Research in Science Education (2023) 53:1063–1079
https://doi.org/10.1007/s11165-023-10122-9

When Science Is Taught This Way, Students Become Critical Friends: Setting the Stage for Student Teachers

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Accepted: 21 June 2023 / Published online: 8 July 2023
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Abstract

Effective science education draws on many different ways of teaching science. The literature on science education documents some potential benefits of argumentation instruction as a powerful tool for learning science and maintaining wonder and curiosity in the classroom. Unlike expository teaching, which relies on a teacher-driven pedagogy in which students accept the teacher's authority over any content to be justified a priori, argumentation teaching allows students to focus on the importance of high-quality evidence for epistemic knowledge, reasoning, and justification. Using a quasi-experimental design, two study groups of undergraduate student teachers were exposed to two different learning conditions, the Exp-group with dialogic argumentation instruction (DAI) and the Ctrl-group with expository instruction. Each group received the same science content twice a week for 12 weeks (2 h per lesson). Pre- and posttests were administered to collect data. One-way MANCOVA with the pretest results as covariates showed that the instructional approaches (Wilk's $\Lambda = 0.765$, $p < 0.001$) had a significant effect on the tested variables after the intervention. A pairwise comparison of performance indices between the two study groups revealed that the exp-group was better able to evaluate alternative solutions and defend arguments for collaborative consensus on unstructured scientific problems. This suggests that dialogic argumentation instruction can be used to help students improve their scientific reasoning, thinking, and argumentation skills, which are required to solve problems involving scientific phenomena.

Keywords Dialogic argumentation · Traditional instruction · Students · Physics · Problem-solving

Introduction

Over the years, science education research has examined various issues related to science learning, including its nature, content, goals, and problems, and has found that some problems that appear to be specific to science education actually reveal broader instructional

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issues that affect students' interest in science, their achievement, and their perceived usefulness (Eccles & Wigfield, 2002; Ogunniyi, 2022; Toma & Lederman, 2020). Considering this, scholars and science education reformers recommend that science instruction be tailored to encourage students to reflect critically on science (International Council for Science [ICS], 2011), solve real-world problems, make and defend arguments about scientific knowledge (Iwuanyanwu, 2020), and gather and evaluate scientific evidence on a variety of topics to gain new knowledge (Osborne, 2019; Tarekegn et al., 2022). According to the social constructivist perspective (Schreiber & Valle, 2013), the process of gathering and analyzing scientific evidence to gain new knowledge requires students to engage in a dialogic relationship with their teachers and peers who contribute to the construction of knowledge through reasoning, thinking, and sense-making (Iwuanyanwu, 2022). When participating in a dialogic relationship with peers, students are able to freely express their views, learn to ask questions, identify assumptions, think through problems with peers, gather and weigh evidence to find solutions, or reach a collaborative consensus.

The many benefits of engaging students, especially student teachers, in a dialogic relationship that promotes social construction of knowledge can provide them with the skills they need to function as critical friends within the teaching profession as well as the scientific community in general. However, research has shown that student teachers and in-service teachers have difficulty completing these cognitive tasks (Erduran et al., 2016; Ghebru & Ogunniyi, 2017; Iwuanyanwu, 2017). For example, one of the reasons for conducting the current study was that student teachers in physics lectures were becoming increasingly perfunctory in formulating, presenting, and defending arguments for the best solution to unstructured problems and in evaluating evidence from opposing sides based on new data. In the literature, physics teachers who have encountered this type of student difficulty report observations that led them to incorporate dialogic argumentation in their lectures to allow their students and preservice teachers to explore possibilities for social negotiation and to discuss the uncertainty of multiple solutions to unstructured scientific problems (Etkina et al., 2019; Gürel & Süzük, 2017; Syafril et al., 2021). In light of this, dialogic argumentation instruction plays a significant role in equipping student teachers with the methodological repertoire needed to resolve scientific and socio-scientific issues both inside and outside the science classroom (Iwuanyanwu & Ogunniyi, 2018).

Considering the above useful suggestions, the present study expands on the exploration of dialogic argumentation instruction in physics classroom, focusing on two study groups of student teachers (experimental and control groups) as they learn to construct arguments, evaluate solutions, and justify them when faced with uncertainty. The following research question guided the study's data gathering and analysis: How do student teachers in expository and DAI-based classes differ in their ability to develop valid problem-solving strategies, formulate, present, and defend arguments, and provide reasonable solutions to given problems?

Review of Literature

Recent research has explored how the argumentation framework can be used in physics education to enhance physics instruction and achieve various learning objectives (Erduran & Park, 2023; Syafril et al., 2021). Argumentation, which involves asserting claims and using evidence to support them, mirrors as closely as possible the enterprise of science learning (Kuhn & Udell, 2007). According to this perspective, the structure of an argument is determined by how evidence, data, reasons, and claims are presented to support the argument (Toulmin, 2003), which can follow inductive or deductive reasoning from premises to conclusions (Iwuanyanwu, 2019). Consistent with social constructivism, students' dialogic interactions with teachers and peers have been shown to promote argumentation in physics classrooms (Gürel & Süzük, 2017; Hansson & Leden, 2016). Thus, the present study fits within the paradigm of dialogic argumentation (Ghebru & Ogunniyi, 2017; Iwuanyanwu, 2022). In science classrooms, the process of dialogic argumentation becomes evident when a student presents a reason for or against an assertion about a phenomenon (Iwuanyanwu, 2017). In such cases, a common goal is to reach consensus between different perspectives about plausible or acceptable claims (Erduran & Park, 2023). As Ogunniyi (2022) points out, learning and teaching science through dialogic argumentation (DAI) provide students and teachers with a forum to express themselves, clarify doubts or anomalies, better understand scientific phenomena, and possibly revise their viewpoints based on new knowledge about scientific phenomena.

In the current study, the focus on DAI aligns with the objective of helping physics student teachers become better at arguing and defending arguments and producing reasoned solutions to science problems, which are essential skills for the science teaching profession (Erduran & Park, 2023). In learning environments where dialogic argumentation has flourished, student teachers' drive to explore has also evolved (Iwuanyanwu, 2022). In this regard, DAI approach requires teachers to serve as mediators and ask thought-provoking questions to help students understand science (Iwuanyanwu & Ogunniyi, 2020; Koichu et al., 2022).

Conceptual Scheme of Dialogic Argumentation Instruction

Dialogic argumentation instruction (DAI) focuses on the components of learning that occur in a socially interactive context in which students learn about subject-specific concepts, formulate, present, and defend arguments and counterarguments to resolve contentious issues. Essentially, DAI includes three types of arguments that reflect the exploration of classroom activities, beginning with the individual argument or self-talk (intra-locutory arguments). Intra-locutory arguments are driven by a student's self-talk, wonder, curiosity, or passion to understand and solve a particular scientific problem or phenomenon. During this phase, the student may notice something that intrigues her or stimulates her curiosity, leading her to ask questions, which in turn stimulates her inquiring mind. As she moves through this phase, the student puzzles over the task, asks more questions, and hypothesizes to create a new mental framework for the phenomenon. By focusing on the phenomenon more carefully and resolving related problems, the student may gain a better understanding of it (Iwuanyanwu, 2020). Consequently, the student provides evidence/data to support claims and/or counterclaims, and at best uses such evidence to justify arguments or solutions to given problems (Belland et al., 2011; Iwuanyanwu, 2022).

After completing the individual tasks, students move to their assigned small group to work on the next tasks, which are saturated with arguments and require reflective judgments. In this case, students enter into dialogues with their peers (inter-locutory arguments) to address issues that arise from their individual tasks or that are part of the group tasks. In this type of argument, dialogic relationships occur within and between subgroups in which students ask questions, critically engage with each other's arguments and counterarguments, solicit responses, and connect meanings to reach a common consensus. In the current study, this is evident when students analyze different strategies for solving problems by collecting and comparing critical evidence for opposing viewpoints, making arguments and counterarguments using structures such as if/and/then/but/therefore, or considering facts for which additional evidence/data is needed to establish a common consensus about the uncertainty of solutions to particular problems (Gürel & Süzük, 2017; Iwuanyanwu, 2022; Jonassen, 2011). When dealing with unstructured problems, a plausible or acceptable solution is derived from the sum of all defended reasonable solutions (Geifman & Raban, 2015; Iwuanyanwu, 2020).

Moreover, in large group sessions, decisions made at the individual and group levels are mobilized again and typically articulated by group representatives (trans-locutory arguments), and the teacher serves as a mediator to facilitate learning with the explicit goal of reaching consensus. From this perspective, it can be said that teaching physics through dialogic argumentation can provide student teachers in the current study with a better understanding of physics that goes beyond the presentation of facts, definitions, laws, and problem-solving skills (Erduran & Park, 2023; Iwuanyanwu, 2019). When physics is taught in the context of dialogic argumentation instruction, it provides insight into students' prior knowledge and views about specific scientific phenomena (Ghebru & Ogunniyi, 2017), including views that may not be consistent with valid scientific knowledge and may influence the way they approach learning physics concepts (Voss, 2006). In addition, some research evidence agrees that learning physics concepts through DAI can improve students' ability to present and defend arguments and find reasoned solutions to given scientific problems (Erduran & Park, 2023; Gürel & Süzük, 2017; Iwuanyanwu & Ogunniyi, 2020).

Furthermore, the importance of solving scientific problems, making and defending judgments regarding the problems, and developing reasoned solutions to the problems cannot be overstated. After all, problem solving is a ubiquitous activity and an indispensable skill for students and teachers to acquire (Iwuanyanwu, 2020). According to UNESCO (2020), real-life challenges and recent COVID-19 health problems have led to an urgent need to address the gaps in students' ability to think for themselves, reason, and solve different types of problems related to STEM education and other socio-scientific contexts. Recent studies by Erduran and Park (2023) and Tarekegn et al. (2022) suggest that educators could use dialogic argumentation instruction to address these identified gaps, which are among the skills students need in the twenty-first century. In light of this, DAI is a very important tool to help student teachers in the current study think independently; challenge the views of their classmates, lecturers, and others with reasoned arguments and counterarguments; and investigate the unresolved issues related to physics phenomena and problems. By doing so, students can build a broad range of knowledge and inquiry skills and gain more experience to be better able to act as critical friends within a larger scientific community.

Methods

This study followed a pre–posttest control group design with quantitative data collection and analysis as described below.

Setting and Samples

The faculty of education at a South African university where this study was conducted offers a four-year science education program that prepares students to become science teachers. The program includes science subjects such as chemistry, physics, and biological sciences. Since the study was prompted by a problem identified in physics education class, it focuses on physics instruction. In the first and second years of the physics education program, student teachers must take an introductory physics module, usually offered in two separate classes. The module includes learning concepts such as dynamics of uniform circular motion, thermodynamics, fluids, forces and motions, waves, and sound. Student teachers were taught specific topics in two separate classes in their first year and mid-year in their second year, during which the study was conducted. The organization of the lectures is such that students attend two hours of physics lectures twice a week for 16 weeks.

The participants were second-year physics student teachers ($n=79$, 37 females, 42 males) enrolled in the above program. Of the two classes, one was inducted as Exp-group ($n=46$) and the other as the Ctrl-group ($n=33$). Rural, suburban, and urban student teachers were represented in each class. They were mostly between 19 and 23 years old (average age = 20; standard deviation = 3.86). Family income ranged from dual income to middle-income. Student teachers who volunteered to participate in the study after it was approved by the ethics committee gave their consent by completing the POPIA consent form. Using POPIA guidelines, all tasks submitted and assessed were treated with privacy, confidentiality, and anonymity. The first step of the study was to use a self-developed research instrument to generate baseline data to compare students in the two classes. Details of the instrument review process are provided under instrumentation. The first application of the instrument (pretest) lasted for two hours in week 1. Pretest data suggests that the study groups did not differ significantly ($F=4.82$; $p=0.295$). Based on this result, the study groups were inducted according to the pretest–posttest control group design.

Instrumentation

Seventeen different science problems were developed. The tasks required students to develop valid problem-solving strategies, formulate and defend arguments, evaluate the reasonableness of alternative solutions, and defend reasonable solutions, as shown in Table 1. Most tasks do not have unique correct answers/solutions (see, for example, the science problem SP-Q2). The tasks were designed to elicit agreement and/or disagreement about their solutions, even when the tasks are considered solved. The instrument was tested for validity and reliability by two independent science educators who reviewed the tasks. In this regard, the study instrument was appraised for its content level, language appropriateness, and conceptual coverage. After several revisions of the instrument, the final version yielded Cohen's kappa value of 0.78. The Kuder–Richardson 21 reliability coefficient was 0.73. These data indicate that the overall consistency and reliability of the 17 items were satisfactory, reliable, and appropriate (Creswell, 2013). Each of the 17 items required students to (a) develop valid problem-solving strategies, (b) formulate defensible arguments for their chosen strategies, (c) judge the reasonableness of alternative solutions (if applicable) to resolve ambiguities, and (d) defend the reasonable solutions/collaborative consensus reached. Following the existing literature, it was believed that the combination of the four variables (a–d) could allow for the integration of many of the skills and abilities student teachers need to collect and evaluate data/evidence, formulate and defend arguments, and, at their best, use arguments to solve physics problems and communicate scientific knowledge (Adams & Wieman, 2015; Belland et al., 2011; Iwuanyanwu, 2020).

Procedure

In accordance with the experimental pre–posttest control group design, the two study groups were subjected to a series of biweekly physics lectures lasting 2 h per session over

Table 1 Students' use of arguments in scientific problem solving

Targeted variables	Description of DAI activity	Proficiency judgement
Construct valid problem-solving strategies	Students gather or use available data to generate a set of images of the problem context, as well as organize and analyze known and/or unknown quantities/variables of given problems from various sources. Identify, define, and represent the problem to be solved diagrammatically (where applicable). Evaluate the potential strategies in light of viable or acceptable alternatives (Asterhan & Swartz, 2007; Iwuanyanwu, 2020)	Students show evidence of generated ideas in a network of mental spaces in order to read, translate, and make sense of the complex set of relationships within the context that provide background for the problem (Iwuanyanwu, 2022)
Formulate defensible arguments for chosen strategies	Students use data to make claims and/or counterclaims (I agree/disagree with…), back up claims with evidence or points to evidence, provide reasoning episodes to back up counterclaims, and at best use evidence to support strategy choice, and finally formulate reasoned solutions (Erduran & Park, 2023; Iwuanyanwu, 2020).	Students used text structures such as if/then/but/then to build a supporting argument for their strategy selection (Iwuanyanwu, 2022; Osborne, 2010). Further to that, students use the structural elements of arguments such as claims, data, evidence, reason, and counterclaims to make, defend, and evaluate judgments. At best, students show how one argument's claim serves as the data for another argument (Iwuanyanwu, 2020)
Judge the reasonableness of alternative solutions to resolve uncertainties	Students argue for or against alternative solution pathways, critique selected strategies, clear anomalies/ambiguities, use evidence/data to cite or insist on their positions, particularly after listening to others (Belland et al., 2011; Ogunniyi, 2022)	Students pose provocative questions about alternatives, uncertainties, or missing components in order to examine alternative solutions within or across small groups and use the sum of all defended reasonable solutions to reach a consensus (Geifman & Raban, 2015)
Defend reasonable solutions/collaborative consensus reached	Students participating at the intra-, inter-, or trans-locutory argument levels use the argument structure (data, claims, warrant, backing, or other conceptual resources compatible with valid scientific knowledge) as well as use text structures such as if/then/but/therefore to advance reasoned arguments required to produce justified solutions	Students attempt to justify their positions, play devil's advocate, reconsider their positions in light of more compelling arguments (Iwuanyanwu, 2017), and, most importantly, demonstrate how they find solutions to a given problem (Voss, 2006)

a 12-week period. The language of instruction was English. Both groups received the same content (advanced mechanics) and the same amount of teacher contact and were pretested and posttested with the same instrument (4 h in weeks 1 and 12). During the 12-week teaching–learning period, the exp-group participated in a series of argumentation-based lessons delivered by the author using DAI (Erduran & Park, 2023; Gürel & Süzük, 2017; Iwuanyanwu & Ogunniyi, 2020), while the Ctrl-group received expository instruction from another instructor in the science education faculty (Adams & Wieman, 2015). Both teaching approaches consisted of cycles of preparation and reflection, which in turn led to the next cycle of instruction (Geifman & Raban, 2015). During week 1 (0.5 h on Day 1) of the study, students were briefed on the study project and given guidelines for their learning behaviors throughout the study. Following this meeting, the two-hour pretest data collection session took place. In week 2 (5 min before the DAI lesson began), students were asked to form groups of 5–6 students per group and were given a unique identification code for data collection.

Using the DAI guidelines as presented in the literature review, teaching and learning were facilitated through three key phases to actively engage students in learning scientific concepts as individuals (elaborating intra-locutory arguments within individuals), as small groups (elaborating inter-locutory arguments between subgroups), and as a whole class (elaborating trans-locutory arguments across groups). Following this mode, learning physics concepts using basic argument structures was taught to help students learn how to use the structural elements of arguments, such as claims, data, evidence, reason, and counterclaims to formulate reasoned solutions to scientific problems (see Table 1). In weeks 2 through 12, the DAI process was scaffolded, and students were guided. The structure and guidance decrease as students become better at creating evidence-based arguments to solve scientific problems and communicate scientific knowledge.

Moreover, since scientific problems by their nature require arguments and counterarguments to solve them (Voss, 2006), students in the Ctrl-group received guided instructions from their instructor, who likes to play the role of devil's advocate. Since both groups received the same content and research instrument, the instructor in the Ctrl-group was asked to guide her students to become aware of the four target variables in order to solve scientific problems and develop reasoned solutions. Her instruction was processed as shown in Table 2.

Data Collection and Analysis

The instrument (consisting of 17 items) was administered to both the Exp-group and the Ctrl-group as a posttest (within 2 h at week 12) toward the end of the semester. Following posttest data collection, the researcher compiled each student's solution script, removed identifying information, and then assigned a number code. The same number code was used to track student performance and progress throughout the study. Student performance on the targeted science concepts and variables (Tables 1 and 2, respectively) was then analyzed using one-way MANCOVA (multivariate analysis of covariance), which was considered the most appropriate analysis to examine whether the two study groups differed on the outcomes of the four variables after the intervention. The purpose was to test whether participation in DAI and expository classroom activities helps students develop valid problem-solving strategies, formulate and defend arguments, and find reasoned solutions to given problems. Using pretest scores as covariates, the outcome variables were assumed to have

Table 2 Expository instruction for scientific problem solving

Targeted variables	Description of expository activity
Construct valid problem-solving strategies Formulate defensible arguments for chosen strategies Judge the reasonableness of alternative solutions to resolve uncertainties Defend reasonable solutions/collaborative consensus reached	Step I: introduces the topic through interactive whiteboard (ppt) and communicates the focus of the lesson Step II: links the new lesson with previous knowledge Step III: explains the content of the topic by giving the conceptual and operational definitions of concepts and relevant knowledge resources Step IV: in some cases, instructs the students to check for meaning of concepts Step V: gives and solves a few examples of problems Step VI: calls on a volunteer student who has solved the problem to share the solution with the class To stimulate her students' reasoning as they think-aloud about scientific phenomena and associated problems to solve, the lecturer was noted prompting her students to consider the following thought-provoking questions: What do I already know about the given problem? How can I construct a problem space that does not only have some levels of plausibility or acceptability, but is capable of leading to justifiable solution/s? What arguments do I need to produce to convince others why my solution is the best possible solution about the given problem? I know scientific problems may have multiple solutions and often are not final: have I considered other alternatives and examined their constraints? Have I provided evidence to back up alternative or proposed solutions? How will I know if the problem has been satisfactorily resolved?

a linear relationship in terms of multivariate normality and variance–covariance matrices $(x^2 = 33.19, df = 28, p = .012)$ (Creswell, 2013).

Findings and Discussion

According to the results of this study, under two different teaching approaches, both study groups made significant progress in learning how to create and use evidence-based arguments to solve scientific problems and communicate knowledge. For example, the quantitative data and student reasoning episodes showed that a significant number of students progressed from the pretest to posttest phase in terms of (a) constructing valid problem-solving strategies, (b) giving defensible arguments about their chosen strategies, (c) judging the reasonableness of alternative solutions to resolve ambiguities, and (d) defending reasonable solutions/collaborative consensus. From pretest to posttest, the Exp-group made significant progress in constructing valid problem-solving strategies ($t = 6.75$, $p < 0.001$) and was able to provide defensible arguments for their choice strategies ($t = 4.39$, $p < 0.001$). The Ctrl group made significant progress from pretest to posttest only in developing valid problem-solving strategies ($t = 3.26$, $p < 0.001$).

Table 3 Results of one-factor MANCOVA

Variables	Wilk's Λ	*df*	*F*	*p*-value	Effect size (η^2)
Construct valid problem-solving strategies					
Pretest	0.543	3	25.63	0.000***	0.397
Instructional approach	0.716	3	6.72	0.000***	0.481
Formulate defensible arguments for chosen strategies					
Pretest	0.661	3	29.40	0.000***	0.120
Instructional approach	0.728	3	4.82	0.000***	0.223
Judge the reasonableness of alternative solutions					
Pretest	0.46	3	49.56	0.000***	0.754
Instructional approach	0.656	3	10.67	0.0021*	0.582
Defend reasonable solutions or collaborative consensus					
Pretest	0.643	3	33.08	0.000***	0.491(L)
Instructional approach	0.765	3	3.40	0.000***	0.240(M)

$^{**}p < 0.005$

$^{*}p < 0.05$

$^{***}p < 0.001$

Table 4 Results of repeated measure of ANOVA

				Post hoc		
Source	*F*	*p*-value	Partial eta square (η^2)	Time	*p*-value	Group
Time	5.36	0.000***	0.057	V3 > V1	0.042***	Exp > Ctr (0.042)
Group	0.297	0.461	0.043	V4 > V1	0.016***	
Time × group	4.82	0.000***	0.167			

V1 construct valid problem-solving strategies, *V2* indicate defendable arguments about choice of strategies, *V3* judge the adequacy of alternative solutions for uncertainties, *V4* defend reasonable solutions or collaborative consensus.

$^{**}p < 0.005$

$^{*}p < 0.05$

$^{***}p < 0.001$

Table 3 is a summary of the results for the four variables measured in the two study groups at pre- and posttest levels. A one-way MANCOVA using pretest scores as a covariate suggests that instructional approaches (Wilk's $\Lambda = 0.765$, $p < 0.001$) have a statistically significant impact on postintervention outcomes for the variables tested. The univariate test confirmed significant differences in posttest scores between the study groups on judging the reasonableness of alternative solutions to resolve ambiguities ($F = 10.67$, $p = 0.0021$) and defending reasonable solutions/collaborative consensus ($F = 3.40$, p 0.001). Thus, students' posttest scores on defending arguments related to solutions or consensus about scientific phenomena were significantly influenced by the instructional approach used. Further post hoc tests (Tukey HSD), shown in Table 4, indicate that there was a difference between the two study groups at posttest (Exp group > Ctrl group), ($p_{(\text{post-Var.3})} = 0.042$) and ($p_{(\text{post-Var.4})} = 0.016$). Note: see Table 4 for a full description of "Var. 3" and "Var. 4."

The results of repeated measures of ANOVA with one factor Exp or Control are summarized in Table 4. The between-subjects factor is the group, and the within-subjects factor is the time (pre or post scores). Scores on the pretest demonstrated significant differences between time and exp-group ($F=5.36$, p 0.001), along with a significant time main effect ($F=4.82$, p 0.001). However, posttest scores were not significantly affected by the Ctrl-group ($F=0.290$, $p=0.461$).

A pairwise comparison of test time for learning in the study groups is shown in Table 5. There was a significant difference in posttest scores between study groups ($F=5.36$, $p=0.001$, $\eta_p^2=0.032$). However, the pretest scores were not significantly different between the two groups ($F=4.82$, $p=0.195$, $\eta_p^2=0.0063$). In the Exp-group, the posttest results differed significantly from the pretest by ($F=0.46$, $p<0.001$, $\eta_p^2=0.02$) and in the Ctrl-group by ($F=6.56$, $p<0.001$, $\eta_p^2=0.26$). Also, in the experimental group, the difference between pre- and posttests means was greater than in the control group.

Overall student performance suggests that the control group performs at a much lower level than the experimental group on physics problems that depend on theoretical foundations or assumptions. This suggests that encouraging students to learn physics concepts and solve related problems in a DAI-based classroom may help students develop different reasoning skills (Asterhan & Swartz, 2007; Osborne, 2010; Voss, 2006). Of the 46 student teachers in the Exp group, 28 provided evidence-based arguments and rationales for multiple or alternative solutions. By comparison, 11 of their peers in the Ctrl group did likewise. More than 49% of the group could not judge the adequacy of their proposed solutions to ill-structured problems using the structural elements of arguments such as claims/counterclaims, data, evidence, and reasoning. The following is an example of an ill-defined scientific problem that student teachers addressed during the pre–posttests (SP -Q2, Table 6, Figs. 1, 2, 3, 4).

Student Teachers' Deliberation on Scientific Problem

When student teachers were presented with the task SP-Q2 during the pre- and posttests, they were asked to perform the first two of the four variables examined in the study. In this phase, they were allowed to make mistakes, correct mistakes, make predictions, and self-regulate their own thinking. In small groups of five, students negotiated the question and its meaning. They gathered data and used available evidence to approach the problem

Table 5 Pairwise comparisons of item scores

				Observed confidence level (95%)	
Comparisons	MD	*S* error	*p*-value	Low bond	Up bond
Posttest Exp–pretest Exp-group	4.45	0.78	0.000***	2.56	5.95
Posttest Ctrl–pretest Ctrl-group	2.11	0.43	0.000***	3.58	5.12
Pretest-Exp–pretest-Ctrl	−0.39	2.03	0.195	−1.83	1.18
Posttest-Exp–posttest-Ctrl	1.95	0.49	0.000***	5.54	8.09

Exp experimental group, *Ctrl* control group.

**$p<0$-0.005

***$p<0.001$

*$p<0.05$

Table 6 Inquiry about the Great Pyramid

SP-Q2: about 4500 years ago, ancient Egyptians constructed the Great Pyramid, which is made up of about 2,300,000 stone blocks, the majority of which weigh between 2000 and 3000 kg. Many generations have wondered how the ancient engineers and craftsmen were able to carry the stones into place, which are over 140-m high. Some claim that a big group of workers probably lifted the blocks up a substantial earthen ramp that went up one side of the pyramid at a little incline during building. However, there is no proof for this theory (such as debris or painted images). According to modern scholars, the pyramid was encircled by a spiral ramp. Such a ramp, meanwhile, would have been extremely unstable, and moving a 2000-kg stone around it would have been difficult, if not impossible
Develop valid problem-solving strategies, formulate defensible arguments for the chosen strategies, and evaluate and defend the reasonableness of alternatives to answer this question: *how did the ancient Egyptians move the blocks up and into position?*

Fig. 1 Pyramid scientific ill-defined problem. Source: unsplash.com

in their subgroups. After this phase, students were referred to the remaining variables, but this time they were asked to develop possible strategic solutions based on sound arguments and evaluate their solutions. To do this, they planned, collected, recorded, and analyzed the approach they would take to address the problem. To complete the final phase, each individual or group was asked to explain their proposed solutions, applying the argumentation skills they had acquired. As each group shared their progress, they were encouraged to challenge the evolving evidence by making claims/counterclaims, presenting their evidence, and communicating and justifying their solutions. Using the guidelines outlined in

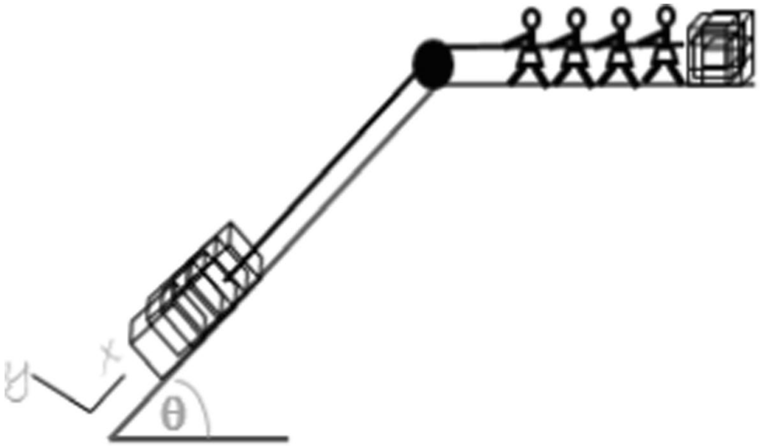

Fig. 2 Initial predictions of work done during the construction of the pyramid

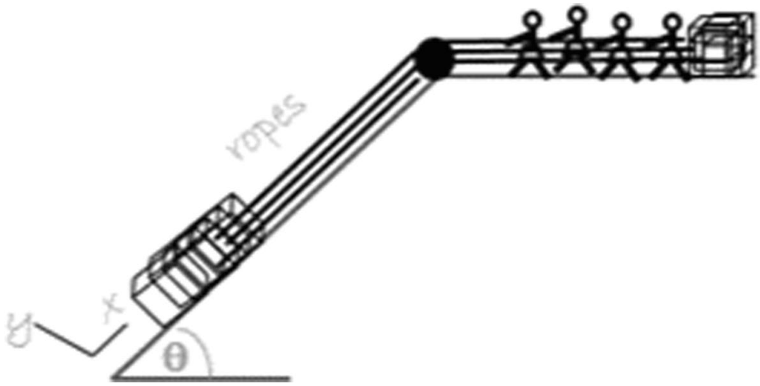

Fig. 3 Final predictions of work done during the construction of the pyramid

Fig. 4 Free-body diagram to support arguments generated

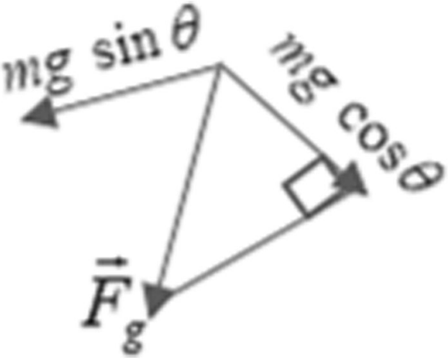

Table 1, the instructor constantly challenged the Exp-group to provide reasons for their claims/counterclaims, to pose thought-provoking questions, to persuade their classmates, who serve as critical friends and to provide evidence or data to support or refute opposing viewpoints.

Comparison of Student Teachers' Responses to Ill-Defined Problems SP-Q2

Five student teachers in the Ctrl-group reported closely related problem-solving strategies and some arguments that included text structures such as if/then/but/therefore to support their solutions to Task SP-Q2 (Table 6, Fig. 1), as did most of their peers in the Exp-group. However, the extent to which they presented arguments in support of their solutions based on the four outcome variables differed markedly from their peers in the DAI-based class, who consistently presented better arguments and used reasoned evidence to support their solutions. Considering that a problem solver may frame ill-structured problem-solving strategies differently based on his or her knowledge, experience, and/or insight into the problem context, the final solutions produced by the Ctrl group showed some inconclusive reasoning episodes. According to the final proposed solutions of SP-Q2 presented by the Ctrl-group, some incompatible excerpts of invalid scientific knowledge found in their solution scripts suggest they considered the problem statement superficially without adequately defining the problem context or exploring it using reasoned arguments. Their lack of experience with argumentation instruction may account for the discrepancy. By engaging students in argumentation instruction while learning physics concepts, they can develop complex learning skills that will assist them in their future workplaces and in everyday life (Iwuanyanwu, 2022). Due to space limitations, only a few subgroup presentations were selected to show how students developed problem-solving strategies, made and defended arguments, and developed reasoned solutions to item SP-Q2. The question was as follows: *how did the ancient Egyptians move the blocks up and into position when building the Great Pyramid?* For simplicity, a student teacher is referred to as 'ST.'

Excerpt 1: Subgroup 3 Presented, Subgroup1 Responded

> ST33: The question says: …in building the Great Pyramid, how did the ancient Egyptians move the blocks up and into position?
> ST77: The Pyramid has a shape of a prism block…how they moved the blocks up is a mystery…
> ST33: …but we can't simply say the problem belongs to mystery…
> ST49: I have been looking at the Pyramid image, I think they probably moved the blocks up the side of the Pyramid using a rope…
> ST61: How is that possible? …how did they build the side of the Pyramid then, to now use it to support the upward movements of the blocks?
> ST49: …they probably started from the foundation to get to a height that requires to pull the blocks up and into position
> ST49: Here is my sketch, the rope is parallel by the opposite link…
> ST33: …they probably had no machines, like crane, so those men pulling the rope must be able men to pull 2000–3000kg block up there against gravity (Fg) and frictional force (f_f)…how many men could have done so?
> ST61: …certainly, it will depend on how strong the men were…and the magnitude of force each man could produce

ST77: That I agree, even so one wonders how they managed to secure the block against gravity and frictional force that Mercy was alluding to…

ST49: … with the frictional force downward the plane to oppose the pending motion… one can say from Newton's second law that $F - mgsin\theta - f_s$

ST61: The block could have been secured to a wood sled or something and …is pulled by multiple ropes
ST49: So, are you saying that one rope…a strong rope will not do the job?
ST77, ST33: …definitely not, Dawson …think about 2000-3000kg…

ST49: Therefore, with multiple ropes once the block began to move upward, one expects.$F = \mu_s mg\cos\theta + mg\sin\theta$

ST77: When the block is on the verge of moving the pyramid side, the static friction: $f_s = f_{s\ \mathrm{max}}$
ST61: It makes sense then from this
ST33: So, the blocks could have been pulled up into position by teams of able men as Dawson said from the beginning…no evidence is available to suggest exactly how many men did so
ST49: Yeah

For student ST61, the premise presented by Dawson (ST49) suggesting that "the builders of the Great Pyramid probably used ropes to move the blocks up the side of the pyramid" (ST49) led him to ask, "…how did they build the side of the pyramid then to use it now to support the upward movements of the blocks?" His search for warrant was simply to point out that 'facts' are the arguments that can be made to support the premise. However, to make sure he understood the context, ST49 tacitly constructed his initial problem strategies and asked his group to identify and explore possible limitations. Available research suggests that ST49 is aware of the activity at levels of different cognitive styles, prior knowledge, experience, and reasoning ability (Jonassen, 2011; Osborne, 2010), and it is this level of awareness of the activity that is most likely to have an impact on him (Redish & Kuo, 2015) and lead to internalization (Adams & Wieman, 2015).

As can be seen, their arguments relate to important components of the kinematics and dynamics of the movements of objects. This supports the assumption that it would have required teams of capable men to lift 2000 to 3000 kg blocks of stone against gravity and the force of friction and move them into position, since machines such as cranes did not exist in those years (descriptive claim of ST33). Since there is much to consider, and after refuting her colleague's initial claim that "getting the blocks up and into position is a mystery" (ST77), she colored her thoughts with Newtonian concepts—how many men did it take? In response, ST61 added that it certainly depends on the strength and power that each man can muster. In fact, as part of the solution path, his argument holds that "… several ropes could have been used to move the blocks upward, which explains the connection between epistemological optimism and the later inclusion of "$F = \mu_S mg\cos\theta + mg\sin\theta$." After looking at some major components of the problem, they concluded that "…the blocks could have been pulled into position by teams of capable men …but in terms of the hard core, there is no indication of exactly how many men did this."

According to the findings of this study, approximately 27 students who received DAI lessons and 11 students who received expository lessons completed 9 of the 17 tasks at a level that met all four dependent variables tested. The remainder from both groups were unable to dismiss the potential conflicts inherent in the ill-defined structured tasks as unimportant or the whim of mythical science. Although Shin et al. (2003) argued that students can solve unstructured science problems using general strategies if they are aware of or have sufficient knowledge about the problem domain, the current study adds that in order to solve unstructured problems and formulate reasoned solutions, students must be able to formulate and defend arguments that support their solution paths/strategies.

In terms of initiating and reflecting on alternatives, constructing arguments, evaluating, and reasoning, most students were idiosyncratic on some of the unstructured problems in the area of force and motion as they occur in everyday life. They were unable to identify with the meanings articulated by their classmates, who serve as critical friends. Other studies have shown that successful solvers of unstructured problems need to justify their decision about selected strategies in order to generate plausible or acceptable solutions (Belland et al., 2011; Gürel & Süzük, 2017; Syafril et al., 2021). While some of the students in the current study attempted to justify the decisions that led to the formulation of problem-solving strategies, some others did not do so satisfactorily. As a result, this study shows that the creation and defence of arguments to develop a reasoned solution to an unstructured scientific problem occurs through processes controlled by conditions that include students' existing knowledge, reflective judgement, and subject-specific knowledge. Although not all student teachers were able to integrate expertise arguments and reasoning skills when they were needed to construct valid problem-solving strategies, the arguments and justifications generated from the completed worksheets indicated that they were motivated to engage in the activity as critical friends (e.g., ST11, ST27, and ST8).

Conclusion

This study has described an interesting type of science learning that fuses explicit teaching of science knowledge with student solving of unstructured problems. It has also provided compelling data showing how dialogic argumentation instruction can help foster students' thinking when they must make and defend judgments about different sides of issues, thereby contributing to the extant literature (Erduran & Park, 2023; Evagorou & Osborne, 2013; Tarekegn et al., 2022). The results of the current study are consistent with other research evidence demonstrating the efficacy of dialogic argumentation instruction for cultivating scientific knowledge among students and teachers (Asterhan & Schwarz, 2007; Iwuanyanwu & Ogunniyi, 2020; Lubben et al., 2010; Ogunniyi, 2022).

Additionally, the current study supports the claims of Erduran and Park (2023) and Gürel and Süzük (2017) that argumentation instruction plays a more prominent role in assisting student teachers to better understand physics concepts and solve related problems. To some extent, the use of dialogic argumentation instruction appears to have helped students in the Exp-group mobilize better strategies for solving scientific problems. For example, the underlying assumptions they made about the four variables listed in Table 1 all showed indicators of shared tacit knowledge, sharing of cognitive discourse and understanding among their classmates. In addition, the group was generally enthusiastic about the intervention program delivered via DAI, except for the few who found the repetition of the stages of the four variables tedious when solving problems individually. Nonetheless, students need argumentation skills and knowledge to solve complex problems such as those encountered in everyday life.

Finally, this study has shown that engaging student teachers in dialogic argumentation instruction can help them improve their ability to think, reason, and solve different types of problems related to subject knowledge and socio-scientific contexts, which are essential skills for the science teaching profession. It should be noted that the results of this study may be affected by some limitations. Primarily, this was a case study of physics student teachers from a single institution taught by different instructors. Generalizations of the results to the entire population of university science students should be made with caution. For example, the study lasted only 12 weeks and included only 79 students. Therefore, a study with larger samples is recommended before implementing the approach on a large scale.

Funding Open access funding provided by North-West University.

Declarations

Conflict of Interest The author declares no competing interests.

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