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What Students Gain by Learning Through Argumentation

Paul Iwuanyanwu
North-West University

Argumentation is central to science learning. Students in every domain of science should have the opportunity to develop the ability to think and act in ways associated with argumentation. When engaged in argumentation, students learn how to puzzle through problems, to see multiple ways of finding solutions, to gather and evaluate evidence on different sides of issues, and communicate scientific knowledge. These skills can ultimately equip students with the ability to function effectively at work and in the everyday world. In this study, argumentation was processed as a dialogical interaction for students who are in a dialogical relation with others, and who contribute to a conversation by means of thinking, sense making, reasoning, and problem solving in the science classroom. Eighty-seven students completed 48 written tasks, twelve of which deal with problem-solving tasks on mechanics concepts and 36 other tasks concerned with features of how they make and defend arguments. The results show that about two-thirds of the students tended to place primacy on claim making and evidence evaluation on problem-solving tasks that have clear solutions. However, when they had to solve problem tasks that have multiple solutions or no clear-cut answers, regardless of the type of scenarios, their performance dropped considerably. These findings provided additional insight for where more emphasis needs to be placed in both students' arguments and pedagogical explanations on how argumentation in science classrooms can be conceptualized.

The increasing focus on argumentation as a topic in science education research indicates its growing importance among scholars (see, for example, Asterhan & Schwarz, 2007; Kuhn & Crowell, 2011; Özdem et al., 2017 and references therein). By its analytical, dialectical, and rhetorical nature, argumentation is an essential skill in learning to solve various kinds of problems (Jonassen, 2011). One aspect which illustrates the significant role of argumentation skills in science education stems from the fact that science generally advances by argumentation, dialogue, and revolutionary ideas than by doctrinaire (Popper, 1965; Voss, 2006). In this instance, Von Aufschnaiter and colleagues (2008), suggested three reasons why students, in particular science students, should be exposed to argumentation: (a) scientists engage in argumentation to develop and improve scientific knowledge, (b) the public has to use argumentation to engage in scientific debates, and (c) students' learning of science requires argumentation (p. 102). For this reason, it is important that students of all ages engage in argumentation and develop their argumentation and reasoning skills to gain a better understanding of science, themselves, others, and the world (Özdem et al., 2017). Although the importance of argumentation in the development of scientific knowledge and solving of problems encountered in everyday life has long been recognized by researchers (Albe, 2008; Belland et al., 2011; Jonassen, 2007; Spector & Park, 2012), more research is needed into the framework of dialogical argumentation-based instruction (DAI) which provides a very different perspective on students who are in a dialogical relation with others, and who contribute to a conversation by means of thinking, sense making, reasoning, and problem solving in the science classroom. One line of argument deals with the need to engage students in activities in which argumentation structure depicts how reasoning is used in relation to solving ill-defined science problems. Unlike well-defined problems (WDPs) which can be solved with a high degree of certainty and the solution is agreed upon by experts, ill-defined problems (IDPs) often possess multiple solutions or unclear answers, and thus the student has to examine different possibilities, assumptions, and evaluate possible solution outcomes (Iwuanyanwu, 2020; Jonassen, 2011). At the end, when a solution is proposed, it usually is justified by arguments and/or counterarguments that indicate why the solution is reasonable (Voss, 2006). Thus, the interplay between students developing the ability to solve IDPs (Shekoyan & Etkina, 2007) and acquiring the concepts of science through a dialogical argumentation-based instruction-DAI (Asterhan & Schwartz, 2007; Iwuanyanwu & Ogunniyi, 2020) – one building upon the other – is indispensable in successful science learning. Hence, the present study used dialogical argumentation-based instruction (DAI) to explore how students develop and revise their argumentation strategies while solving various kinds of ill-defined problems. The study is guided by the following research question: How do students exposed to dialogical argumentation-based instruction develop and revise their argumentation strategies while solving science IDPs in groups?

Literature Review

One critical aspect of science education is to help students develop the skills they need to tackle real-world problems. In this connection, numerous studies have been conducted on problem-solving in the science education literature. General consensus is that problem solving is a lifelong learning skill that learners of all ages need to acquire (Jonassen, 2011; King & Kitchener, 2004). An examination of the existing literature revealed that argumentation mirrors the social environments under which people acquire knowledge (Belland et al., 2011; Bottcher & Meissert, 2011; Gomez et al., 2018). In particular, dialogical argumentation serves as a key skill for logically making decisions and solving problems (Evagorou & Osborne, 2013; Spector & Park, 2012). A previous study reported that the teaching of argumentation through the use of appropriate activities and pedagogical strategies can be a means of promoting epistemic, cognitive, and social goals, as well as enhancing students' conceptual understanding of science (Erduran et al., 2004). Results that support this suggestion were obtained by Özdem et al. (2017) who investigated the instructional strategies adopted by some science teachers, namely one elementary science teacher, two chemistry teachers, and four graduate students, in their argumentation-based science teaching. They found that to "encourage argumentation," all teachers tended to provide experimental data/figures/graphs/scientific information/statements in their lesson plans and teaching practices, in addition to which they prompted justification when they wanted students to provide verification for their claims. Another interesting result from their study suggests that when students participate in high quality "collaborative argumentation," they write better arguments.

Furthermore, McNeill and Pimentel (2010) analysed transcripts from three teachers' classrooms, examining both the argumentative structure as well as the dialogic interactions between students. They found that between 19% and 35% of the discourse which focused on scientific argumentation was used successfully by students as evidence and reasoning to justify their claims. Social or dialogic process and persuasive interactions characterised by student-student interactions only occurred regularly in one teacher's classroom, where "open-ended questions" were used to encourage students to construct and justify their claims (p. 224). On the other hand, the conversation in two other teachers' classes examined was dominated by "teacher talk" and driven by transmission of known facts (p. 215), and "student-to-student interactions" were rare (p. 224). But, transmitting a set of known facts to students is unlikely to result in the desired 21st century science learners reported in Osborne's (2007) study. It makes the case that the primary goal of any science should be to provide students learning opportunities where they can engage in critical thinking about scientific concepts, solve problems, make claims, support their claims using evidence, and justify their ideas with practicable explanations, as opposed to the classroom conversations of the two teachers in McNeill and Pimentel's (2010) study. Given the results from their study, McNeill and Pimentel (2010) suggested that the use of open-ended questions may play a key role in supporting students in argumentation, in terms of both providing evidence and reasoning for students' claims and encouraging "dialogic interactions" between students (p. 225). And whilst the development of argumentation skills in the science classroom is fundamentally a dialogic event carried out among two or more individuals, it is more feasible in a context in which student-student or teacher-student interaction is permitted and fostered through discussion and debate (Evagorou & Osborne, 2013; Ogunniyi, 2007). The evidence that exists suggests that students must, at the very least, be provided with science activities that are rich in conflicts and ill-defined as a result of which debate should occur (Jonassen, 2007; King & Kitchener, 2004). Usually, this requires students to constantly use scientific concepts and principles to construct written and oral arguments. While engaging in such activities, students will have the opportunity to examine their peers' perspectives and be able to use discourse strategies to effectively interact with each other. They can also learn how to construct scientific knowledge through justifying, evaluating, and challenging different views on scientific and socio-scientific issues (Jin et al., 2015).

In order to promote dialogical argumentation and/or argument-based instruction, educational researchers have conducted substantial work to investigate students' argumentation practice. In the literature, dialogical argumentation instruction has been used by science educators to develop and enhance students' sense making, thinking, reasoning, and problem-solving skills (Asterhan & Schwarz, 2007; Diwu & Ogunniyi, 2012; Iwuanyanwu & Ogunniyi, 2020; Kuhn & Crowell, 2011). Some studies have focused on analysing the many skills involved in solving complex physics problems (Adams & Wieman, 2015; Belland et al., 2011. Others have focused on analysing science classroom discourse from a dialogical argumentation point of view (Gomez et al., 2018; Rapanta & Christodoulou, 2019; Walton, 2008). Additional studies have also shown that students had difficulties in constructing valid arguments (Jin et al., 2015), rebutting counterarguments (Walker & Sampson, 2013), using evidence to justify claims (Berland & Reiser, 2009) and providing relevant evidence to support claims (Albe, 2008). Despite this, learning through dialogical argumentation continually provides students with the opportunity to make first-hand decisions (Gomez et al., 2018). While engaging in learning activities characterized by dialogical argumentation, students can learn how to organise data, how to portray the patterns created by the data, and what conclusions to accept or reject as they work (Belland et al., 2011). It is of significance that they can also learn to develop their decision-making capacities in collaboration with their peers. In short, engaging students in dialogical argumentation can provide teachers a window through which they can see students' thinking and analyse the knowledge and dispositions students bring to bear on their activities. More recently, Iwuanyanwu and Ogunniyi (2020) found that undergraduate students enrolled in a science education course were generally successful in using argumentation strategies developed in a dialogical argumentation-based classroom to solve physics problems. Through dialogical argumentation instruction, students can acquire science concepts in an authentic fashion and can, therefore, be aware of the level of conceptualisation they have achieved through dialogic interactions with their peers (Asterhan & Schwarz, 2007). Therefore, the richer argumentation dialogue, the more necessary it is to identify who defends what, and who becomes accountable for which ideas (Rapanta & Christodoulou, 2019).

Methodology

Participants were 87 third year undergraduate students (53 females and 34 males, mean age = 21.5 years, *SD* = 5.6 years) enrolled in a four-year science education program at a South African university. Students spend the first two years of their education program in the Science Department to complete basic science courses on physics, chemistry, and biology. All 87 students had completed or were soon to complete a two-year undergraduate basic science course. At the third and fourth years, they register for Methods of Teaching Science which is taught as part of the university's teacher preparation program and is taken by students prior to their teaching practice. The course emphasizes inquiry or learning-cycle teaching methods, and thus is not a lab course in the traditional sense. Rather, any innovative teaching methods are used to provoke initial explorations, which are followed by the introduction and explication of related terms on basic science topics, which are then followed by application or extension activities. In this study, students did not receive any instruction on argumentation prior to and at the beginning of participating in the study.

Instrumentation and Administration

The instrument developed by Iwuanyanwu and Ogunniyi (2020) in a companion study was used to determine how students exposed to dialogical argumentation instruction use argumentation strategies to solve conceptual physics problems. Specifically, the instrument consisted of 48 items, 12 of which included problems based on mechanics concepts, and 36 others examined how students deliberated on argumentation strategies while solving the problems. In terms of face validity and content validity, two independent science education experts vetted the instrument. The criteria were met by ensuring that the instrument matched the content level of the study group and that the 48 items covered the range of concepts and argumentation skills required to address the items. The final version of the instrument had a Cohen's kappa value of 0.79 after several revisions. The reliability coefficient was 0.81 for the 12 items using Kuder-Richardson 21, and 0.76 for the 36 items using Cronbach's alpha. Another index taken into consideration in the adoption of the instrument is technical efficiency; it can be completed within a realistic time scale for a particular group of students. In the original instrument, the majority of the questions were presented as well-defined problems, and the test instrument had a Cronbach's alpha of 0.76. For the current study, they were adapted to be a mixture of open-ended and ill-defined questions in accordance with the extant literature (McNeill & Pimentel, 2010). While the well-defined problems are invariably satisfied by given solutions, which leave no room for alternatives, the open-ended and/or ill-defined version promotes diverse thinking and presents a degree of uncertainty about concepts, rules, and principles that might be necessary for proposing solutions (Iwuanyanwu, 2020; Jonassen, 2011; Shekoyan & Etkina, 2007; Voss, 2006). Some examples of the test items are presented in Table 1. They were chosen because of (a) the breadth of knowledge required to resolve them, (b) the difficulty level of the major concepts in the problems, (c) the intricacy of problem-solution procedures, and (d) the relational complexity among major concepts in the problems (Jonassen & Hung, 2008). The first administration of the instrument before DAI took 4 hours in week 1. After the baseline data collection, a set of argument-based lessons which consisted of cycles of preparation, experimental teaching, and reflection for 12 weeks began. Each lesson places primacy on students' real-life experiences and activities (see Table 1), which in turn leads to the next teaching cycle.The author who mediated the dialogical argumentation instruction had over 12 years of physics teaching and practical experiences in argumentation teaching. In the section that follows, the major components of the dialogical argumentation instruction provide a feel for how it was implemented in the study.

Supporting Dialogical Argumentation in Science Classroom

In this study, the dialogical argumentation instruction intended to mediate at least three layers of conflict resolution within a community of learning, namely (a) from the individual or self-conversational level (intra-argumentation), (b) to the small group level (inter-argumentation), and (c) at the whole class or community level (trans-argumentation; Diwu & Ogunniyi, 2012; Iwuanyanwu & Ogunniyi, 2020). According to this practice, students were divided into

Table 1
Questions of Conceptual Physics Problems in Mechanics

<table>
<tr><th colspan="3">Content of questions</th><th>Cues for deliberating skills that constitute to argumentation strategies</th></tr>
<tr><td>1</td><td colspan="2">Your younger twin siblings both in grade 7 were playing with spring loaded toys (a truck and a car) that can bounce off each other. Amanda picks up a truck and Jim picks up a car that is lighter than the truck. They push them against each other in the center of the living room on the wooden floor ready to let go. Before they do that, you ask: “Which one will get to reach the wall on their side faster?”

Amanda: Mine, the truck
Jim: Mine, the car.

Use justifiable arguments to convince either Amanda or Jim which toy will get to reach the wall faster.</td><td rowspan="2">1) Identify the concepts, theories, alternative ideas, why is a certain concept you are considering correct or incorrect? Try to explain, elaborate and justify why the argumentation strategies you proposed will produce a correct solution(s).

2) Explain why the claim to your proposed solution is true. Elaborate on the reasons. Before doing so, imagine your classmate telling you that something is wrong with the argumentation strategies that you produced to back-up your claim, and that an in-depth discussion with his/her group in which you would argue for and/or against each other’s views could help to convince them of your solution and the weights you placed on it.

3) As you work together in small groups, you will find that you must change certain things you are doing to make your group reach a consensus. What changes do you have to make in your solution pathway? Explain how your decision has helped you to better understand the problem.</td></tr>
<tr><td>2</td><td>A woodpecker hammers its beak into the limb of a tree to search for insects to eat, to create new nest/storage space, or to audibly advertise for a mate. The motion toward the limb may be very rapid, but the stopping once the limb is reached is extremely rapid and would be fatal to a human. Thus, a woodpecker should seemingly fall from the tree either dead or unconscious every time it slams its beak into the tree. Not only does it survive, but it rapidly repeats the motion, sending out a rat-tat-tat signal through the air.

By constructing a problem representation supported with arguments, propose justifiable solution/s to show: Why can the woodpecker survive the severe impacts with a tree limb?</td><td>
Figure 1 Ill-defined conceptual problem Source: unsplash.com</td></tr>
</table>

small groups of 5 to 6 per group to practice dialogical argumentation, which is aimed to enhance their argumentation skills needed for solving various kinds of ill-defined problems. Starting week 2, students received 3 hours per week of lectures (a double-class period of 2 hours on Monday and a single-class period of one hour on Wednesday). During these periods in week 2, students were introduced to dialogical argumentation instruction in which various scenarios and science activities were used to show them how to participate in a dialogical relation with their peers. The terms/phrases of the basic structure of an argument such as claim, data, warrant, qualifier, backing, and rebuttal were introduced and defined, as was the pattern of the *if/then/therefore* argumentation. In this connection, each lesson session began by helping students to familiarise themselves with the criteria for a good argument and how to revise their stances on account of stronger arguments or grounds (evidence, warrants, backings) and rebuttals, which has proved to be successful in promoting students’ argumentation skills (Evagorou & Osborne, 2013; McNeill & Pimentel, 2010; Voss, 2006).

During weeks 3 to 12 of instruction, the exploration of real-life ill-defined science activities was followed, in which students learned how to construct and use argumentation strategies to produce reasoned arguments in favour of, and against, another person’s views to reach consensus on a subject matter in question. In doing so, they contribute to classroom conversation by means of thinking, sense making, reasoning, and problem solving. When a task is given, students construct and share ideas, values, knowledge, and skills with the aim of reaching possible consensus. The goal of this process was to establish dialogic relationships within and between the subgroups within which they would explore multiple approaches to solving a given problem, while simultaneously gathering and comparing critical evidence on opposing viewpoints and sharing newly acquired knowledge. Table 1 represents two of the 12 problem items. The last column represents three items for each of the 12 problem items, making the 36 "other" items. In Table 1, the cues (1 and 2) help to promote construction of arguments within a problem-solving context and the third cue facilitates judgement of learning or evaluation of evidence on different sides of issues. At the end of the twelfth week, the final instrument administration was arranged with students, and data were collected in 4 hrs through classroom observations using a digital voice recorder and digital cameras. Additional data included completed worksheets by students.

Data Analysis

To address the research question about how students exposed to dialogical argumentation-based instruction developed and revised their argumentation strategies while solving science IDPs in groups, a careful analysis of their problem-solving transcripts and oral argumentation were performed. The written tasks were scored according to the practical levels of arguments adapted from Erduran et al. (2004). Evidence for how students framed their argumentation strategies while solving problems come primarily from looking at the justification and/or grounds (evidence, warrants, backings) and rebuttals they offered (Evagorou & Osborne, 2013; McNeill & Pimentel, 2010; Voss, 2006). A fine-grained data analysis based on the classroom observation allowed this study to further investigate students' written solutions and oral arguments through identifying episodes containing either an argument or counterargument between students. Features of the analysis concentrated on the arguments students constructed (i.e., the extent to which they have made use of data, claims, warrants, backings, and qualifiers for judging the adequacy of IDPs solutions), and the extent to which they produce grounds to refute an anticipated opposing position. This required an extended process of defining how they engaged in elaborating knowledge resources, reinforcing or opposing the arguments of their peers at intra-inter-trans-argumentation levels. The question for the analysis then becomes which of these are the substantive or sound arguments and which are subsidiary arguments or unsatisfactory (i.e., argument contains a fallacy). The following section illustrates the method of coding the students' solution transcripts using the practical levels of arguments modified after Erduran et al. (2004) as a guiding framework (Table 2).

Using SPSS (version 23), the permutations based on components rubric (Table 2) were generated as follow: (DI = 8pts, DH = 7, BI = 6, DF = 5, DE = 4, CH = 6, CG = 5, CF = 4, CE = 3, BG = 4, BF = 3, BE = 2, AF = 2, and AE = 1). These descriptions guided the analysis, in which the frequency counts of the overall scores were converted into percentages, as shown in Table 3, and used to enrich the discussion. With this analysis, themes, similarities, and differences that emerged across or within groups arguments were identified and examined to corroborate students' responses to the IDPs. The groups of arguments were then judged to be satisfactory (i.e., sound argument) or unsatisfactory (i.e., argument contains a fallacy; Table 2). Thus, an argument was considered "sound" if it included levels 2 and 3 of acceptability and used the words *if/and/then/but/therefore* to construct a supporting argument with grounds levels 2 to 5. On the other hand, "unsatisfactory" argument included levels 0 and 1 of non-acceptability, regardless of the use of the words *if/and/then/but/therefore* to construct supporting arguments with no grounds (level 1). The brackets preceding each argument contain the reason it was judged as such. The analysis of data collected before and at the end of dialogical argumentation-based instruction (DAI) resulted in rich descriptions of the assessments carried out in the study. Table 3 shows the results of student score comparisons before and after DAI generated using the rubric described in Table 2. The results are compared in the discussion section in relation to the extant literature.

Results

The results of this study show that students' difficulties to construct and use argumentation strategies to solve science IDPs before DAI varied. More than 36% of students attained categories CG, BG, and CE to show how they construct and use argumentation strategies to attempt some of the IDPs (Table 3). The majority of the students made little or no attempt to construct and/or use argumentation strategies to solve IDPs before DAI. Argumentation strategies with missing or confusing elements were ignored. Likewise, arguments that fail to consider single/multiple grounds were grouped based on similarities and differences as depicted in Table 2.

The CG category implies the students used the words *if/and/then/but/therefore* to construct a supporting argument for IDP-solutions that are

Table 2
Components Rubric for Evaluating Possible IDP Solution

Levels	Description
Acceptability and Non acceptability of solution	
0	Non acceptable, with no justification (A)
1	Non acceptable, with justification (B)
2	Acceptable solution, with no justification (C)
3	Acceptable solution, with justification (D)
Grounds in terms of some level of plausibility or acceptability	
1	No grounds (E)
2	Single grounds (F)
3	Multiple grounds (G)
4	Single/Multiple grounds with counter-claim (H)
5	Single/Multiple grounds with counter-claim and rebuttal (I)

Grounds = data, warrants and backings

acceptable, but could not provide justification for multiple grounds they generated. For those who attained BG category, they used such words *if/and/then/but/therefore* or otherwise multiple grounds to provide justification for unacceptable IDP-solutions. Likewise, students who achieved the CE category provided no grounds or used such words *if/and/then/but/therefore* to justify the IDP-solutions that they proposed. At the conclusion of dialogical argumentation-based instruction, 53.8% of the students attained categories DH, CH, and DF. This shows that more than half of the students were successful at generating a sound argument to the extent they use the words *if/and/then/but/therefore* correctly to provide acceptable IDP-solutions with justification, single/multiple grounds, and with counterclaim and rebuttal. Owing to space limitation, only a few examples to show how students developed and/or revised their argumentation strategies through DAI while responding to item 1 in Table 1 are provided. Once again, consider item 1 in Table 1, students were asked to *use justifiable arguments to convince either Amanda or Jim which toy will reach the wall faster*.

In responding to the item, it should be noted that students used the cues provided in Table 1 as a starting point for solving the problem. Interestingly, a good number of students saw the need to initiate and reflect on alternative solution pathways. For ease of reference, a numbering system ranging from 1 to 45 beside students' responses was used to help the reader follow the sequence of arguments, results, and discussion. The excerpts below are representative of the discourse that ensued among students during one of the classroom observations.

Theme: Advancing Argumentation Strategies

1. S2: Certainly, Jim's car will get there first.
2. S4: And what is your reason?
3. S2: Amanda's truck is heavy, and Jim's car is light, so their mass difference plays a role.
4. S5: Yes, that is the difference…but I do not think the lightness of cars makes them move faster than trucks. For example, the sports car "Fiat-Uno," very light, but it cannot match the speed of a truck.
5. S6: Yes, I agree. That is what you would imagine him to think.
6. S4: That's a point to consider, also the scenario says both the truck and the car starts from the same point of departure, and the same surface, so regardless of their masses, they will take the same time to get to the wall on either side.
7. S2: And how am I to convince you guys, if you are not already convinced by what I have just said?

Theme: Developing and Revising Argumentation Strategies

8. S8: Both the truck and the car are toys, so it can be assumed their masses are the same.
9. S9: There are other conditions the scenario inserted which would have been unnecessary if they don't matter.
10. S23: Like what conditions?
11. S9: Like…springs that connected the truck and the car, presumably these springs could prevent movement.

12. S23: So, your point is that the springs would generate frictional force…
13. S9: Yes, that is what I think.
14. S8: I agree with Norah…that appears to me to be true, surely it is something one can see through observation. It was thought of you, Norah. I initially overlooked that aspect.
15. S23: But what if the surface is smooth and in such condition that the frictional force is ignored, would you assume the impact?
16. S9: No, no…certainly not, we need to make an observation to be sure if it is the case. From what the problem stated, we assume that can be the case.
17. S23: Why can't we assume the surface is smooth? As it is…we have no access to make observation. Even if the surface is not smooth, but only appear to be so…it is only fair to consider every option, as Shakoora said earlier. Or have you made any observations?

Although the problem as defined concerns two toys and their respective motions, thus far students have not considered the exploration of the problem-solution procedures in the context to which it applies. They have tried many alternative contexts similar to the one in question to generate sources of knowledge, but this will not do. As far as possible, the foregoing arguments have shown that our knowledge grows through the correction of our mistakes (Popper, 1963, p. ix). The arguments continue.

Theme: Evaluating and Rebutting Counterarguments to Resolve the Intricacy of Problem-Solution Procedures

18. S21: Earlier Martins says Jim's car will reach the wall first, so he must prove that the car will get to the wall first, if he can't prove it, then I must be right…
19. S13: I agree in thinking that Jim is right, this I support with Newton's law. Probably, the points we highlighted earlier failed to recognise…that the bigger the mass of an object, the smaller the acceleration of the object, according to Newton's laws.
20. S4: So, guys what have we agreed upon? I think we need to make an observation to get a clear picture.
21. S6: Cindy, we have deduced that the toys are to move from the same point, to travel to the same distance, with the car lighter than the truck, with the surface smooth, they will arrive there at the same time regardless of their mass difference.
22. S2: I am not for such thought. On account of Newton's second law, I think the smaller the mass an object has, the faster its speed. So, I believe Jim is right. By the way, why do you say, "regardless of their masses"?
23. S23: If we apply Newton's third law, which says, if object A (Amanda's truck) exerts force on object B (Jim's car), Jim's car (object B) will exert equal, but opposite force on Amanda's truck (object A). This means, the masses of the truck and the car do not count, so, if mass is constant, then, force is directly proportional to acceleration (Newton's second law). Hence, we say the car and the truck will reach the wall at the same time.
24. S2: I see…Is that the strongest point of all? Are there not also other factors to take into consideration? With these words I would like to ask…

Students often use physics principles/laws to validate their claims to knowledge, even when faulty claims or tentative assumptions are inherent in their thinking. It can neither be assumed that all Newton's laws (see S13's argument, line 19) are applicable to all contexts nor plausible to think "Newton's law is one size fits all."

Theme: Resolving the Relational Complexity Among Major Concepts in the Problem

25. S2: …would you not consider that the weight exerted on any object is very important to know the speed the object can travel? Because I want to know in which instance this applies, also for which of the toys?
26. S23: Okay, Jali you can answer her…no, go ahead.
27. S19: Presumably…the weight of the object could be one key issue, I should wish really to persuade you, if I could…there is reason in your question…what is your reason for asking?
28. S2: The force acting in the opposite direction which Jim's car is traveling can also affect it and the smaller it is the quicker it can overcome this.
29. S19: Probably, you are alluding to the impact of frictional force cause by the coefficient of the kinetic friction.
30. S2: Yes, that's right.
31. S9: But did we not say this earlier? And it was admitted. Do not suppose that I approve of what you are saying that Jim's car will get to reach the wall faster, no, not until I am convinced. Also, I implied the impact of frictional force differently, contrary to your real opinion.
32. S2: Then I will repeat the question which I asked before, in order that our use of the frictional

force is examined. A statement was made seeking for what we have agreed upon, and it was Van Wyk who elaborated on that. You would not deny that if you are right in your view, then I am also right, hence the impact of frictional force. I am delighted you are nodding for yes.

33. S9: I agree, I did not mean to quarrel when I distanced my opinion from yours. I see on the one aspect - frictional force we share the same view from different viewpoints. How clever of you to figure that out…lekker! ("Lekker" is an Afrikaans word for "nice.")

From the foregoing arguments, students generated multiple grounds, with at least one rebuttal that challenged the grounds on which the claims/counterclaims are based. Importantly, they attempted to operate at a metacognitive level by checking the force components of the situation.

Theme: Evaluating and Rebutting Counterarguments to Reach a Possible Consensus

34. S15: Can't we try to construct a model to help us make an observation? Probably, that would be the better way and far more easy to make assertions.
35. S23: Good proposal. But, to do so, as I am inclined to think, will be a very serious task. Think about it. You would find, rather, that with every single step you take, the need for further steps increases in getting a complete resemblance to the problem situation, as the scenario puts it.
36. S4: What then do you think? We can barely keep time; we have spent too much time deliberating from one viewpoint to another. What shall we do? Martins, can you think of something else?
37. S23: I do not, of course, deny that if we can create an ideal model that fits all the features of the scenario, the problem is not half-solved. It seems to me that we will end up formulating an inexact picture of the problem.
38. S11: Where does that leave us?
39. S9: But if you guys are interested in the way our group visualized the problem, which I tried to explain earlier with the help of Van Wyk, you may help me by criticizing our assertion as severely as you can; and if you can design a model to test which you think might refute our assertion, I will be happy to accept it.
40. S2: By all means, can you explain one more time, what do you mean? I do not understand your meaning…
41. S9: There is no point repeating what Van Wyk said earlier. If the truck and the car are to be in reality context, we still don't know their engine capacities as well as other factors that need to be in place before the physics principles can be applied. This is why we had better assume they will reach the wall at the same time. That was my meaning.
42. S23: I agree with you.
43. S2: And what do you think of Newton's Third Law, how does it nullify my early stance on the weight of an object, say, Jim's car?
44. S23: I cannot answer you without more thought. Jim's car and Amanda's truck are both objects to which Newton's III law can be applied, if we suppose a change in motion, that change must be affected by both objects.
45. S2: That is conceivable, at last your thoughts are the reflection of my own...that change in motion of an object due to its weight must be taken into account...

As a whole, students have explored quite a range of arguments to reach a possible consensus. It is worthy of note that some students (31.6%) seemed not to realize how to use counter-arguments to construct alternative viewpoints. Before engaging in DAI, a majority of students (63.6%) incorrectly thought that a conclusion is a statement of grounds. After being exposed to DAI, less than half (46.2%) committed errors in their problem-solutions that serve to confuse. These errors appear to fall into two categories: (a) arguments that fail to consider multiple grounds, and (b) arguments in which the justification for problem-solution does not follow from evidence or otherwise of the knowledge base and conceptual understanding about a subject matter in question. As stated above, about 54% of students demonstrated sound arguments and successfully constructed justifiable solutions for the IDP items.

Discussion and Conclusion

The results from this study showed evidence of students' growth in developing and/or revising their argumentation strategies while solving science ill-defined problems in a dialogical argumentation-based classroom. Interestingly, after being taught through DAI, many students (53.8%) were successful at constructing sound arguments at high categories DH, CH, and DF (Table 3) to solve most of the ill-defined problems. Students who attained these categories were considered as better problem-solvers (Jonassen, 2011; Voss, 2006), listed in order of success; they proposed multiple justifiable solutions for the IDPs tested. This performance shows that students demonstrated the ability to generate sound arguments as well as mobilising the knowledge resources pertaining to a given problem

Table 3
Percentage of Scores at Each Level for Outcome Variables

	Component levels in percentage (%)	
Tests	Before DAI	After DAI
Arguments generated within IDP solving context	20.65	29.5
Evaluation of possible solution	15.75	24.3
Categories by (%)	36.4	53.8
	CG, BG, CE	DH,CH, DF

and its possible solution. In addition, the attainment of categories DH, CH, and DF, in particular, DH and CH, show improvement in the students' development of argumentation strategies, thinking, sense making, reasoning, and problem solving in science. This success and the relatively poorer performance on the IDPs before DAI are partially consistent with those of Shekoyan and Etkina (2007) as well as Spector and Park (2012) and provides some evidence for where more emphasis needs to be placed in both students' arguments and pedagogical explanations on how argumentation in the science classroom can be conceptualized.

Likewise, the argumentation strategies they generated supported other findings in the area of argumentation (Belland et al., 2011; Von Aufschnaiter et al., 2008). From their explorations (lines of arguments 25 to 33), students made reasonable attempts to explore the relational complexity among major concepts in the given problem and the intricacy of problem-solution procedures highlighted in the work of Jonassen and Hung (2008). As they argued further across or within groups, their knowledge base and conceptual understanding about ill-defined problems increased (lines of arguments 34 to 45). Thus, these results indicate that engaging science students in argumentation practice in which class activities are characterised by ill-defined problems can help them learn to present their work in a public forum to their classmates who serve as critical friends. Nevertheless, performance varied considerably across other IDPs tested. For instance, when students had to solve tasks (e.g., item 2 in Table 1 and the like) that have no clear-cut answers, their performance dropped considerably. One primary reason is that some students admitted in their dialogical interaction with their peers that they have never seen a woodpecker hammering its beak into the limb of a tree to search for insects to eat or to create a new nest/storage space or to audibly advertise for a mate. Based on existing research findings, Jonassen (2007) highlighted some factors that affect problem solving which are internal to students. These include students' levels of prior knowledge, experience, reasoning ability, various cognitive styles, and epistemic beliefs. But notice in Table 3 that the gain in students' success at generating sound arguments across time is 8.85%. This difference could have been more if the IDPs tested have direct observable experience to the students. This alone may explain the relatively low success rate before students were exposed to DAI. However, other factors may be at work. Certainly, it seemed difficult for students to construct and use argumentation strategies needed to solve IDPs prior to and at the beginning of participating in the study.

For some students, using argumentation strategies when backing their claims or providing justification was difficult, and as a result they failed to notice that a different set of ideas (alternative ideas which their opponents generated) could quickly and easily facilitate a resolution to a problem in question. The difficulty may have stemmed in part from students' persistent belief that all science problems are restricted to observation and known facts (lines of arguments 34 to 38). Although the results provide evidence of progress made after being exposed to DAI, the difficulties in constructing a reasonable argument may have stemmed in part from students' lack of familiarity with the major concepts in the problems as discussed by Jonassen and Hung (2008), and Voss (2006). As mentioned, difficulties in developing and/or revising argumentation strategies needed to solve IDPs varied, but the challenge students faced was that they viewed the primary difference between claims and counter-claims to be reliance on facts that can only be verified through observations. For instance, S15 asked, *"Can't we try to construct a model to help us make an observation?"* (See line 34 of arguments). Student (S4) had uttered this view earlier when she said, *"I think we need to make an observation to get a clear picture"* (line 20 of arguments). Student (S9) agreed with this view (line 16 of arguments). By contrast, S23 was more inclined to "predictive arguments" and sponsored such views in his argument (line 35). This was not challenged by students (S15 and S21), so the discourse moved on to the next question, to which multiple alternative viewpoints were collectively formulated. When asked about the sources of controversy in scenario item 1, students (S2, S9 and S4) stated, *"when there is more than one possible solution, then solving the problem becomes complex and the answer is not always clear* (S6), *especially when many facts are unavailable"* (S15). Such views are considered naïve, in that the use of creative thought is restricted to facts rather than being viewed as an inherent and necessary component of arguing to learn and learning to argue that is described in the work of Walker and Sampson (2013). If this lack of clarity is not resolved in the minds of future science teachers, such as those who took part in the current study, little progress among future students can be expected.

Finally, the findings from this study have shown how argumentation skills affect problem solving among students. Students need to learn the skills that will prepare them for life beyond graduation so that they can solve real-life problems and make informed decisions. The findings also revealed that less than half of the students exposed to DAI have yet to develop adequate argumentation strategies to enable them to learn and teach science conscientiously. Although teaching science might be overwhelming to some novice teachers, helping future science teachers gain knowledge of science, knowledge of pedagogy, and the belief that teaching science through argumentation is important, as well as providing possible ways of helping their future students learn science effectively is critical for science teacher education programs. It was in light of this that this study exposed these students to empowering learning experiences on ill-defined problem solving using a DAI as an approach.

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PAUL N. IWUANYANWU is a science education lecturer at North-West University in Potchefstroom, South Africa. He received his doctorate (PhD) and master's degrees in science education from the University of the Western Cape. Dr. Iwuanyanwu specializes in physics, chemistry, and mathematics and conducts research in these fields in relation to knowledge corpus in pedagogy and education effectiveness and quality improvement, STEM education, problem-based learning (PBL), argumentation, mathematical thinking, teaching and teacher education, indigenous knowledge, and cultural studies.