



Abstract. *Science educational standards are increasingly emphasising on argumentation skills. However, students' argumentation skills are often not developed well as their experience of science knowledge in schools is often in the form of uncontested facts. This research asserts that argumentation skills should be developed through explicit teaching of argumentation while engaged in practical work that draws on students' science process skills. In turn, developing argumentation skills also improves their science process skills. Thus, this research sought to examine the effect of the Modified Argument-Driven Inquiry approach (MADI), Inquiry without Argument approach (IWA), and the conventional practical work approach (CON) on the development of argumentation and science process skills of Grade 10 students in practical biology. This research employed the quasi-experimental methodology involving Pre-test Post-test Non-equivalent Control Group design. The data were collected through tests on argumentation skills, science process skills and diffusion and osmosis concepts' understanding. The MANOVA results showed that there was a significant improvement in the argumentation skills, science process skills and biology understanding among the students who experienced the MADI approach in practical biology. In contrast, students who experienced the IWA approach in practical biology showed significant improvement only in biology understanding.*

Keywords: *argumentation skills, practical work, modified argument driven inquiry, science process skills*

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EXPLICIT TEACHING OF SCIENTIFIC ARGUMENTATION AS AN APPROACH IN DEVELOPING ARGUMENTATION SKILLS, SCIENCE PROCESS SKILLS AND BIOLOGY UNDERSTANDING

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Introduction

The skills to make claims based on evidence, i.e. argumentation skills are important for scientists to carry out their work as these skills help them to challenge scientific discoveries and theories, enhance their scientific literacy and solve problems, and ultimately allow science to progress and develop further. The importance of argumentation skills therefore necessitates that such practices be encouraged and developed among students in science classroom learning environments. A number of empirical research has studied the different ways argumentation is developed in the science classrooms as well as the ways of motivating students to participate in argumentation (Kuhn, 2012; Osborne, 2012; Osborne et al., 2004b; Tiberghien, 2007). However, only a few of these have researched into argumentation in practical work (Katchevich et al., 2013). Practical work is an important context for scientific argumentation (Driver et al., 2000). According to Osborne (2012), there are four consequences for school science in the absence of construction of scientific explanations and participation in argumentative discourse within the classroom practice including in practical work. Firstly, it disregards the epistemic teaching and learning in science which is the basic characteristic of science that has contributed to the identification of science practice and the significance of evidence in the culture of improvement in science education. Secondly, restricting student's opportunity to think about ideas of science and carrying out exploration of the ideas might detach students from being interested or wanting to be involved in science. Thirdly, it constricts the amount of learning routes accessible to students, leading to science teaching and learning that is ineffective or less effective than it could be. Fourthly, it confines the potential of science in school to provide possibilities for students to collaborate, to think critically and creatively, and to support one another in the process of learning. This is because during scientific inquiry, students will acquire greater understanding of scientific ideas when they are able to recognise mistakes in their own arguments and the reasonings of others.

Research Problem

Argumentation in science teaching, which is demonstrated in the process of scientific investigation, involves justification of claims based on evidence. The process of making claims based on evidence is facilitated by employing science process skills (Gultepe & Kilic, 2015). Hence, by developing argumentation skills one could also develop science process skills together with science content learning (Demircioglu, & Ucar, 2015; Enderle et al., 2013; Enderle et al., 2012; Gultepe & Kilic, 2015; Sampson et al., 2012; Sampson & Walker, 2012). One of the ways in scaffolding students when learning argumentation skills is by explicitly teaching them the ways to justify claims based on evidence. A possible strategy to explicitly teach students argumentation skills in the science classroom is by way of carrying out laboratory investigation during practical work (Driver et al., 2000; Osborne, 2015; Osborne et al., 2013; Sampson et al., 2011b). Students will be involved in the process of tabulating and analysing data systematically so that they are capable of producing evidence that can defend the claims made in relation to the data obtained from the practical work activities.

Many tend to view practical work as the essence of the national science curriculum in the quest to nurture science process skills among student. This is because a person should have science process skills to be scientifically literate (Halim, 2013). In facing the challenges of life and work in the 21st century and advancing a country towards becoming a highly developed nation, having a large pool of scientifically literate citizens is imperative because their ability to critically evaluate scientific findings would become a valuable asset to the country (Osman et al., 2011). Hence, focusing on science process skills in the curriculum of science is vital. According to Yildirim et al. (2016), science process skills serve as a driving factor for scientific inquiry. Meanwhile Özgelen (2012) support students' reasoning and thinking in solving problems. Accordingly, many countries highlight the importance of explicit teaching and learning of science process skills in their science curriculum (Arnold et al., 2018). The same situation prevails in Malaysia. Since practical work is seen as a classroom strategy for enabling students to build their science process skills, it is therefore widely practised in science classrooms.

The role of practical work in developing students' acquisition of science process skills has been well researched (Abrahams, 2009, 2011; Abrahams & Reiss, 2012; Abrahams, Reiss, & Sharpe, 2011; Hofstein & Kind, 2012; Hong et al., 2013; Woodley, 2009). However, practical work may not be playing an effective role in promoting learning (Millar & Abrahams, 2009; Needham, 2014; Osborne, 2015; Osborne & Millar, 2017; Puttick, Drayton, & Cohen, 2015). Osborne (2015, p. 19), for instance, remarked: "*Given that the fundamental purpose of practical work is to help students make links between the world of ideas and the real world of objects and events, there is little evidence that such work is contributing to this goal*". Millar and Abrahams (2009) revealed that the time used to discuss ideas in practical activity is insufficient; additionally, they also found that from the 25 lessons they had observed in their study, none involved the inquiry process. This therefore supports the view that practical work is used for the purpose of assessment rather than to develop understanding in making justification of the evidence. Osborne (2015) views practical work's role as extremely central to the teaching of science and recommends that further research work is carried out to ensure improvements of pedagogic practices in practical work. This is so that practical work can be utilized to develop students' understanding of the nature of science particularly in relation to how scientists challenge or support claims based on empirical evidence.

Research by Sampson and Clark (2009) has shown that students were more inclined to manipulate data instead of rejecting a preconceived conclusion. Similar findings were also found in Berland and Reiser's (2009) study. They noted that students would ignore or reinterpret inconsistent data in order to defend incorrect claims. Equally, the students in Sampson, et al. (2011b) study fail to draw upon scientific theories to make sense of their observations or use the scientific models as a way to critically evaluate the validity of a potential explanation. Instead of using suitable evidence and reasoning to back up their assertion, the students tend to only detail out their raw data, laboratory observations and methodology. Such findings are consistent with earlier studies in science classes where the findings revealed that many students did not understand what is considered to be good explanation of science (Mcneill & Krajcik, 2007). Studies have also discovered that students were unable to form argumentation because of their inability to identify relevant and sufficient information and evidence to support their claims (Sampson et al., 2011b; Walker & Sampson, 2013). Advocates of argumentation in science education remarked that students have a tendency to rely on baseless conclusions to support their ideas based on unwarranted conclusions or evidence (Osborne et al. 2004a). A recent study (Choi et al., 2015) also found that even when students did manage to grasp the concept of evidence, there is a strong tendency for these students to accept the evidence as all-inclusive and to neglect linking the correlation between questions, claims and evidences because they experienced difficulties



in developing meaningful arguments such as building claims and making correlations between questions, claims and evidences. Thus, students' lack of argumentation skills in science is a result of their misunderstanding of what constitutes argumentation in science. Accordingly, these research findings highlight the need to provide greater opportunities for students to participate in and practice argumentation in the science classroom.

Research Context

Recently, a number of challenges have been highlighted in relation to practical work, and this includes it not being effective in promoting learning (Needham, 2014). Some researchers argue that cognitive skills are not emphasised enough in laboratory activities (Abrahams, 2011; Abrahams & Reiss, 2012; Hofstein & Kind, 2012). For example, studies have demonstrated that students often carry out practical work without actually understanding the underlying principles (Hasni et al., 2016; Friedler et al., 1987). Thus, ensuring that the role of practical work is made more effective than it actually is at the present time is of vital importance (Millar & Abrahams, 2009; Osborne, 2015; Tekkaya, 2003; Wei et al., 2018).

Learning many of the science concepts to the point that in depth understanding is achieved is extremely difficult for middle and high school students. For instance, diffusion and osmosis are versatile concepts because both concepts are related to the features of many living organisms, act as fundamental concepts in understanding important life processes and are frequently confronted by students in their daily life. Even so, understanding the mechanisms of the concepts is something that many students find challenging to attain (Hasni et al., 2016; Fisher, Williams & Lineback, 2011; Lee & Daniel, 2013).

Science lessons need to involve students in inquiry-based science learning and at the same time give students the opportunity to participate in argumentation. Efforts have been continually invested in cultivating students' habits of constructing and communicating argumentation when it comes to designing science teaching processes as well as scientific inquiry (Clark & Sampson, 2007; Driver et al., 2000). Argumentation is one of the crucial processes of scientific inquiry (Demircioglu & Ucar, 2015; Sampson et al., 2011a). However, when it comes to designing lessons that could nurture and cultivate habits of inquiry and constructing arguments that would guide students towards both understanding of the scientific concepts and the practices of science, many science teachers are unsure of how to go about achieving such tasks (Sampson & Gleim, 2009; Mahmud et al., 2018).

Hence, the formation of argumentation skills through practical-based inquiry activities was the focus of this research. This research aimed to examine the effect of the teaching and learning activities in the LAB-MADI module on students in different groups: the MADI group, the IWA group and the CON group. The following were the research questions of this research:

1. Does the MADI approach improve the achievement of students in argumentation skills compared to the IWA approach and the CON approach?
2. Does the MADI approach improve the achievement of students in science process skills compared to the IWA approach and the CON approach?
3. Does the MADI approach improve the achievement of students in the concepts of diffusion and osmosis compared to the IWA approach and the CON approach?

Research Methodology

General Background

Pre-test post-test non-equivalent control group design was employed in the research. The research design is presented in detail in Table 1. This design is suitable for the aim of the research which sought to examine the effectiveness of the three learning approaches used in the research. The duration of the intervention was eight weeks of teaching based on practical work. The practical work began with 'Lab1: Introduction to Biology – Applying Scientific Investigation' and the last class was 'Lab 8: Enzyme: The Effect of Temperature on the Activities of Amylase'. The learning approaches used during the experimentation were the Modified Argument-Driven Inquiry (MADI) approach, the Inquiry Without Argument (IWA) approach, and the conventional approach (CON). This research examined the effect of the three learning approaches on argumentation, science process skills and understanding of diffusion and osmosis concepts among Grade 10 Biology students who were studying in rural government secondary schools in one of the divisions in the state of Sarawak, Malaysia.



Table 1
Research design

Groups	Pre-tests	Learning approaches	Post-tests
Experimental group 1	UKH, UKPS, UKRO	MADI	UKH, UKPS, UKRO
Experimental group 2	UKH, UKPS, UKRO	IWA	UKH, UKPS, UKRO
Control	UKH, UKPS, UKRO	CON	UKH, UKPS, UKRO

Note. UKH is Achievement Test in Argumentation Writing; UKPS is Achievement Test in Science Process Skills; UKRO is Achievement Test in Concepts of Diffusion and Osmosis; MADI is Modified Argument-Driven Inquiry Approach; IWA is Inquiry Without Argumentation Approach and CON is the Conventional Approach.

Participants

The participants of the research were students of the science stream in two schools (School A and School B) who were taking biology subject as one of the three pure science subjects. A total of 112 students consisting of 64 female and 48 male students were selected as the study sample with 40 students participating in the CON group, 42 participating in the IWA group, and 30 participating in the MADI group. The research design involved teaching 30 students in the first experimental group using the MADI approach, 42 students in the second experimental group using the IWA approach, and 40 students in the control group using the existing CON approach specified in the Biology Curriculum. Before gaining access to the schools, the researcher had obtained approval and permission from the Division of the Research Department, Ministry of Education to conduct the study in the schools. The school principals, teachers and students were informed of the nature of the study. Anonymity of the schools, teachers and students involved in the research were upheld.

Instrument and Procedures

Data were obtained through the pre-test and post-test conducted during the course of the research. Data were measured based on a) the argumentative essay the students wrote which was set under the Argumentation Skills Test (UKH), b) the written practical test set under the Science Process Skills Test (UKPS) and c) the multiple choice test under Understanding of Diffusion and Osmosis Concept Test (UKRO). The format and development of the instruments for UKH, UKPS and UKRO have been presented in other papers along with the determination of the instruments' validity and reliability (Ping et al., 2019a; 2019b). All instruments were framed in the context of Malaysia based on the Curriculum Specification for the subject of Biology (MOE 2012); hence, the instruments are aligned with the Biology Curriculum which is designed for the Malaysian education system.

The conceptual framework of the research in relation to the MADI approach in which the MADI model was used and the process of determining the content validity of the LAB-MADI Module have been presented in a different paper (Ping & Osman, 2019). Meanwhile, the details of the LAB-MADI Module and the result of the pilot test study have been presented in another paper (Ping et al., 2019a). A summary of the research procedures as discussed below including the intervention procedures following the type of group involved is presented in Table 2.

Teacher A who taught the MADI group was first given preparation exercises including daily teaching plans along with the teaching and learning materials and handling of apparatus used in the practical work. Explanation of the MADI approach was based on the background of the development of the LAB-MADI Module and the teaching strategies using the MADI Model. The teacher was provided guidance on how to use and operate the LAB-MADI Module to ensure that the teacher understands the module well; this included providing the teacher with brief notes on the MADI model. In order to ensure that the teacher has the knowledge and skills to effectively handle the module and perform the activities in the module, a six-hour training session within the period of two days was provided to the teacher.

Teacher B played the role of providing support in terms of knowledge acquisition when the students were going through the practical work while using the LAB-MADI Module. However, there were differences in the approach during the Elicit, Expand and Evaluation Phase (in that for the IWA approach, these three phases were not included). Teacher B is said as not using the MADI approach because the teacher did not provide the argumentation framework to the students after the students had collected the data and prepared the report of the experimental results. Therefore,



Teacher B was only required to distribute copies of the worksheet to the students while carrying out the practical work. The students were not provided the argumentation framework.

Meanwhile, in the case of Teacher C who taught the CON group, none of the information on the LAB-MADI Module was passed to the teacher. Teacher C who taught the CON group, i.e. the control group, was asked to continue with the Biology lessons in the same manner as was previously practiced. The researcher together with the teacher (Teacher C) prepared a summary of the Biology practical work according to the teaching methods that were commonly used or practised. This was carried out with the purpose of ensuring that the duration of time for the Biology practical work of the control group was equal to those of the treatment groups (the MADI and IWA groups).

Table 2*Intervention procedures following type of group*

Type of group	MADI group	IWA group	CON group
Type of approach	Modified Argument-Driven Inquiry	Inquiry Without Argumentation	Conventional
Intervention Material	LAB-MADI Module	LAB-MADI Module without the argumentation session (Expand Phase), elicit students' prior knowledge session (Elicit Phase), reflective session (Evaluation Phase)	MOE Practical Book
Procedure	Step 1	Elicitation phase: The teacher leverages existing knowledge of the students.	Engagement phase: The teacher guides each group to identify the problems and the research questions.
	Step 2	Engagement phase: The teacher guides each group to identify the problem statement and the research question.	Exploration phase: The teacher guides the students in the investigation and data collection.
	Step 3	Exploration phase: The teacher guides the students in the investigation and data collection.	Explanation phase: The teacher guides the students in analysing data.
	Step 4	Explanation phase: The teacher guides the students in analysing data and producing tentative arguments.	Elaboration phase: The teacher guides the students in reflecting on the experimental results.
	Step 5	Elaboration phase: The teacher guides the students in engaging in the argumentation session.	Evaluating phase: The teacher assesses the students' progress based on the investigation report.
	Step 6	Evaluation phase: The teacher guides the students in the reflective discussions to evaluate the results of the investigation.	The teacher describes the content of the investigation and the expected results.
	Step 7	Extension phase: The teacher assesses the students' progress based on the investigation report and application in questioning.	The teacher introduces the problem statement.
			The teacher instructs the students to collect data.
			The teacher provides the procedure for data analysis to the students.
			The teacher assesses the students' progress based on the investigation report.

Data Analysis

The research data were in the form of pre-test and post-test scores which were tested statistically by using Multivariate Analysis of Variance (MANOVA) with significance level established at 5%. If any significant learning outcome was found between the groups, the data were then tested using the Bonferroni test. Before the data analysis was conducted using MANOVA, the assumption tests were performed, including test for normality (skewness and kurtosis) and test for homogeneity (Levene's Test for Equality of Variance). Prior to carrying out the pre-test and post-test, the validity of all the test items had been ascertained. The error variance for the students' scores in the pre-test indicated that it was equal across the MADI ($N = 30$), IWA ($N = 42$) and CON ($N = 40$) groups for the Test of Argumentation Skills $F(2,109) = .890, p > .05$, the Test of Science Process Skills $F(2,109) = 2.041, p > .05$ and the Test of Understanding of Diffusion and Osmosis Concepts $F(2,109) = 1.999, p > .05$, indicating that the three groups had homogeneity of variance.



Research Results

Table 3 presents the descriptive statistics for the pre-test and post-test of argumentation skills, science process skills and understanding of diffusion and osmosis concepts including the mean score and the standard deviation for the three learning approaches. The summary of MANOVA results for argumentation skills, science process skills and understanding of diffusion and osmosis concepts in relation to the learning approaches is displayed in Table 4 and 5.

Table 3

Descriptive statistics including mean score for the pre-test and post-test of argumentation skills, science process skills and understanding of diffusion and osmosis concepts for the three learning approaches

Dependent variables	Learning approaches	N	Pre-test	Post-test	Pre-test SD	Post-test SD
Argumentation skills	MADI	30	5.23	41.73	11.242	11.965
	IWA	42	8.40	26.19	10.020	12.623
	CON	40	7.43	15.68	9.030	8.532
Science process skills	MADI	30	25.13	70.93	8.266	11.706
	IWA	42	29.52	63.88	10.081	10.160
	CON	40	27.05	57.10	8.978	13.481
Understanding of diffusion and osmosis concepts	MADI	30	40.30	66.07	17.517	15.682
	IWA	42	47.79	66.38	17.007	17.787
	CON	40	41.73	55.20	17.570	19.779

Table 3 shows that the mean scores for argumentation skills, science process skills and understanding of diffusion and osmosis concepts for all the groups increased from the pre-test to the post-test. For argumentation skills, the results obtained showed the post-test mean score of the MADI group was higher than the IWA group and the CON group. This indicates that the students in the MADI group outperformed the students in the IWA and CON group. The same pattern of results was obtained for science process skills where the post-test mean score of the MADI group was greater than the IWA group and the CON group. However, for understanding of diffusion and osmosis concepts, the post-test mean score of the IWA group was slightly higher than the MADI group but greater than the CON group.

The positive findings on the effectiveness of the MADI learning approach presented in Table 3 are further supported by the MANOVA test results on the effect of the learning approaches on the students' argumentation skills, science process skills and understanding of diffusion and osmosis concepts which is shown in Table 4.

Table 4

Summary of MANOVA test results on the effect of the learning approaches on the students' argumentation skills, science process skills and understanding of diffusion and osmosis concepts

Dependent variables	Source	Pillai's Trace/ Wilks' Lambda	F	Hypothesis df	Error df	p	Partial Eta Squared
Argumentation skills	Groups	.650	25.974	8.000	432.000	.001*	.325
	Time	.638	94.691	4.000	215.000	.001*	.638
	Groups*Time	.618	24.125	8.000	432.000	.001*	.309
Science process skills	Groups	.912	5.122	4.000	434.000	.001*	.045
	Time	.250	325.939	2.000	217.000	.001*	.750
	Groups*Time	.895	6.193	4.000	434.000	.001*	.054
Understanding of diffusion and osmosis concepts	Groups	.949	2.855	4.000	434.000	.023*	.026
	Time	.765	33.284	2.000	217.000	.001*	.235
	Groups*Time	.953	2.662	4.000	434.000	.032*	.024

* $p < .05$



The results of between-subject effect are presented in Table 4. The results obtained showed that the effect of group was significant in terms of the students' argumentation skills, science process skills and understanding of diffusion and osmosis concepts. Furthermore, the effect of time was significant in terms of the students' argumentation skills, science process skills as well as understanding of diffusion and osmosis concepts. Meanwhile, the interaction of groups and time was significant in terms of the students' argumentation skills, science process skills and understanding of diffusion and osmosis concepts. It indicates that the different learning approaches and time influenced and improved the students' achievement in argumentation skills, science process skills as well as understanding of diffusion and osmosis concepts. Additionally, the interaction effect of the learning approach and time on the students' achievement in argumentation skills, science process skills and understanding of diffusion and osmosis concepts was found to be significant.

Comparison of between-subject effect and interaction between group*time for each subscale of argumentation skills, science process skills and understanding of the concepts of diffusion and osmosis for the three learning approaches is presented in Table 5. The results showed that there was a significant difference in students' achievement in argumentation skills for the MADi approach, IWA approach and CON approach. Additionally, the mean scores for two out of the four subscales for argumentation skills were statistically significantly different, indicating that the MADi approach was more effective than the IWA approach and the CON approach for the subscale of stating evidence and for the subscale of stating reason. In contrast, no significant difference was found in the mean score of the three learning approaches for the subscale of stating claim and for the subscale of stating counterclaim. However, the mean scores of stating claim and stating counterclaim for the MADi approach and the IWA approach were higher than the CON approach, suggesting that the MADi approach was as effective as the IWA approach in improving the students' skills in stating claim and stating counterclaim compared to the CON approach. In terms of the students' achievement in argumentation skills, the values for between-subject effect on Group*Time indicated that the MADi approach was more effective than the IWA approach and the CON approach in relation to stating evidence and stating reason.

Table 5

Summary of mean scores, standard deviations and *p* values for performance in each subscale of between-subject effect on interaction between Group*Time

Dependent variables	Sub-scale	Learning approaches	M_{pre}	SD_{pre}	M_{post}	SD_{post}	MANOVA
Argumentation skills	Claim	MADi	.37	.556	1.63	.718	$F(2,218) = 1.708$, $p = .184$, $\eta^2 = .015$
		IWA	.67	.570	1.62	.764	
		CON	.53	.506	1.40	.709	
	Evidence	MADi	.07	.365	1.93	.640	$F(2,218) = 153.852$, $*p = .001$, $\eta^2 = .585$
		IWA	.05	.216	.17	.437	
		CON	.00	.000	.00	.000	
	Reason	CON	.38	.740	.48	.847	$F(2,218) = 3.294$, $*p = .039$, $\eta^2 = .029$
		IWA	.33	.754	1.45	2.734	
		MADi	.23	.679	1.33	1.213	
Counterargument	MADi	.03	.183	.13	.434	$F(2,218) = 1.759$, $p = .175$, $\eta^2 = .016$	
	IWA	.00	.000	.64	2.667		
	CON	.00	.000	.00	.000		
Science process skills	Basic	MADi	8.60	2.127	16.60	2.415	$F(2,218) = 10.757$, $*p = .001$, $\eta^2 = .090$
		IWA	9.17	1.962	13.90	2.516	
		CON	9.03	2.646	13.43	2.900	
	Integral	MADi	2.90	1.936	7.97	2.060	$F(2,218) = 5.168$, $*p = .006$, $\eta^2 = .045$
		IWA	3.67	1.690	7.45	1.783	
		CON	2.78	1.874	4.90	1.959	



Dependent variables	Sub-scale	Learning approaches	M_{pre}	SD_{pre}	M_{post}	SD_{post}	MANOVA
Understanding of diffusion & osmosis concepts	Passive transport	MADI	38.61	18.110	56.67	17.698	$F(2,218) = .257,$ $p = .774, \eta^2 = .002$
		IWA	43.85	21.310	63.89	20.714	
		CON	37.92	22.165	53.33	22.233	
	Passive transport with organisms	MADI	42.33	23.146	77.33	19.286	$F(2,218) = 4.846,$ $*p = .009, \eta^2 = .043$
		IWA	51.67	24.685	69.76	22.250	
		CON	46.50	19.942	57.50	26.287	

* $p < .05$

In addition, the mean scores for the subscales of science process skills were significantly different for the subscale of basic science process skills and for the subscale of integral science process skills as shown in Table 5. Therefore, the results of between-subject effect on Group*Time for students' achievement in science process skills signified that the MADI approach was more effective than the IWA approach and the CON approach for both basic science process skills and integral science process skills.

In relation to understanding of diffusion and osmosis concepts for the subscale of passive transport in terms of students' achievement under the MADI approach, the IWA approach and the CON approach, no significant difference was found as demonstrated in Table 5. On the other hand, there was a significant difference in students' achievement for understanding of diffusion and osmosis concepts for the subscale of passive transport of organism. Additionally, the mean scores obtained for students' understanding of the concept of passive transport between the MADI approach and the IWA approach were found to be approximately equal. In contrast, the between-subject effect on Group*Time for students' achievement in understanding of the concept of passive transport for the MADI approach and the IWA approach was higher than the CON approach. The results obtained showed that the MADI approach was as effective as the IWA approach in improving students' understanding of the concept of passive transport compared to the CON approach. The results of between-subject effect on Group*Time in terms of students' achievement in understanding of diffusion and osmosis concepts indicated that the MADI approach was more effective than the IWA approach and the CON approach for the subscale of passive transport with organisms.

Discussion

The findings reveal that the implementation of argumentation in the modified argument-driven inquiry (MADI) approach in the practical work was found to be more effective in improving the Grade 10 biology students' argumentation skills in comparison to the inquiry without argumentation (IWA) approach and the conventional (CON) approach. Throughout the argumentation activities of the LAB-MADI Module, the students were presented with the opportunity to generate and justify a claim. However, it is believed that the elaboration phase in the learning module served as the initiation point in the development of argumentation. Meanwhile in the extension phase, the students were given the reinforcement to broaden their science process skills together with argumentation skills. This aligns well with the Constructivist Theory which explains that knowledge cannot exist beyond the mind of the students but is built into the mind based on actual experience. Accordingly, when students have to draw upon their science process skills to generate evidence to support a claim, the students would experience learning that is more meaningful. Meanwhile, the Cognitive Load Theory relates to how an individual's learning can be optimised by ensuring that the complexity of the information learned and the cognitive ability of students to process information to create new learning is addressed. Thus, scientific argumentation through the MADI approach in this research can promote and support scientific inquiry in the subject of biology.

The findings show that the students in the MADI group were able to develop clear explanations based on claims with evidence. In contrast, the students in the CON and IWA groups tended to provide explanations based on claims with data only without evidence. Sampson et al. (2011b) believed that the practical work through the ADI Model provides students with an opportunity to reflect on the outcome of the practical work so that students develop the ability to evaluate arguments and appreciate the importance of evidence in the



science context. In this research, by implementing the argumentation session during the elaboration phase, the students in the MADi group were able to develop their skills and provide more evidences in the argumentation discourse. The students who experienced the argumentation session were more focused on claims and reasons since these are the most important elements of problem solving. Hence, the students' answers of the given questions were stated in the claims and were supported with evidences.

Furthermore, in the MADi approach, the students were guided to plan and carry out the investigation, collect and analyse data, communicate, and justify their ideas with one another. Thus, compared to the students in the IWA approach and the CON approach groups, the students in the MADi group were given the opportunity to practice the scientific method and engage in scientific argumentation so that they could develop their argumentation skills. Although the students in both the IWA group and the CON group were working in groups, the students did not have the chance to interact with each other in discussions unlike the students in the MADi group. This finding is in line with Sampson et al. (2011b) who in their study found that working, communicating or participating in groups do not necessarily lead students to being able to provide effective verbal and written scientific argumentation. An important element is to involve students so that they are given the opportunity to construct and develop evidence-based explanation or argument of the scientific phenomena being investigated. Clearly, this points to the need for science education to emphasise on argumentation (Simon et al., 2006). When argumentation is constructed explicitly in practical work, students are properly guided, and this would ultimately make the students understand the science phenomenon better.

In this research, all three approaches, namely the MADi approach, the IWA approach and the CON approach were found to have contributed to the development of the students' science process skills. However, the students in the MADi approach were encouraged to defend and support their claims. In addition, these students were also expected to listen to different claims and make decisions on the validity of the claims. All these activities and way of thinking promote effective development of science process skills among the students in the MADi group in comparison to the students who were in the IWA group and the CON group. Previous studies have also shown that scientific argumentation based on teaching approach leads to the improvement in their scientific thinking skills as well as conceptual understanding (Driver et al., 2000; Gultepe & Kilic, 2015; Sampson & Gleim, 2009; Simon et al., 2006). This MADi approach can trigger cognitive conflicts and promote restructuring of ideas as students share ideas from their own perspective. When more interactions are created, the more skilful students will become better in evaluating and choosing the information that is useful for them because of the reorganisation of ideas that occurs, which is the essence of Piaget's Constructivist Theory.

Scientific process skills development involves an active process (Yerrick, 2000). Creating argumentation sessions in science practical work allows students to ask questions to evaluate the explanations of their peers, to interpret and analyse data, and to consider and think of alternative explanations (Gulpepe & Kilic, 2015). In this research, the students who experienced the practical work activities through the MADi approach took on a more active role in evaluating their observations, in interpreting data, and in deciding the ways in which their evidence were to be presented. In contrast, the students in the practical work involving the CON approach were directly given the equipment and tools to carry out the activities. Moreover, they were also directly given the problem statement and hypothesis and were only asked to carry out the experiment to verify it, to record the obtained data, and to submit their report. Accordingly, the findings suggest that over time, improvements on students' scientific process skills can be achieved through the MADi approach and the support of suitable student activities as students are given the opportunity to use the science process skills in various ways. Students can make use of operational definitions to construct answers to questions, make use of inferences and construct hypotheses to justify their views, make use of the investigation design to explain procedures, and make use of graph interpretations to interpret and explain the data. Through the linkage between practical work and argumentation, students are provided ample opportunity to make up their mind about the experiment.

This research has shown that the intervention of the MADi approach in the practical work of Grade 10 Biology is more effective in improving students' understanding of the concepts of diffusion and osmosis, i.e. passive transport with organisms compared to the IWA approach and the CON approach. This finding is in line with the findings of Cigdemoglu et al. (2017), Demirbag and Gunel (2014), Enderle et al. (2012), Grooms et al. (2015), and Songsil et al. (2019). The intervention of arguments during the elaboration phase helped the students in this study to better explore the concepts of diffusion and osmosis, thus fostering the students' understanding of the science concepts. However, this finding is inconsistent with the findings of Becker (2014) who



found that explicit teaching of scientific explanation and argumentation cannot improve students' scientific content knowledge. Becker (2014) deemed that this may be due to the length of time needed for the intervention to have an effect; he believed that it would take longer than one semester of study to obtain a change in knowledge achievement among the students. Nonetheless, it is clear that students can be effectively taught and can attain mastery in difficult subjects like Biology through practical work as has been observed among the MADI group students. Students' understanding of the concepts of diffusion and osmosis can be enhanced when teachers can detect students' misconceptions and subsequently change their misunderstanding of the concepts through triggering of cognitive conflicts during the elicitation phase based on the Constructivist Theory and Cognitive Load Theory.

Conclusions

Overall, the research shows that the MADI approach has a better effect on students' argumentation skills, science process skills and conceptual understanding compared to the IWA and CON approach. The findings provide useful insight for educators of science and educational designers who are interested in promoting and supporting argumentation in practical work. The modified argument-driven inquiry (MADI) approach has appropriate learning phases needed by students to enhance their argumentation skills. This research has also demonstrated that students are able to develop and improve their argumentation skills, science process skills and understanding of the concepts by being involved in the production of spoken and written argument. Therefore, teaching and learning process that uses inquiry-based practical work to construct scientific arguments should be designed to promote students' argumentation and science process skills along with improvement in students understanding of biology. One significant outcome of the study is that the MADI approach provides a way of implementing a learning approach that is non-intrusive for teachers who typically have to meet the various demands of being a teacher. In addition, the MADI approach is an alternative approach to the common way of developing argumentation skills, i.e. through providing socio-scientific issues where students who are dominated by teacher centred scenario will often require time to adapt.

One implication of the study is the need to develop the role of teachers in supporting the MADI approach. The development of the LAB-MADI Module in the form of structured inquiry and supervised inquiry is one of the approaches that can be implemented by science teachers in teaching biology. However, implementation of the MADI approach in the science classroom requires the teacher to play a variety of roles, not only as the source of information for students but also as a facilitator, mentor, trainer or elicitor for the students. These different roles played by the teacher are aimed at increasing student engagement. Therefore, related training for the development of these roles is imperative.

In addition, students need to be oriented towards active engagement in the process of doing the practical work. In particular, students have to conduct discussions and allow peers to review the findings of the experiment. They also need to be trained in the process of justifying the hypothesis with evidences. Nonetheless, based on their existing knowledge, the hands-on and mind-on activities and the guidance provided by the teachers, students would be given the opportunity and be encouraged to build new knowledge by themselves. All these point to the importance of classroom management skills for the teachers so as to create such teaching and learning environment. This underscores the need for teachers to develop competency in these important skills.

One of the limitations of the research is that the quality of students' construction of their scientific argument has been presented in the quantitative form. Hence, for future research, researchers can use individual interviews to explore the students' quality of argumentation skills. In conclusion, establishing a science classroom culture that values argumentation across various school levels and types of schools is deemed necessary for effective implementation efforts of approaches such as the MADI approach and the likes.

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