognition in teaching and learning. In particular to science education, the different metacognitive practices employed from the most to least frequently are as follows: (1) metacognitive prompts; (2) metacognitive writing; (3) practice and training; (4) teacher-led metacognitive discussions; (5) student-led metacognitive discussions; (6) explicit instruction; (7) ICT use for metacognitive instruction; (8) concept mapping and visual representations; and (9) metacognitive modeling. The utilization of these practices indicated that metacognition has been extensively utilized in classroom instruction (Zohar & Barzilai, 2013).

In recent years, fostering metacognition has been found to be integrated with the use of ICT. In the study of Lai, Hwang, and Tu (2018), a learning management system was developed to support students' metacognitive skills. Students set their goals for learning and evaluate their learning performance before and after their courses in the self-regulated system. The teacher provides comments corresponding to a student's inquiry performance and self-regulation in the teacher management system. Subsequently, students write reflections after reading the comments and set another goal for the succeeding science inquiry. In other studies, Moser, Zumbach, and Deibl (2017), and Huang, Ge, and Eseryel (2016) incorporated metacognition to improve simulation-based learning. The metacognitive scaffoldings in the form of training and prompts were seen to support learning provided that students use prompts in an appropriate manner (Moser, Zumbach, & Deibl, 2017). Meanwhile, the metaconceptual scaffolding-enhanced simulation-based inquiry learning was reported to significantly scientific misconceptions (Huang, Ge, & Eseryel, 2016).

The integration of metacognitive strategies in inquiry-based learning can improve students' understanding of science, academic achievement, and process skills (Seraphin, Philippoff, Kaupp, & Vallin, 2012). It is seen as a vital component of the scientific process and of learning in general. Without the use of and knowledge of metacognitive skills, scientific inquiry cannot be carried out. Hence, an environment that fosters students' metacognitive skills is important for them to make decisions about their learning and how they learn (van Opstal & Daubenmire, 2017). According to Tanner (2012), building a teaching and learning environment grounded from metacognition can be done through explicit teaching of metacognitive strategies. This includes encouraging students to examine their current thinking (pre-assessments), allowing them in identifying their confusion (muddiest point), pushing them to recognize conceptual change (retrospective post-assessment), and providing them an opportunity to monitor their thinking (reflective journals). Additionally, Schraw (1998) suggested the use of a checklist that may help facilitate the regulation of cognition. It consisted of metacognitive prompts in the form of questions categorized as to planning, monitoring, and evaluation. Prompts may be also cues or probes that are introduced in writing, by the teacher, by student peers, or in an ICT environment (Autio, Jamsek, Soobik, & Olafsson, 2019; Wallace-Spurgin, 2019; Zohar & Barzilai, 2013). In relation to the present study, this action research aims to provide a metacognitive teaching and learning environment that employs the explicit integration of metacognitive strategies (Tanner, 2012) and prompts (Schraw, 1998), coupled with an instructional approach that incorporates scientific argumentation and inquiry.

Argument-Driven Inquiry

The Argument-Driven Inquiry (ADI) is a novel instructional approach that was introduced by Sampson, Grooms, and Walker (2009). It aims to provide students with learning experiences that mimic the actual practices of science through scientific argumentation and inquiry-based learning. The original iteration of this pedagogical approach provides opportunities for students to conduct their own investigations; collect and analyze data; communicate ideas with others through argumentation sessions; write investigation reports and; engage in peer review during laboratory investigation (Sampson, Grooms, & Walker, 2009). It is theoretically

based on the social constructivist theory of learning (Sampson & Walker, 2012), highlighting that learning stems from social interactions amongst and between students and knowledgeable others.

In the literature, several empirical studies in different disciplines of science have extensively examined and reported the efficacy of ADI in improving students' conceptual understanding (Myers, 2015; Celep, 2015; Celik & Kilic, 2014; Walker, Sampson, Grooms, Anderson, & Zimmerman, 2012; Enderle, Grooms, & Sampson, 2013). Previous studies showed that ADI can also help foster students' argumentation skills in science (Çetin & Eymur, 2017; Kadayifci & Celik, 2016; Myers, 2015; Walker, Sampson, Grooms, Anderson, & Zimmerman, 2012; Demircioglu & Ucarb, 2015; Celik & Kilic, 2014). To cite an example, Enderle, Grooms, and Sampson (2013) conducted a comparative case study on the impact of ADI on students' science proficiency over traditional laboratory instruction. Results revealed that both groups of students exposed to ADI and traditional laboratory instruction made substantial gains in terms of their content knowledge and their overall scores on the performance task. However, only the students exposed to ADI made significant gains with respect to their scientific writing abilities and their understanding of the development and nature of scientific knowledge. Larger effect sizes are also reported in the different aspects of science proficiency in comparison to students exposed to traditional laboratory instruction. Although Enderle, Grooms, and Sampson (2013) did multiple quantitative assessments for assessing students' science proficiency, findings of the study would have been more convincing if they did qualitative collections of data through classroom observations or interviews to triangulate quantitative data.

Moreover, some researchers found out that ADI enhanced science process skills (Eymur, 2018; Kadayifci & Celik, 2016; Demircioglu & Ucarb, 2015), student engagement (Myers, 2015), self-efficacy (Eymur, 2018) academic achievement, (Demircioglu & Ucarb 2015), and attitudes (Walker, Sampson, Grooms, Anderson, & Zimmerman, 2012; Celik & Kilic, 2014). For instance, in a two-year period of study of Kadayifci and Celik (2016), the ADI instructional approach was used in a General Chemistry course among preservice teachers where its effects on their levels of reflective thinking, their science process skills, their argumentative ability, and their ability to identify flaws in an argument were investigated. Results showed that participants had remarkable improvements in the aforementioned variables. Qualitative data suggested that participants had positive views towards ADI in learning Chemistry. However, the impact of ADI on students' level of reflective thinking is inconclusive since the researchers failed to take into account students' reflective thinking skills at the onset of the study. They only determined the students' level of reflective thinking after exposure to ADI. Development of or changes of such skills through pre-post tests were not carried out. Nevertheless, this is the only study that attempted to examine students' reflective thinking who were exposed to an argument-based instruction. Hence, the potential of ADI in promoting reflective thinking skills during scientific learning is not yet clear.

Further, there were previous studies that investigated the effectiveness of ADI on students' metacognitive awareness (Erenler & Cetin, 2019; Prastio & Hasnunidah, 2019). The nature of ADI-based activities enabled pre-service teachers to develop from all dimensions of metacognitive awareness (Erenler & Cetin, 2019). This is similar to the study of Prastio and Hasnunidah (2019) who reported the efficacy of ADI in enhancing secondary students' metacognitive awareness while learning a biological concept. Based on previous studies culled from the literature, however, researchers have not yet investigated the effects of ADI on students' biological learning in higher education in much detail. Apart from this, to the best of the researcher's knowledge, no study has attempted to synergize metacognition and ADI and examined its effect on students' reflective thinking skills. Hence, this pedagogical action research aims to investigate the effectiveness of ADI in improving teaching and learning experiences that may facilitate students' development of reflective thinking skills.

Reflective Thinking Skills

Rogers (2001) defined reflective thinking as a way of "integrating the understanding gained into one's experience to enable better choices or actions in the future as well as enhance one's overall effectiveness." In teaching and learning, Oliver and Herrington (2002) argued that there are important elements that need to be present in achieving an effective learning environment that promotes and cultivates reflection. These consist of learning resources, learning tasks, and learning support. Engaging learning tasks can help students participate in the different stages of cognitive processing and levels of reflection. Learning support through scaffolding assists students to complete the task and encourages them to become independent learners. Finally, multiple learning resources allow students to interact with the content, information, and knowledge they need to fully engage in reflective thinking. When these elements are present, students may engage in reflective thinking processes and thus reach deeper levels of learning.

Kember *et al.* (2000) explain that reflective thinking skills can be described in four levels, in which the first two levels, habitual action and understanding, are considered non-reflective, while reflection and critical reflection are reflective levels. Habitual action refers to working on activities without significant or with little conscious thought about it (Kember *et al.*, 2000). It is characterized when students follow procedures without thinking on what is happening about it. It is linked to a surface approach to learning that occupies the lowest level of the reflection and involves minimal thought and engagement (Biggs *et al.*, 2001; Leung & Kember, as cited by Peltier, 2005). Following this, the understanding level focuses on the student's comprehension but without thinking of its relation to his or her personal experiences or other learning situations (Kember *et al.*, 2000). Although students may search for underlying meaning at this level, there is still no reflection. Meanwhile, in the reflection level, students do not only reach an accurate understanding but can also reflect on their personal experiences. Finally, as the highest level of reflective thinking, the critical reflection level implies a transformation of students' perspectives over a fundamental belief of the understanding of a key concept or phenomenon.

There have been few empirical studies in the literature that aimed to improve students' reflective thinking skills; however, differing results were reported from these studies. For example, in the study of Tican and Taspinar (2015), the comparison of reflective thinking skills between the control and experimental group was found to be insignificant. However, students were found to exhibit reflective thinking skills to a great extent. This is similar to Recede (2017) who also found out that the integration of metacognition and analogy-based instruction in teaching Biology among high school students did not lead to significant developments in students' reflective thinking skills. Likewise, Murphy (2014) noted that high school science students, who received reflection-based instruction, were not able to develop significant changes in their reflective thinking skills. On the contrary, Chen, Hwang, Chang (2019) ascertained that the students exposed to a reflective thinking-based approach in the "before-class" stage of flipped learning had significantly improved reflective thinking skills more than those exposed in the traditional flipped learning approach. Considering these existing literature, the development of students' reflective thinking skills appears to be rarely investigated, especially in higher education. There were studies that examined the effects of ADI on students' metacognition (Erenler & Cetin, 2019; Prastio & Hasnunidah, 2019), but no study has yet coupled metacognition with ADI and empirically explored its effects on students' reflective thinking skills.

Theoretical Framework

Grounded from the constructivist lens, the roots of the ADI instructional approach can be primarily traced from the social constructivist theory of learning (Sampson & Walker, 2012). According to Lev Vygotsky, the main proponent of social constructivism, effective learning stems from social interactions that occur amongst and between students and knowledgeable others. He argued that effective learning is promoted through collaborations, where individual knowledge construction is achieved through social interactions (Vygotsky, 1978). This theory specifically proposes that learning entails personal and social processes. The social process of learning relies on the social interactions of individuals, while the personal process of learning involves individual construction of knowledge and understanding through the accommodation of ideas, habits of mind, and other essential skills.

The integration of metacognition in teaching and learning is influenced by the theory of metacognition. Flavell (1987) argues that metacognition consists of two main components: knowledge of cognition or metacognitive knowledge, and monitoring of cognition or metacognitive regulation. Metacognitive knowledge refers to one's awareness of strategies and thought processes (Pintrich, 2002). Meanwhile, metacognitive regulation serves as the "active side" of metacognition, which involves the use of metacognitive strategies that one uses to control cognitive activities. In the context of teaching and learning, a metacognitive approach can help students actively control and monitor their learning progress towards achieving them (Buoncristiani & Buoncristiani, 2012). It is viewed as an essential and foundational element of any inquiry process because it leads individuals to more fully functional processes that assist their learning (van Opstal & Daubenmire, 2017).

In an inquiry-based learning environment like ADI where the teacher provides students with an open-ended problem, students need to be metacognitive to ensure successful and effective learning. Students need to utilize metacognitive regulation strategies in accomplishing activities such as planning, monitoring, and evaluating (Schraw, 1998). These will help them define and set their goals, monitor, and evaluate their progress in achieving them. Moreover, students must be able to activate their prior knowledge, examine their current thinking, identify their confusion, recognize conceptual change, and reflect their own learning and experience

through reflections (Tanner, 2012). These metacognitive strategies are deemed vital in assisting students towards meaningful learning. Thus, explicitly teaching and assisting students with metacognitive strategies will help them to take control of their own learning, which, in turn, could help them become thoughtful and reflective learners. Grounded on the theoretical bases of ADI and metacognition, this study designs a Metacognitive and Argument-Driven Learning Environment (MADLE) to enhance classroom instruction that will facilitate students' development of reflective thinking skills.

Research Question

This study aimed at designing and examining the effects of a Metacognitive and Argument-Driven Learning Environment (MADLE) in cultivating students' reflective thinking skills. The study seeks to answer the research question: "Is there a significant change in students' reflective thinking skills before and after exposure to MADLE?"

Methodology

Research Design

The study employed a mixed-method approach (Creswell, 2003), where both quantitative and qualitative data were gathered and analyzed to answer the research question. Specifically, one-group pretest-posttest design was used under the paradigm of pedagogical action research. Although the study acknowledges the weakness of this design, it was conducted under the paradigm of pedagogical action research since it aims to systematically investigate and enhance teaching and learning practices and contribute to theoretical knowledge (Norton, 2018). In this study, the teacher-researcher aimed to better understand his teaching practice and how it could help foster students' reflective thinking skills. A single cycle of action research was employed to determine the effectiveness of MADLE in developing students' reflective thinking skills. The study specifically utilized the Plan-Do-Study-Act (PDSA) model of action research, a protocol that guides teachers to examine whether the implemented instructional changes lead to improvements (Deming, 2000). The effectiveness of MADLE was investigated by means of thorough planning, implementing, observing the consequences, and then acting on what is learned from the results, which will be used for the improvement of the intervention in the next cycle.

Research Locale and Participants

The study involved one group of third-year students (n=23) taking up Bachelor of Secondary Education major in Biological Science in a state university in Bulacan, Central Luzon, Philippines. These students were enrolled in the Microbiology course and handled by the teacher-researcher himself during the second semester of the academic year 2018- 2019. The majority of these students were female with a frequency of 17 (73.91%). With regards to age, majority are within the age range of 21-22 (30.43%), followed by 19-20 (21.74%), 23-24 (17.39%), 25-26 and 29-30 (13.04%), and 27-28 (4.38%). Since the sample size of the study is very small, the author acknowledges that it is a major limitation of this study that makes it difficult to generalize findings to a larger population.

Research Instruments

Reflective Thinking Questionnaire

The Reflective Thinking Questionnaire (RTQ) developed by Kember *et al.* (2000) was adapted in this study to measure students' reflective thinking skills prior to and after exposure to MADLE. This Likert scale instrument consisted of sixteen (16) statements that describe the four levels of reflective thinking skills, mainly: Habitual Action, Understanding, Reflection, and Critical Reflection. Each statement in the said questionnaire was translated in Filipino to facilitate easy comprehension. A Filipino language expert was asked to translate each statement. Meanwhile, the reliability of the instrument in each construct was established by acceptable Cronbach alpha values of 0.621, 0.757, 0.631, 0.675, respectively. Table 1 shows the number of items in each level and the sample statements in the RTQ.

Table 1. Number of Items and Sample Statements in the Reflective Thinking Questionnaire

Level	Number of Items	Sample Statement
Habitual Action	4	When I am working on some activities, I can do them without thinking about what I am doing. (<i>Kapag ako ay may ginagawa, kaya kong gawin ito nang hindi iniisip ang aking ginagawa.</i>)
Understanding	4	In this course, I have to continually think about the material I am being taught. (<i>Sa kursong ito, patuloy kong iniisip ang mga bagay na itinuturo sa akin.</i>)
Reflection	4	I sometimes question the way others do something and try to think of a better way. (<i>Minsa'y iniisip ko ang ginawa ng iba at umiisip ako ng iba pang mas magandang paraan.</i>)
Critical Reflection	4	This course has challenged some of my firmly held ideas. (<i>Binago ng kursong ito ang ilang pinaniniwalaan kong ideya.</i>)

Assessment of Scientific Argumentation inside the Classroom Observation Protocol

The developed and validated ASAC observation protocol of Sampson, Enderle, and Walker (2012) was adapted in this study. This classroom observation protocol aimed to describe the nature and quality of scientific argumentation that occurred between and among students inside the classroom. In the implementation of the study, teacher-observers were invited to conduct classroom observations assessing the different aspects of scientific argumentation.

Students' Reflections and Focus Group Discussion

Students' written reflections after each session were described and analyzed to substantiate quantitative findings. Additionally, qualitative data were gathered through focus group discussions after the conduct of the study. Semi-structured interview questions were asked to elicit responses from the students.

Research Procedures

The following is a detailed description of the Plan-Do-Study-Act (PDSA) model that was used in this pedagogical action research study.

Plan

The teacher-researcher developed a unit plan on Microbial Genetics with a content focus on Antimicrobial Resistance. The contents of the lesson plans included in the unit were based on the learning competencies of the course syllabus as stipulated by the Commission on Higher Education for Microbiology, particularly in the Microbial Genetics unit. As displayed in Table 2, the following topics were the scope of the study:

- (1) Structure and Function of the Genetic Material
- (2) DNA Replication
- (3) Protein Synthesis
- (4) Gene Regulation
- (5) Mutation
- (6) Antimicrobial Resistance

Three (3) experts in Microbiology and Biology Education and one (1) expert on metacognition were requested to examine the content validity of the unit plan. Table 2 presents the lessons and activities included in the unit. The teacher-researcher then prepared the Reflective Thinking Questionnaire (RTQ). A message was sent to Kember *et al.* (2000), author of the Reflective Thinking Questionnaire notifying them that the instrument will be used in the study. Prior to the implementation, permission was sought from the administration of the university where the study was implemented.

Table 2. Lessons and Activities Included in the Unit

Topic/Activity	Guiding Question	Description of the Task
Structure and Function of the Genetic Material	What is the structure of the DNA?	Students used and analyzed the existing data in the DNA Fact Sheet to develop a three-dimensional model that shows the structure of DNA (Sampson, 2014).
DNA Replication	Does DNA follow the conservative, semi-conservative, or dispersive model of replication?	Students interpreted and analyzed the data from the pulse-chase experiment of Meselson and Stahl to investigate which model describes the process of DNA replication.
Protein Synthesis	How does the genetic information flow from DNA to proteins?	Students explored and investigated the processes of transcription and translation using a computer simulation to elucidate the processes involved in protein synthesis. (http://lab.concord.org/embeddable.html#interactives/sam/DNA-to-proteins/1-dna-to-protein.json)
Gene Regulation	How does <i>Escherichia coli</i> regulate the production of β -Galactosidase	Students conducted an investigation using a computer simulation to explore how gene expression is regulated at the levels of transcription and translation in bacteria. (https://phet.colorado.edu/)
Mutation	Does a variant rpoB gene sequence result in resistance to the antibiotic rifampin?	Students used bioinformatics tools to analyze gene sequences of a wild-type and a mutant <i>Mycobacterium tuberculosis</i> strains, and identify if the single-nucleotide polymorphisms in the variant sequence affect the structure and function of the protein, which might lead to antibiotic resistance or susceptibility (Taylor, Davidson, & Strong, 2014).
Antimicrobial Resistance	Are all bacteria susceptible to antibiotics?	Students carried-out a Kirby-Bauer disk diffusion lab susceptibility test to determine the susceptibility or resistance of the test bacteria to antibiotics.

Application

Prior to the implementation of MADLE, the RTQ pretest was administered. After this, students were exposed to MADLE aided by the developed and validated unit plan. The teacher-researcher adaptively implemented the following stages of ADI as part of MADLE: 1) identification of the guiding question; 2) collection and analysis of data; 3) generation of initial argument; 4) argumentation session; 5) explicit and reflective discussion, and; 4) writing argumentation report. As shown in Figure 1, MADLE is informed of the seven phases in the 7E instructional model. The following section is a detailed discussion of each phase.

Elicit. This phase helps the instructor to find out what students already knew about a topic and for students to examine their current thinking (pre-assessments). Metacognitive strategies such as IRF and KWL charts are embedded in this phase.

Engage. This phase intends to capture students' attention, raise questions in students' minds, and stimulate students' thinking through the identification of the guiding question of the activity.

Explore. This phase calls for students to make sense of their investigation, particularly on the data/information they collected, in order to generate an argument that consists of a claim, evidence they are using to support the claim, and reasoning or justification of the evidence. An example of the inquiry-based investigation is shown in Figure 2. In this activity, students used online bioinformatics tools to determine how mutation affects the structure and function of the protein (Taylor, Davidson, & Strong, 2014).

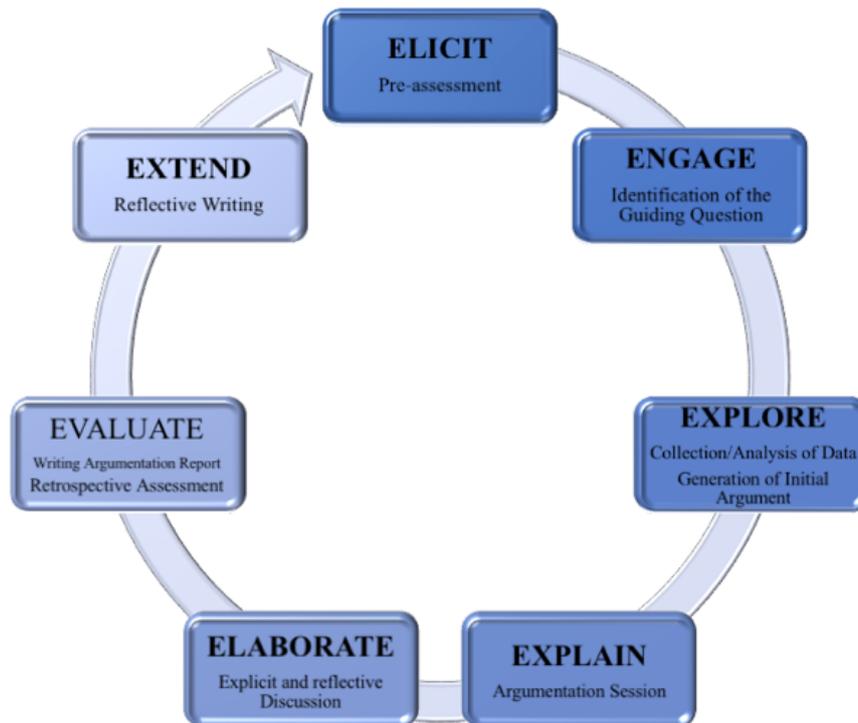


Figure 1. Metacognitive Argument-Driven Inquiry

(a)

Sequence type	Output format for gene prediction	Output options	Optional: results by E-mail
<input checked="" type="radio"/> Prokaryotic <input type="radio"/> Intronless eukaryotic <input type="radio"/> Virus <input type="radio"/> Phage <input type="radio"/> EST/cDNA	<input type="radio"/> LST <input type="radio"/> GFF	<input type="checkbox"/> Protein sequence <input type="checkbox"/> Gene nucleotide sequence Coding potential graph (not for multi FASTA) <input type="checkbox"/> PDF <input type="checkbox"/> PostScript	<input type="checkbox"/> E-mail <input type="checkbox"/> Subject <input type="checkbox"/> GenMarkS <input type="checkbox"/> Compress files

(b)

Figure 2. Screenshots of the Bioinformatics Tools used in Students' Investigations in (a) Identifying Single-nucleotide Polymorphisms and (b) Translating Each Gene Sequence to an Amino Acid Sequence

Explain. At this phase, small groups share their initial arguments (see Figure 3) with other groups and critique others' arguments to determine which claim is the most valid and acceptable or to refine a claim to make it more valid and acceptable. It also gives the instructor an opportunity to evaluate students' progress or thinking and to encourage students to think about issues that have been overlooked or ignored. This phase emphasizes the importance of scientific argumentation. It also helps students to understand what qualifies as a high-quality

argument and how to determine whether the evidence available is valid, relevant, sufficient, and convincing enough to support a claim.

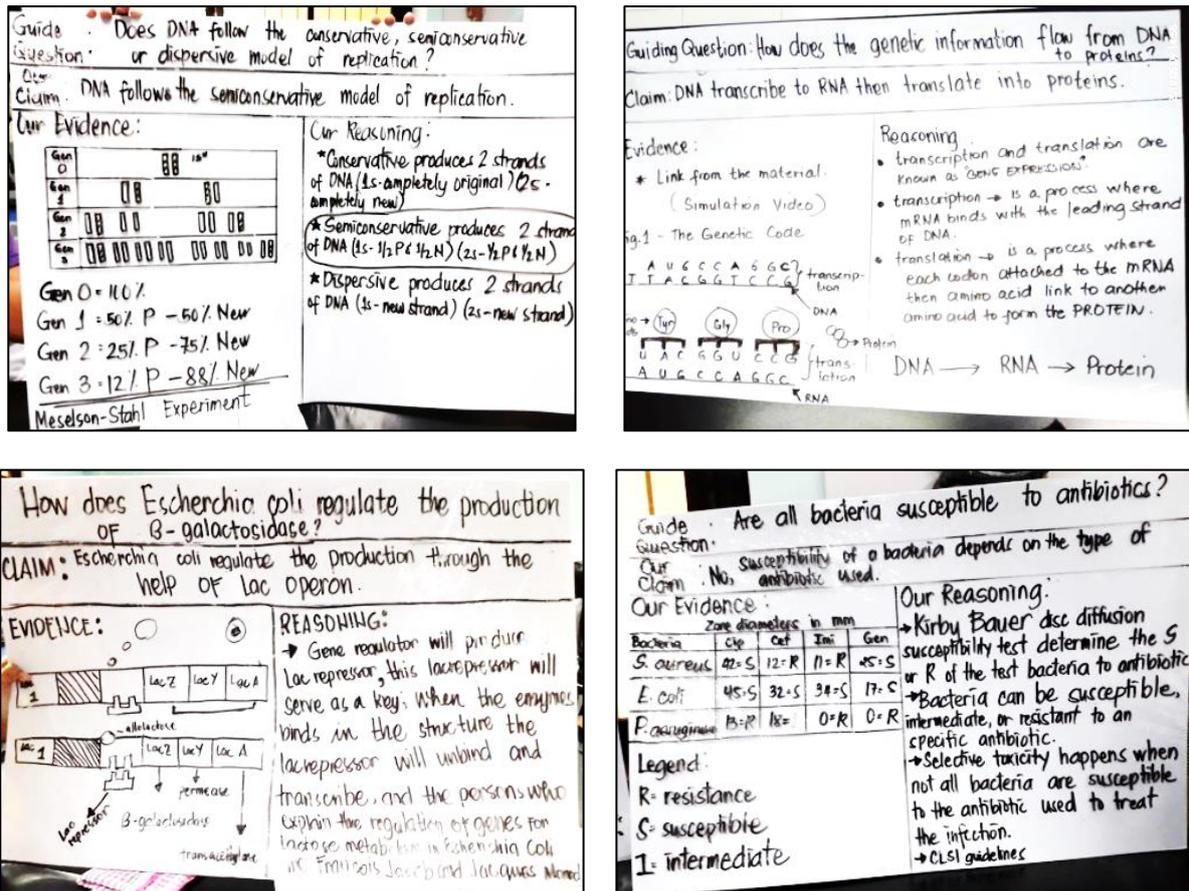


Figure 3. Examples of Argument Boards

Elaborate. At this phase, the instructor’s goal is to facilitate an explicit and reflective discussion about the content at the heart of the investigation.

Evaluate. This phase requires students to write an argumentation report that articulates their final arguments or evidence-based explanations of the guiding question. It also asks students to reflect (retrospective post-assessment) as to what they thought about a topic or concept before the session and what they think about it now.

Extend. This phase asks students to describe what they didn’t understand during class and what they think might help them (muddiest point). Students also make connections between what they are learning and how they are integrating the content into their current learning structures (reflections).

After a 4-week exposure to MADLE, posttests were administered to examine the changes in students’ reflective thinking skills. Two (2) focus group discussions (FGD) were conducted involving 2-3 representatives of each group in the class. This was done to collect qualitative data on students’ reflective thinking, as well as to gather their perceptions and experiences towards teaching and learning through MADLE.

Study

Both quantitative and qualitative data were used and analyzed to determine the changes in students’ reflective thinking skills before and after exposure to MADLE. Appropriate descriptive and inferential statistical analyses were utilized to determine if there were significant changes in the variable being investigated. Specifically, the Wilcoxon Signed Ranks Test was utilized to determine if the implementation of MADLE effected a significant difference in students’ reflective thinking skills.

Moreover, the effect size r was used to determine the magnitude impact of MADLE in students' reflective thinking skills. As suggested by Allen and Bennett (2008) and Clark-Carter (2004), the z statistic results from the Wilcoxon Signed Rank Tests were converted into r effect size, which was obtained by dividing the z values by the square root of N (the total number of observations). The result was then interpreted according to Cohen's (1988) criteria: $d = 0.10$ as small effect, $d = 0.30$ as medium effect, and $d = 0.50$ as large effect size. In terms of qualitative data, students' responses in the focus group discussions were transcribed and analyzed using thematic analysis with the aid of NVivo software. Thematic analysis was employed to probe patterns and themes of students' learning experiences.

Act

Based on the findings of the study, the teacher-researcher has drawn implications towards the use of MADLE in teaching and learning of Biology. Recommendations and/or suggestions for future researches are also given.

Results

This section presents the quantitative and qualitative results on the effectiveness of MADLE in cultivating students' reflective thinking skills.

Quantitative Findings

Table 3. Wilcoxon Signed Ranks Test for the Difference between Pretest and Posttest Scores of Students in the Reflective Thinking Skills Questionnaire

Level	Pretest	SD	Posttest	SD	Mean Difference	z	Asymp. Sig. (2-tailed)	r
Habitual Action	2.620	0.353	2.478	0.516	-.14130	-.991 ^b	.322	0.146
Understanding Reflection	3.587	0.278	3.652	0.359	.06522	-1.094 ^c	.274	0.161
Critical Reflection	3.500	0.399	3.598	0.404	.09783	-.999 ^c	.318	0.147
Overall	3.274	0.235	3.310	0.273	.035	-.939^c	.348	0.138

Note: No. of items = 16; ; *significant at $\alpha = 0.05$; effect size (Cohen's d) value 0.10 (small effect), 0.30 (medium effect), and 0.50 (large effect); a. Wilcoxon Signed Ranks Test; b. Based on positive ranks; c. Based on negative ranks

Table 3 presents the changes in students' reflective thinking skills before and after exposure to MADLE. As can be gleaned from the table, the pretest mean score was recorded at 3.274 ($SD=0.235$) while the posttest mean score was at 3.310 ($SD=0.273$). The Wilcoxon Signed Ranks Test was used to determine if there is a significant change in students' reflective thinking skills at the end of the study. Results revealed that the difference between the overall mean scores in the pretest and posttest was not significant at .05 level, $z = -.939$, with a small effect size of $r = 0.138$. This suggests that students' pre- and post-reflective thinking skills are not significantly different before and after exposure to MADLE.

Qualitative Findings

The qualitative data from the focus group discussions were classified under the following themes: (1) development of students' understanding, (2) collaborative sharing of ideas, (3) development of students' reflective thinking skills. The various responses by the students on each theme are summarized in Table 4.

Table 4. Results of Thematic Analysis

Themes	Codes	Sample Responses
development of students' understanding	limited ideas	Student 15: "Sometimes, my ideas are so limited but the argumentation session [in ADI] helped increase my knowledge."
	understanding	Student 13: "We constructed our own understanding. In other activities, we didn't have any prior knowledge but because of the simulation, we were able to follow what was happening in the process."
	prior knowledge	Student 22: "...can help us express all our ideas."
collaborative sharing of ideas	expression of ideas	Student 23: "...we are keeping our initial argument within our group, and we think that it is a good argument already. And, when the argumentation starts, we get so much information that we used to improve our argument."
	argumentation	Student 19: "When we are doing it, first we are reading it, and we are putting what we think is right. You also see your work as right for the argumentation, and you have nothing to change about it. But, when we are doing the argumentation, we can see what our work is lacking or what is wrong about it."
	collaboration	Student 22: [MADLE] helped us to think first before we answer. When I was writing an essay before, there was no system, but because of the argumentation, I become systematic. We have a claim and evidence. On your evidence, you will put reasoning. On your reasoning, you will reason out with a scientific basis and not just based on opinions. You have a basis, evidence, and reason.
development of reflective thinking	habitual action	Student 14: I observed more that my reflective thinking was promoted better on the part where we are going to make a claim. We need to focus on how we're going to express and prove our claim, or how we will formulate it. So, the reflective thinking is there, in that we should give time to understand it before answering.
	reflection	Student 7: In this activity, I realized that understanding the previous lesson is important to keep up in the present activity. Also, forgetting curve is real. That's why it is important to revisit the previous lesson that is connected to the present lesson.
	realizations	Student 11: Our last argumentation was very fruitful. There are so many concepts that I failed to interpret correctly. I have learned that I should be more critical in making my arguments. I should be more specific in putting the data that I am going to write and say.
	critical reflection	

Classroom Observations

The teacher-observers described the nature and quality of scientific argumentation that occurred between and among the students using a classroom observation protocol (Sampson, Enderle, & Walker, 2012) as to the following aspects: conceptual and cognitive, epistemic, and social aspects. In terms of cognitive and conceptual aspect, the students were found to be actively focused on developing a better understanding or in advancing knowledge on the topic. The teacher-observers expressed:

"The formulated arguments of the groups showed the extent of their understanding of the given facts and how they attempted to combine or reinforce it with their prior knowledge. Generally, they were able to provide scientific explanations/justifications for why the structure of genetic material considered as a perfect double helix."

“It was clear that the development of understanding was a collaborative effort between the students, their peers, and the teacher. Knowledge is not just transmitted the conventional way from teacher to students, but students themselves actively construct knowledge and have a share with their own learning.”

With regards to the epistemic aspect of argumentation, students’ arguments reflected their use of evidence, their evaluation of the evidence, the extent to which they use scientific theories, laws or models during the discussion, and the language of science to communicate their ideas. As the teacher-observer wrote:

“...there were students who challenged the strength of a group’s supporting evidence and the consistencies between their evidence and reasoning. At large, argumentations developed an exciting student-student interaction where the goal of the group is to establish a sound justification/understanding of each other’s argument consistent with scientific conceptions.”

Lastly, the social aspect of argumentation is seen in how the students communicated and interacted with each other. Students were found to be reflective about what they say, respectful for each other, willing to discuss ideas introduced by others, and to solicit ideas from others. As noted by the teacher-observer:

“I have observed that in this session the students have a free discussion of ideas, reasoning and justification based on the claim. Moreover, this strategy makes the learning of the students more active than passive, since they are to argue on the claim of the presenter, be it they agree or disagree. I remember the era of the philosophers. This strategy also requires reflection of the arguments whether it can support or not the claim of the presenter. Subsequently, students tend to be more self-regulated in terms of their learning and seems to develop self-esteem as they assert their arguments with convictions and objectivity.”

Discussion

This study designed a Metacognitive and Argument-Driven Learning Environment (MADLE) to enhance teaching and learning experiences that may facilitate students’ development of reflective thinking skills. Results of the quantitative findings showed that students’ reflective thinking skill did not significantly improve after exposure to MADLE. The result of the study is consistent with the studies of Recede (2017), Tican and Taspinar (2015), and Murphy (2014). Recede (2017) found out that the integration of metacognition and analogy-based instruction in teaching Biology among high school students did not lead to significant improvements in students’ reflective thinking skills. However, students were found to improve in their reflective thinking skills based on their posttest mean scores. Likewise, Tican and Taspinar (2015) argued that although there was no remarkable improvement in students’ reflective thinking skills, the students were still able to demonstrate reflective thinking skills to a great extent. Moreover, high school science students, who were exposed to reflection-based instruction, did not develop significant changes in their reflective thinking skills (Murphy, 2014).

Based on the observations of the teacher-researcher, there have been several factors that could explain the results of the present study. Possibly, students’ reflective thinking skills would have significant improvements when they were exposed to more reflective opportunities in a long period of time. Chen, Hwang, and Chang, (2019) mentioned that the development of reflective thinking skills takes a longer time. Additionally, although MADLE is infused with metacognitive prompts, it was observed that some students skipped in answering such prompts. This might be a factor that hindered the student’s opportunity to review and reflect on their experiences. Apart from this, even though students affirmed that the collaborative sharing of ideas during the argumentation sessions facilitated the development of their understanding of the lessons, most students suggested that there must be an alternation of roles within the group for social loafing was evident especially in the latter part of the unit, where some students in the group were not participating, hence exerting less effort in the group. Besides, the accessibility to the internet remained to be a challenge when performing some of the activities. Students expressed that they had a hard time in accomplishing the activities due to the limited internet connection.

From the themes that emerged from the qualitative data, the development of understanding and collaboration of ideas appeared to be linked to students’ development of reflective thinking skills. In the development of students’ understanding, students signified that the synergy of scientific argumentation and inquiry-based learning led them to an improved understanding of the concepts being learned in the unit. For instance, Student 15 said that he had sometimes limited ideas with regards to the content being investigated in the activity, but the argumentation sessions helped him to understand better the content. Although they did not have prior

knowledge in some of the topics, Student 13 said that the activity enabled them to develop their understanding of the topic with the help of the activity.

The development of students' understanding can be associated with the collaborative sharing of ideas or dialogic interaction as seen during the argumentation session. Through the argumentation session, students had the opportunity to express their initial understanding of the topic and communicate it with their classmates. This supports the idea of Cross, Taasoobshirazi, Hendricks, and Hickey (2008) that engaging in argumentation affords students with opportunities to confirm and extend previous knowledge and to construct new knowledge based on the ideas of others. This is described to be the social process of learning that relies on supportive and educative interactions (Sampson, Enderle & Walker, 2012) between and among individuals. Moreover, Tsai (2013) agreed that discursive and social interaction play critical roles in knowledge construction. Such social interaction provides opportunities for discussion, which allows individual thinking to move from implicit to explicit, resulting in a group reflection in reaching a common understanding. Consequently, students can test and examine their understanding and of others as a mechanism for enriching, interweaving, and expanding their understanding of particular issues or phenomena (Savery & Duffy, 2001).

As uttered by Student 23 and 19, the collaborative sharing of ideas or dialogic interaction during argumentation sessions provided them with opportunities to know the flaws of their initial arguments and use these points to improve. As claimed by the students, their initial arguments improved when they presented it during the argumentation session mainly because of the feedback given by their classmates. Larrain *et al.* (2019) explained that collaborative argumentation between and among students stimulates a process of content knowledge learning that continues at an individual level. Moreover, these results are aligned to the studies of Venville and Dawson (2010) and Asterhan and Schwarz (2007) who observed that dialogic interactions facilitate understanding.

According to Duit and Treagust (2017), the improvement in students' understanding may be attributed to the "restructuring of students' conceptual structures" that helps in the acquisition of concepts during the argumentation process, which, in turn, facilitates the development of students' reflective thinking skills (Hwang, Wu, & Ke, 2011; Limon, 2001). Through MADLE, students affirmed that they were encouraged to continually think about what they are doing while working on the activities in the class. As said by Student 22, MADLE helped them to think before they answered. This means that they were discouraged to work on activities without thinking about them and to develop a habit of doing so. Moreover, it also gave them the idea that if they follow their teacher and read the learning materials, they do not have to think too much. Students' responses also showed that MADLE supports them to become engaged in thinking practices to gain an understanding of the concept or theory, which are essential to be successful in performing the activities. As reflected in students' responses, reflection provides them with the opportunity to think critically, to step back, and consider how to actually improve their future activities and decisions (Rogers, 2011). Moreover, as signified by the students, they displayed stronger reflective attitudes, indicating that they are thinking about what they are doing, considering alternative ways, and looking for areas to improve on for the future. This also goes to the idea that they tend to review and reappraise their previous experiences in order to learn more and improve their thinking practices. It also assisted them in challenging their firmly held ideas and helping them to discover their underlying faults.

The comparable scores of the students in their pretest and posttest mean scores suggest that exposure to MADLE discouraged students on their practices based on habitual actions (nonreflective) but prompted them to engage in higher levels of reflective thinking. This development can also be associated with the metacognitive aspect of MADLE, which helped them become actively engaged in the scientific process using both metacognition and gained understanding (Seraphin, Philippoff, Kaupp, & Vallin, 2012). This allowed them to make decisions about their learning and how they learn (van Opstal & Daubenmire, 2017). Since there were several metacognitive prompts in the activities, students were able to define and set their goals, monitor, and evaluate their progress in achieving them. In the lesson, students were also prompted to activate their prior knowledge, examine their current thinking, identify their confusion, recognize conceptual change, and reflect on their own learning and experience through writing reflections. These structured reflective guides or prompts served as useful tools to enhance reflective processes (Hanya *et al.*, 2014). These assisted students in meaningful learning, which helped them become thoughtful and reflective learners. As mentioned by Kember, McKay, Sinclair, and Wong (2008), students' active participation in the activities, their efforts to understand what is happening, questioning, and comparing them with their own experience can stimulate reflective thinking skills. Overall, it can be deduced that MADLE contributed to the development of students' reflective thinking skills. The use of MADLE in teaching leads to an effective learning environment for helping the students to think reflectively.

Conclusion

In light of the findings from the analysis of the data gathered, although students' exposure to MADLE did not lead to significant improvements in terms of their reflective thinking skills, the data yielded from students' higher posttest mean scores, classroom observations, and responses in the focus group discussion imply the effectiveness of MADLE in stimulating and developing reflective thinking skills. The findings suggest that coupling metacognition and argument-driven teaching and learning environment can help students become thoughtful and reflective learners. Given that MADLE stimulates and facilitates the development of students' reflective thinking skills, teachers may integrate MADLE in their classroom instruction. In achieving this, teachers may restructure their pre-existing learning plans in MADLE, which incorporate metacognition, scientific argumentation, and inquiry-based learning.

Limitations of the Study and Future Research Directions

There are several limitations and issues in this study that need to be addressed for future research. First, the sample size is small, which limits the generalizability of the findings. Future research might conduct a study with a larger sample size to provide further evidence of the efficacy of MADLE in cultivating students' reflective thinking skills. Second, longer exposure to MADLE is necessary to achieve significant improvements in students' reflective thinking skills. Future research might consider a longer time of the implementation of MADLE to substantially impact students' reflective thinking skills. Future researches might also use and examine MADLE in different disciplines of science and its usefulness in enhancing other 21st century skills or those important skills in learning Biology. Lastly, future research might include a control group employing a quasi-experimental design to further investigate the efficacy of MADLE in cultivating reflective thinking skills.

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