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Assessing and Enhancing Pre-service Science Teachers' Self-Efficacy to Teach Science Through Argumentation: Challenges and Possible Solutions

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Abstract The purpose of this study was to explore the impact of an intervention on pre-service science teachers' self-efficacy to teach science through argumentation and explore the challenges they experienced while implementing argumentation. Forty pre-service science teachers in their final semester of schooling participated in an intervention that lasted for 11 weeks. Intervention focused on participants' understanding of argumentation as a scientific practice and as a pedagogical tool. The participants engaged in argument construction, evaluation, and critique, taught three argumentation lessons, engaged in peer observation of teaching, and reflection on their teaching skills. Data were collected through Argumentation Self-Efficacy Scale and an open-ended questionnaire. The results show that the intervention had a significantly positive effect on pre-service teachers' self-efficacy. Despite this reported self-efficacy, participants experienced significant challenges in guiding their students to construct scientific arguments and assessing the arguments developed by their students. Discussion focuses on implications for professional development of pre-service and in-service science teachers.

Keywords Argumentation · Chemistry · Pre-service science teachers · Pedagogy · Science · Self-efficacy

An increasing number of scholars are pushing the agenda for integration of argumentation in school science curricula in recent years (Berland & Reiser, 2009; Duschl, Schweingruber, & Shouse, 2007; Osborne, Simon, Christodoulou, Howell-Richardson

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& Richardson 2013; Sampson & Blanchard, 2012). This interest in pushing for more structured and purposeful integration of argumentation in science classrooms is based on the assumption that argumentation makes positive contributions to students' conceptual understanding of core scientific ideas covered by curriculum (Berland & Reiser, 2009; Kuhn, 2010; Zohar & Nemet, 2002; von Aufschnaiter, Erduran, Osborne & Simon, 2008). First, scholars argue that the activity of attempting to justify claims to knowledge through reasoned discourse should foster the process of knowledge construction (Erduran & Jimenez-Aleixandre, 2008; Kelly & Chen, 1999). It is believed that when students engage in reasoned discourse, they are also engaged in metacognition, which in turn fosters negotiation of ideas based on alternative explanations drawn from experience (Erduran & Jimenez-Aleixandre, 2008). The second argument asserts that because students are challenged to explore the relationships between a set of related ideas more deeply during argumentation, they develop a deeper comprehension of concepts under investigation (Mercer, Dawes, Wegerif & Sams, 2004; von Aufschnaiter et al., 2008). Third, scholars argue that argumentation helps students to appropriate the language of science and thus help them to make sense of the concepts and processes of science more meaningfully (Lemke, 1990). Support for the impact of argumentation on learning is not limited to theoretical justifications. Several case studies in science education have empirically supported the positive impact of argumentation on student learning (Venville & Dawson, 2010; Zohar & Nemet, 2002).

In spite of the reported benefits of argumentation in student learning, current literature from across different countries indicates that students are rarely given the opportunities to participate in argumentation-based learning (Christodoulou & Osborne, 2014; Cross, Taasoobshirazi, Hendricks & Hickey, 2008; McNeill, 2011; Osborne, Erduran & Simon, 2004; Venville & Dawson, 2010). This is partly due to the fact that most teachers do not have a sophisticated understanding of scientific argumentation, lack pedagogical knowledge and skills to teach science through argumentation (McNeill & Knight, 2013; Osborne et al, 2004; Sampson & Blanchard, 2012).

Review of Relevant Literature

The science education reform documents and science education studies that have been published within the last three decades have emphasized the importance of engaging children in the discourses and practices of science such as argumentation (Erduran & Jime'nex-Aleixandre, 2008; Sampson & Blanchard, 2012). This call to integrate argumentation in science learning activities has "raised the stakes for science teachers and science teacher educators who prepare them" for the classroom (Zembal-Saul, 2009, p. 1). As a result, science teacher educators have worked on ways to empower pre-service science teachers with knowledge and skills needed to teach science through argumentation.

Erduran, Ardac & Yakmaci-Guzel (2006) worked with 17 pre-service Turkish science teachers in an effort to develop pre-service science teachers' pedagogical knowledge of argumentation using the IDEAS (Ideas, Evidence and Argument in Science Education) pack (Osborne et al., 2004). The authors trained pre-service science teachers over 6 weeks using the IDEAS pack. Each training session lasted for 90 min and focused on empowering pre-service science teachers to place an emphasis on

students' use of evidence in supporting their claims through video exemplars of good practice in the IDEAS pack. Following the training sessions, the participants were given 2 weeks to develop an argumentation lesson around a core chemistry topic consistent with the school curriculum. After 3 weeks of lesson planning, the participants were required to implement their lessons in actual classrooms. The authors videotaped these teaching episodes and used a variety of data, including teacher talk, students' lesson plans, and arguments as sources for their analyses. The results of their study showed that while the participants varied in the way they implemented argumentation in their teaching, all participants used argumentation in their teaching. The authors concluded that short-term training of pre-service teachers resulted in attainment of intended pedagogical and learning outcomes (p.11). However, the authors questioned the sustainability of the motivations and abilities of these teachers to implement argumentation-based lessons in their future classrooms.

Zembal-Saul (2009) worked with pre-service elementary science teachers through project *TESSA: Teaching Elementary School Science as Argument* to help pre-service science teaches acquire dispositions, knowledge, and skills to teach science through argumentation. She exposed pre-service science teachers to TESSA cases, which required them to construct scientific arguments in the context of a methods course. She used pre-service science teachers' responses to six TESSA cases as a measure of their ability to view science teaching as argument. The participants were shown a series of activities in which the students investigated the relationship between air and air pressure. The interns were then asked to answer a set of questions related to the video to capture their thinking related to teaching science as argument. The analyses of data showed "important shifts" in participants' thinking in terms of teaching science as argument. For instance, when talking about the purpose of scientific investigations, the participants started to place an increased focus on the role of evidence and argument. More precisely, the authors reported that by the end of the course, about half of the participants started to view scientific investigations as a means to collect data for constructing evidence-based explanations. In addition, the participants started to experience a shift in their thinking about the role of investigation-based science activities in the classroom. While the majority of the participants viewed the purpose of investigation-based learning activities as collecting data and testing hypotheses at the beginning of the study, more than half of the participants started to see the purpose of these activities as learning about science concepts and science itself. Finally, they found that more than half of the participants started to value the importance of having students to construct scientific explanations from evidence and emphasized the importance of classroom discourse in facilitating students' learning of science.

Simon, Johnson & Johnson (2008) used the portfolio and reflection approach to enhance science teachers' pedagogical knowledge of argumentation in Israel. The authors used portfolios to create opportunities for two dieds of teachers to share ideas, resources, and engage in critical reflection as well as to monitor the growth of their accomplishment in the teaching science through argumentation pedagogy. The participants were asked to gather evidence of how they interpreted expert advice as conveyed through curriculum materials and put the recommendations of experts into practice and share their reflections on their practice. The authors analyzed the participants' portfolios to see whether the participants had successfully taught science through argumentation. More specifically, the authors searched for examples of argumentation practice, the

reasoning that the participants used to select specific evidence and other kinds of evidence to see whether there is growth in teachers' pedagogical knowledge of argumentation. The authors concluded that four teachers who participated in the study made progress towards adopting instructional strategies that are more aligned with argumentation but could not suggest such conclusions with high level of confidence. The authors noticed that those teachers' levels of experience and responsibilities within their schools motivated each teacher in different ways to use argumentation in their teaching. The authors concluded that while portfolios served to be a useful tool for learning about how reflective teachers were they did not help the authors to answer the question of whether the teachers implemented argumentation successfully in their classrooms.

Cutting across all these three studies is the message that helping teachers to adopt a pedagogical innovation and to develop capacity for its implementation is not an easy task. This is not surprising because understanding the philosophy of a particular instructional practice, appropriating its norms in the classroom, and successfully implementing it takes time and requires experience (Osborne et al., 2013). For instance, Ratcliffe, M., Hanley & Osborne (2007, as cited in Osborne et al., 2013) found that it took 2 years for science teachers to become familiar with the goals of a new junior high school curriculum and the instructional practices encouraged by the new curriculum. Despite some challenges, these studies show that short-term interventions can have limited yet positive impacts on pre-service science teachers' knowledge and practice.

Successful implementation of a pedagogical innovation is not a simple matter of developing the knowledge; it is also about developing agency to enact that knowledge (Simon et al., 2008). One way to help teachers achieve agency is by increasing their self-efficacy (Bandura, 1997). Given the definition of self-efficacy being "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (p. 3), there is consistency between agency and self-efficacy (Zimmerman & Clearly, 2006). More important, self-efficacy beliefs are found to influence motivation (cf. Maehr & Pintrich, 1997) and student achievement (Anderson, Greene & Loewen, 1988; White, 2009). Given the importance of self-efficacy for teaching and learning, we designed this study to improve pre-service science teachers' self-efficacy to teach science through argumentation. The research questions that guided our inquiry are the following:

1. What are the effects of a methods course designed around argumentation on pre-service science teachers' self-efficacy to teach science through argumentation?
2. What are the self-reported challenges faced by pre-service science teachers when teaching science through argumentation and perceived solutions to these problems?

Theoretical Framework: Self-Efficacy Theory

The theoretical framework guiding this inquiry is self-efficacy (Bandura, 1997). Self-efficacy is defined as belief in one's ability to successfully accomplish a task under specific conditions (Bandura, 1997). This theory suggests that an individual's perceptions of his or her abilities to perform an action/task such as teaching science through

argumentation to bring about an outcome influences that individual's effectiveness or success. In fact, science educators have previously used this theory in various contexts (Avery & Meyer, 2012; Cantrell, Young & Moore, 2003; McKinnon & Lamberts, 2014; Palmer, 2006). For instance, Avery and Meyer (2012) looked at the impact of an inquiry-based science course on pre-service elementary teachers' self-efficacy for science and science teaching. The authors report that the course made a positive influence on participants' self-efficacy for science and to teach science. Palmer (2006) used a similar intervention with 55 pre-service elementary teachers to see if the intervention would improve participants' self-efficacy to teach science. He also reported significantly positive changes in participant's self-efficacy as a result of their participation in the course. These studies show that well-designed short interventions can produce positive changes in teachers' self-efficacy beliefs.

According to Bandura, several experiences contribute to a person's self-efficacy. These include mastery experiences, vicarious experiences, and verbal persuasion.

Mastery experiences are considered to be the most important factor contributing to a person's self-efficacy. Bandura (1997) argues that individuals are more likely to attempt something new and have a higher sense of capacity to accomplish the task if they have had a similar successful experience in the past. It follows that in order for teachers to develop a positive self-efficacy towards teaching science through argumentation, they must have experiences in constructing, defending, evaluating arguments, as well as experiences in teaching science through argumentation. We provided all of these experiences as described in the intervention section under methods.

Vicarious experiences component refers to the experiences when an individual observes behaviors being modeled or practiced by someone else who may have a similar responsibility as the observer does. When the observer watches someone perform a task that is expected of the observer as well, she/he develops beliefs regarding his/her ability to successfully perform the same behavior (Bandura, 1997). This suggests that in order to help pre-service science teachers to develop high self-efficacy to teach science through argumentation, they must watch others teach science through argumentation. We provided such experiences through engaging them in argumentation-based learning, observations of peer- teaching in class as well as peer evaluation of teaching during the implementation of the argumentation lessons.

Verbal persuasion relates to the feedback regarding performance and capability provided by a respected authority (i.e., teacher) (Bandura, 1997). Bandura states "People who are persuaded verbally that they possess the capabilities to master given tasks are likely to mobilize greater effort and sustain it than if they harbor self-doubts and dwell on personal deficiencies when difficulties arise" (Bandura, 1997, p. 101).

Physiological states refer to emotional and physiological arousal while performing or participating in a task. Depending on whether this arousal is positive or negative, self-perception of competence will be influenced (Bandura, 1997). Negative physiological states caused by factors such as stress, anxiety, worry, and fear can negatively impact self-efficacy and may lead to perception of lack of capability to perform the task successfully (Pajares & Schunk, 2001). In this study,

we addressed this by helping the participants to understand that failure is part of learning to teach and that with time and experience, they would develop sufficient pedagogical competencies to teach science through argumentation.

Methodology

We used a mixed methodology in this inquiry. A mixed methods approach is the integration of both quantitative and qualitative methods for the purpose of gaining an in-depth understanding of a research problem (Greene, 2007). First, we developed and administered a self-efficacy survey to quantitatively measure our participants' self-efficacy. Second, we administered an open-ended questionnaire (1) to explore the challenges experienced by our participants while implementing argumentation lessons and (2) to elicit possible solutions to these challenges from our participants.

Context and Participants

The participants were 40 pre-service elementary science teachers-seniors, chosen from an elementary teacher education program in Turkey. The sample was largely female; females (n=29, 72.5 %) and males (n=11, 27.5 %). The mean age of the participants was 22.50 years (sd=1.01). The participants were selected through purposeful sampling. In our sample selection, we wanted to work with pre-service teachers who had taken sufficient number of required content and pedagogy courses and experience with practicum in the local schools.

Pre-service teachers take science content courses such as General Chemistry I, II, III, IV Special topics in chemistry as well as the associated chemistry laboratory courses during the first five semesters. The students then take science method courses (i.e., instruction principles and methods, teaching technologies and planning materials, classroom management, special topics in chemistry, scientific research methods, science technology and planning, special teaching methods I and II, special laboratory application I and II, measurement and evaluation, school experience, guidance, special education) in the last 2 years.

Students also take an elective content course: in this case, the "experimental design and application in chemistry" course in their final semester while completing their practicum. This course was designed based on the need for pre-service science teachers to develop argumentation-based pedagogical knowledge after argumentation became part of the reformed Turkish Science and Technology curriculum in 2013. The details of the course are described in the intervention section.

Intervention

Consistent with the goal of the course, the purpose of this research project was to improve pre-service science teachers' self-efficacy to teach science through argumentation. More specifically, we were interested in helping pre-service science teachers to understand science as argument, communicate the meanings and structures of scientific arguments, rationalize the importance of teaching science through argumentation, help them articulate the pedagogy of argumentation, familiarize them with the structures/

frameworks for engaging students in construction, evaluation, and critique of scientific arguments, provide opportunities for them to evaluate written scientific arguments so they could become familiar with the weaknesses and strengths in written scientific arguments.

To address all of these goals, our intervention consisted of several stages and involved different activities. First, participants were exposed to argumentation both from a scientific practice and a pedagogical perspective through article readings and follow-up interactive powerpoint presentations. The students were asked to discuss the points highlighted in the presentations in groups of four for every session. Then, participants were put into groups based on their preferences. Three groups included four members, eight groups included three members, and two groups included two members. After the participants were placed in different groups, they were required to develop an argumentation-based chemistry lesson plan (see Appendix F for a sample lesson case), teach a minimum of three argumentation-based lessons in their practicum, and evaluate the arguments developed by their students. The students were given the freedom to choose their chemistry topic as long as their lesson focused on teaching a scientific idea covered by the formal curriculum appropriate for the grade level.

The pre-service teachers were trained about argumentation for 3 weeks. Each training session was conducted twice a week and lasted for 45 min. Sessions included a short powerpoint presentation, highlighting different aspects of argumentation-based teaching as described above: a follow-up discussion, argument construction practice, and within-group verbal argumentations. For instance, we introduced the participants to different argumentation frameworks: the TAP Framework (Erduran, Simon & Osborne, 2004), the CERR Framework to help the participants better understand the nuances of both written and verbal arguments. In addition, we engaged the students in collective analyses of sample of students' written arguments reported in McNeill and Krajcik (2011).

Following the training sessions, the groups were given 2 weeks to develop an argumentation-based lesson around a chemistry topic—consistent with standards and one that they could implement in their practicum schools. The participants were provided with sample argumentation lessons and a template (see Appendix F) for them to design their argumentation cases and lessons (a universal design lesson plan template was also provided). The purpose of this template was to provide the scaffolding needed for the participants to develop their lessons. The sample argumentation cases were developed from existing sources (see Appendix F for an example). During the planning phase, pre-service teachers were in constant communication with the instructor of the course and were provided feedback when needed. After the planning phase, they were asked to implement their argumentation lessons to their peers in class. The in-class mini argumentation lesson presentations/implementations lasted for the following 6 weeks. Both the course instructor and the peers provided feedback after each implementation with the goal of helping pre-service science teachers to develop efficacy to teach science through argumentation. Finally, pre-service teachers implemented three argumentation-based lessons in their practicum schools. Participants implemented these lessons over the course of 3 weeks. Consistent with schools' bell schedule, each lesson lasted for 40 min.

The participants developed one of the lessons and two were adopted from existing sources and given to them by the instructor (please see the list of topics covered in each

of the lesson in Appendix E). Their peers observed the participants during their lesson implementations using a guideline given to them by the instructor (see Appendix D). The purpose of this peer evaluation was: (1) for the implementer to receive feedback and (2) for the observer to see the points of possible challenges while implementing an argumentation-based lesson and thus develop an insight about possible solutions to the observed challenges. Finally, all participants were required to evaluate their students' written arguments using the CERR framework (McNeill & Krajcik, 2011). The purpose of this requirement was to help the participants to both identify weaknesses and strengths in students' arguments as well as to help them develop assessment skills in argument evaluation. We required our participants to use the CERR Framework (Appendix F) for two reasons. First, it provided a nice scaffold for the learners to most effectively engage in construction of scientific arguments. Second, the CERR rubric for evaluating written arguments was better suited for the participants. It gave them a better structure for evaluating their students' arguments. Bransford, Darling-Hammond & LePage (2005) state that in order to accelerate teacher learning, we must "provide frameworks for helping teachers organize their knowledge and their thinking" (p. 3). In the context of this study, the CERR framework served that purpose.

Data and Data Collection

Two data sources contributed to the findings of this study: participants' answers to the Argumentation Self-efficacy Scale (Appendix A) and participants' responses to the open-ended questionnaire (Appendix C).

The Argumentation Self-efficacy Scale was adopted from (Bekiroğlu & Aydeniz, 2013). The scale consists of three parts and includes 30 items (see Appendix A). Six items of the scale focus on argument development (planning) efficacy: 19 items are related to the lesson implementation (instruction) efficacy and 5 items are related to assessment of students learning during argumentation. The rating range for all of the questions was from "strongly disagree" to "strongly agree" and presented in a 1–5 Likert scale. (1=strongly disagree, 2=disagree, 3=somewhat agree, 4=agree, and 5=strongly agree). To test the reliability of the scale, we calculated Cronbach's alpha. Cronbach's alpha is a measure of internal consistency, that is, it tells us how closely related a set of items are as a group. The results of our analyses showed that Cronbach's alpha for pre-test was (α=0.826) and (α=0.930) for the post-test.

Typically, an alpha score of 0.60 or higher is considered to be an acceptable measure of internal consistency (George & Mallery, 2003). While the alpha values for some subscales in the pre-test are lower than 0.60, the overall scale values are higher than 0.80, which is considered to be a good indication of internal consistency. In the post-test, the only (α) value that is at 0.60 is the assessment dimension (see Table 1). Perhaps, this is due to the low number of items in this dimension. We also tested for the correlation between pre- and post-tests. Our calculations resulted in a correlation value of 0.471 between pre- and post-tests (see Table 2). This also contributes to the internal consistency of our scale.

The open-ended questionnaire (Appendix B) included items that aimed to explore specific challenges that the pre-service teachers experienced in implementing argumentation lessons, the specific challenges their students experienced in constructing scientific arguments and the possible solutions offered by the pre-service science teachers.

Table 1 Cronbach's alpha values

Test	Dimensions	*N* items	Alpha (α)
Pre-test	Total self-efficacy	30	0.826
Post-test	Total self-efficacy	30	0.930
Pre-test	Planning	6	0.445
Post-test	Planning	6	0.834
Pre-test	Instruction	19	0.763
Post-test	Instruction	19	0.915
Pre-test	Assessment	5	0.474
Post-test	Assessment	5	0.598

Collectively, these two instruments provided sufficient evidence for us to draw conclusions about our participants' self-efficacy to teach science through argumentation (Table 2).

Data Analyses

To measure the effect of the intervention on participants' self-efficacy to teach science through argumentation, we used the paired samples *t* test, the results of which are discussed in the next section. A paired sample *t* test was used to determine whether there is a significant difference between the mean values of the same measurement under two different conditions. Using a paired *t* test has much more statistical power when the difference between groups is small relative to the variation within groups (Abbott, 2011).

To explore the specific challenges that the pre-service science teachers experienced in teaching science through argumentation, and to identify solutions to address these challenges by the participants, we conducted content analyses of participants' responses to the open-ended questions in the questionnaire. Both authors are pre-service science teacher educators with years of teaching and research experience. They have analyzed both quantitative and qualitative data before and have published in peer-reviewed journals both independently and in collaboration with other colleagues.

First, each author independently explored the themes that emerged from participants' responses. There was a 70 % consistency between the two authors thematic

Table 2 Paired samples correlations

Dimensions of self-efficacy scale	*N*	Correlation	*p*
Pre-self-efficacy and post-self-efficacy	40	0.47	0.002
Pre-planning and post-planning	40	0.32	0.045
Pre-implementation and post-implementation	40	0.49	0.001
Pre-assessment and post-assessment	40	0.40	0.012

coding after the first reading. The two authors then discussed the emerging themes and came to a consensus on the core themes. Then, the two authors re-evaluated the participant responses. Finally, we calculated the frequencies of occurrence for each theme and reported them in graphs.

Findings

The results of paired samples *t* test show that participants made significant improvements in their self-efficacy to teach science through argumentation. The mean score went up from 3.47 to 3.83 between pre- and post-tests with a large size effect ($d>0.08$) (see Appendix B). The scale consisted of three parts: planning, implementation, and assessment. The participants made greater improvement in the assessment dimension of the scale. The mean score for the assessment dimension went up from 3.29 to 3.75 between pre- and post-tests with a large size effect ($d=0.80$). The mean score for the planning dimension went up from 3.52 to 3.88 between pre- and post-tests with a medium size effect ($0.05<d<0.08$). The mean score for the implementation dimension went up from 3.50 to 3.83 between pre- and post-tests with a medium size effect. Overall, students made significant improvements in all dimensions of the self-efficacy scale. Table 3 provides a summary of the results.

Findings from Open-Ended Questions

We explored two areas of possible concerns through open-ended questions and participants' proposed solutions through an open-ended questionnaire post-implementation. First, we explored the types of challenges they experienced while implementing argumentation lessons and the solutions they proposed to address these challenges. Second, we explored the challenges that the participants experienced while assessing their students' written arguments. We were most interested in participants' ability to identify possible difficulties associated with implementing argumentation and assessing the efficacy of the solutions proposed by them.

Table 3 Paired samples *t* test results

Group	*N*	*M*	SD	*df*	*t*	*p*	*d*
Pre-test of self-efficacy	40	3.47	0.35	39	−4.785	<0.001	0.81
Post-test of self-efficacy	40	3.83	0.52				
Pre-test of planning dimension	40	3.52	0.45	39	−3.548	<0.001	0.66
Post-test of planning dimension	40	3.88	0.63				
Pre-test of implementation dimension	40	3.50	0.36	39	−4.085	<0.001	0.69
Post-test implementation dimension	40	3.83	0.57				
Pre-test of assessment dimension	40	3.29	0.54	39	−0.0670	<0.001	0.80
Post-test of assessment dimension	40	3.75	0.60				

The Challenges of Implementing Argumentation

Participants identified nine main challenges that they experienced while teaching science through argumentation. These expressed challenges and the frequency of their occurrence are summarized in Fig. 1.

The results show that pre-service teachers experienced unique difficulties in teaching science through argumentation. The most frequently cited reasons for these difficulties include (1) students' lack of understanding about argumentation, (2) gaps in students' conceptual understanding, (3) students' lack of understanding of different components of argumentation, and (4) lack of student ability to write warrants and rebuttals.

In response to these experienced challenges, participants proposed 12 different solutions to address them. While each solution occurred at a different frequency in participants' responses, they provide evidence about their efficacy to teach science through argumentation. A summary of these solutions and their frequency are shown in Fig. 2.

Pre-service teachers proposed 12 solutions to address the reported challenges. The majority believed that they would overcome the reported challenges by (1) addressing the gaps in students' conceptual understanding before engaging them in argumentation, (2) practicing argumentation with students through use of relevant examples, (3) through experience with teaching through argumentation, (4) by having students to research the argumentation topic before engaging them in argumentation, and (5) by using interesting argumentation cases.

In addition to exploring the challenges that the pre-service teachers experienced in teaching science through argumentation, we also wanted to explore participants' observations about the quality of students' arguments and the challenges they themselves experienced in evaluating students' written arguments.

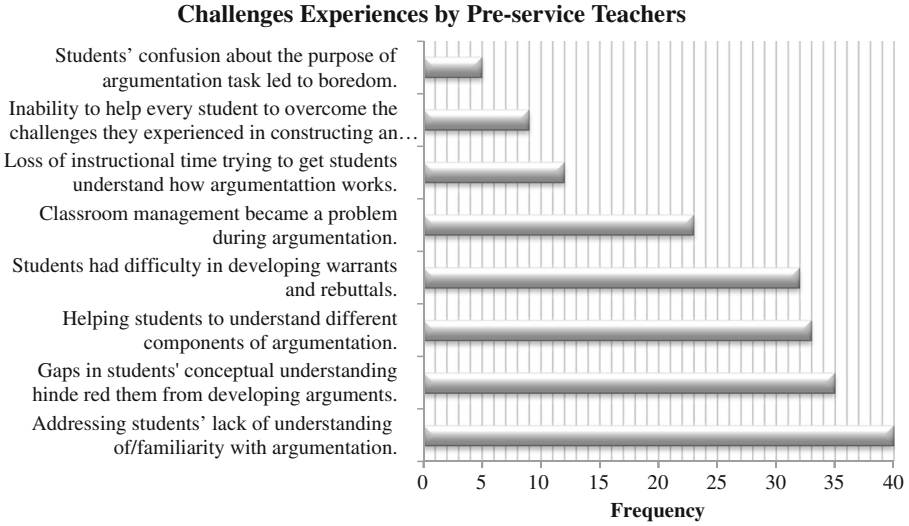


Fig. 1 Challenges experienced while implementing argumentation

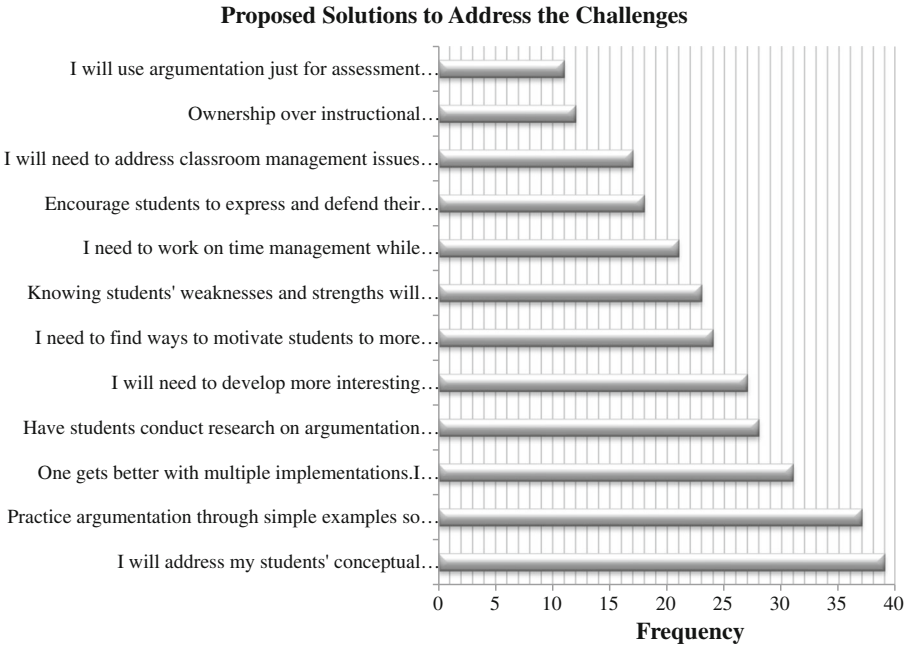


Fig. 2 Proposed solutions and their frequencies

Challenges Experienced by Students

Participants reported six main challenges experienced by their students while constructing scientific arguments. These challenges are reported in Fig. 3.

These results show that students experienced most difficulty in forming quality arguments because they (1) lacked sufficient content knowledge, (2) did not understand the purpose of argumentation, and (3) failed to provide sufficient evidence to back their claims.

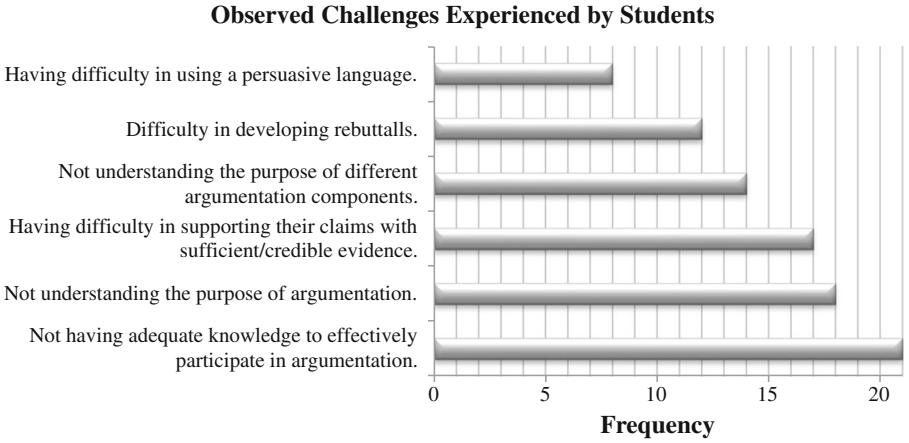


Fig. 3 Observed challenges experienced by students

Challenges in Assessing Students' Arguments

The participants reported five unique challenges related to assessment of students' arguments. These challenges are reported in Fig. 3 below.

The participants experienced significant challenge in assessing students' reasoning, putting students' reasoning, and evidence in different quality categories and evaluating students' justifications (Fig. 4).

Strategies that Can Help Students to Overcome Their Challenges

We also asked the participants to elaborate on strategies that they would use to help their students to overcome the challenges they experienced with learning science through argumentation. They suggested several strategies (see Fig. 5). Participants most frequently cited four main strategies. These include (1) securing students' conceptual understanding before engaging them in an argumentation task, (2) securing students' understanding of argumentation before engaging them in argumentation task, (3) helping students to understand different components of argumentation through examples, and (4) guiding students to more effectively engage in argumentation during group argumentation sessions.

Discussion

In this study, we developed and implemented an intervention informed by assumptions of self-efficacy theory to increase pre-service science teachers' self-efficacy to teach science through argumentation. Our intervention involved (1) convincing the participants of the importance of argumentation in science and in teaching science, (2) providing mastery experiences where they engaged in argument construction, evaluation, and critique, (3) modeling argumentation lessons for them, (4) supporting them in development and implementation of argumentation lessons, and (5) engaging them in peer evaluation of teaching and reflection upon practice. Through these interventions, we aimed (1) to enhance pre-service science teachers' self-efficacy to teach science through argumentation and (2) to explore the perceived challenges faced by pre-service science teachers while teaching science through argumentation.

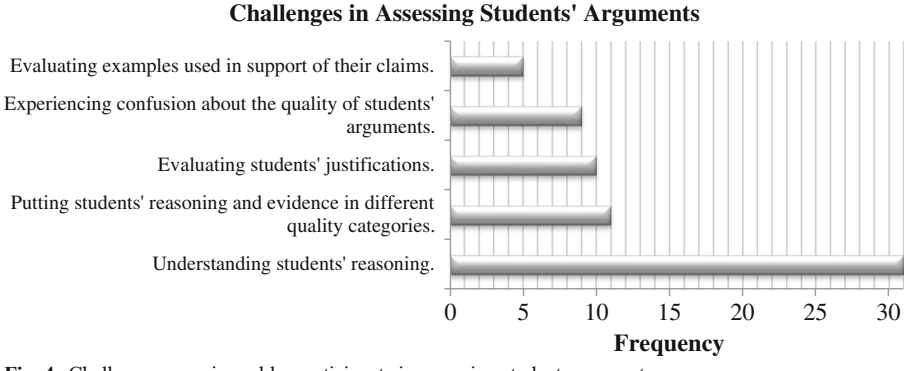


Fig. 4 Challenges experienced by participants in assessing student arguments

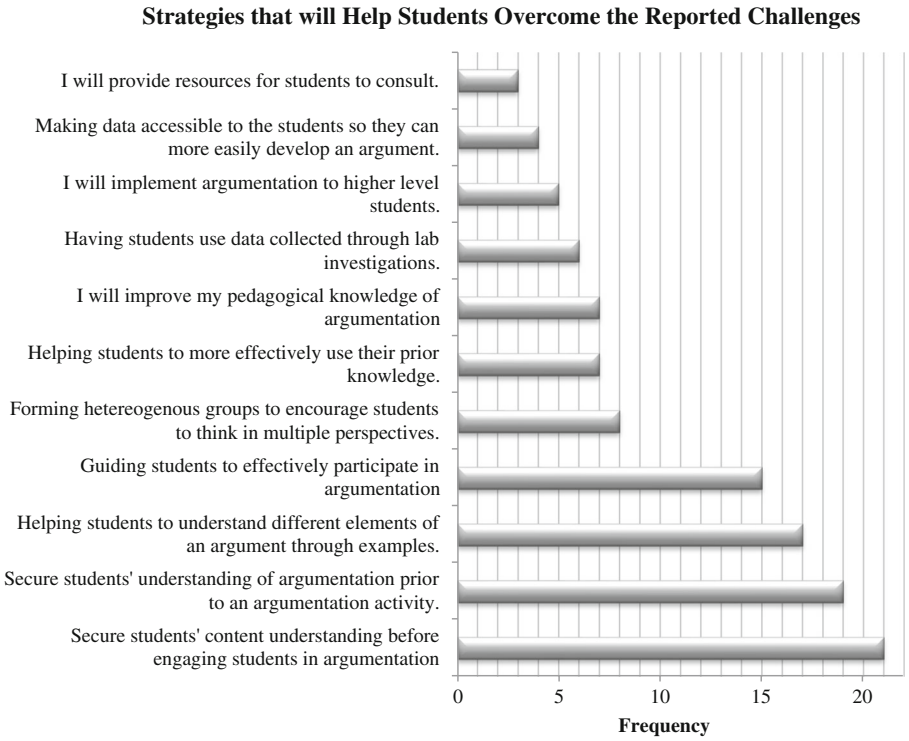


Fig. 5 Strategies that will help students to overcome the challenges

The results point to a significant increase in pre-service science teachers' self-efficacy to teach science through argumentation between pre- and post-test. Several factors might have contributed to this positive outcome. First, pre-service teachers developed a more informed understanding of argumentation as an instructional strategy both from a theoretical and practical perspective. They had not had any exposure to argumentation from a pedagogical perspective up until they took this course nor from a scientific practice perspective. The content of the course might have contributed to participants' understanding of argumentation as well as its value for student learning. The course instruction focused on two aspects of participants' learning related to argumentation: their understanding of argumentation as a scientific practice and their pedagogical understanding of argumentation. The structured reflective group discussions after presentations might have contributed to their enhanced understanding of argumentation. Second, mastery experiences: task of constructing scientific arguments in class, evaluating their peer's argument quality, and critiquing each other's arguments and lessons may have also contributed to participants' increased self-efficacy. However, based on participants' responses to the open-ended questions, we can deduce that implementing argumentation in class made the most contribution to the participants' self-efficacy to teach science through argumentation. This finding is consistent with previous work in self-efficacy. Cantrell et al., (2003) conducted a study to identify factors that contributed to pre-service elementary science teachers' self-efficacy. They found that the factor that gave the rise to largest effect size on the self-efficacy scale was

the amount of time pre-service science teachers spent in teaching science to children in an elementary classroom. The participants who were able to teach science for more than 3 h across the span of their 3-week practicum performed significantly better on the self-efficacy scale than those who did not have such experience.

Through implementing argumentation lessons, pre-service science teachers may have became aware of their limitations as teachers and the challenges that their students experienced as learners. The follow-up in class reflective discussions and peer feedback could have challenged them to think about ways to address their limitations as future teachers and help their students to overcome the challenges they experienced in constructing scientific arguments. The implication for science teacher educators is to provide extended opportunities for implementation of lessons designed in our methods courses. This experience is likely to contribute to their growth as professionals and efficacy as they experience failure, success, and psychological states associated with success and failure.

Participants also reported several challenges that they experienced while implementing argumentation. These include not being able to effectively guide students to use sufficient credible evidence to justify their claims, guiding them to form rebuttals, forming and facilitating group-based learning in the context of argumentation, and assessing students' arguments. This is understandable because this is the first time that these pre-service teachers are implementing argumentation lessons. Some of these reported challenges are related to general instruction (e.g., facilitating group learning), and perhaps, some of them may be related to teachers' ability to frame student thinking in the context of argumentation (Berland & Hammer, 2012). In the absence of effective framing, teachers may not be able to effectively engage students in argumentation. In order to effectively frame student learning, teachers themselves must understand the epistemology of argumentation and develop pedagogical skills (Christodoulou & Osborne, 2014), which comes through experience. One limitation of this study is that we did not observe the participants while they were teaching; we only relied on the self-report data from the participants who answered the questions based on their limited experiences with argumentation in the classroom. While the participants reported several challenges associated with their implementation of argumentation lessons through self-reports, the data may not be enough to support an argument about the difficulties and problems that really happened in classrooms. Therefore, to fully capture the depth and breadth of what actually happened in the classroom, in future studies, these self-reports must be supported with classroom observations and follow-up interviews.

The problems with students' abilities to construct scientific arguments reported by participants are consistent with current literature. For instance, existing argumentation literature also points to the effect of students' prior knowledge on the quality and complexity of arguments constructed by students (Bell & Linn, 2000; Cross et al., 2008; Sadler & Donnelly, 2006; von Aufschnaiter et al., 2008). Thus, our findings suggest that it is difficult for students to develop quality scientific arguments or effectively engage in persuasive arguments without adequate disciplinary knowledge. This is consistent with current literature (Cross et al., 2008; Garcia-Mila, Gilabert, Erduran & Felton, 2013). More important, the pre-service teachers witnessed these difficulties, reflected on them, and collectively sought out possible solutions to help their students overcome such challenges. For instance,

they emphasized the importance of teaching their students the language of argumentation, disciplinary knowledge, and practice argumentation tasks that did not require disciplinary knowledge. This awareness is important in that it can help the teachers to constantly monitor their students' abilities to construct arguments and provide the necessary scaffolding in helping them to cruise through a learning progression for developing increasingly sophisticated arguments (Berland & McNeill, 2010). However, teachers themselves will need to cruise through this learning progression that is the progression of learning to teach science through argumentation. We argue that in order for teachers to successfully move through this progression, they will need to develop more sophisticated understanding of argumentation as a scientific practice, and pedagogical knowledge needed to teach science through argumentation. While some of this learning can be gained through experience, especially beginning teachers will need more structured support to develop pedagogical proficiency. For instance, participants reported that they experienced the most difficulty in assessing students' arguments. Experience alone may not be sufficient for the teachers to develop proficiency in argumentation to assess the quality of their students' arguments.

In addition to reporting the challenges that they experienced during the implementation of argumentation lessons, participants also elaborated on possible solutions to address these challenges in their future teaching. However, the solutions proposed by pre-service teachers are superficial in that the content of the solutions appears to be a description of the objectives. The challenge for science teacher educators is finding ways to help pre-service science teachers to achieve these objectives. Limited yet emerging research shows that in order for pre-service and in-service science teachers to develop adequate pedagogical knowledge and skills to teach science through argumentation, they must first understand the underlying philosophy both from a learning sciences and scientific practice perspectives (Erduran & Jimenez-Aleixandre, 2008; Christodoulou & Osborne, 2014; Osborne et al., 2013). Second, they must understand argumentation-based teaching through lesson design activities, teach science through argumentation, assess student work, and engage in ongoing and meaningful reflection about their practice as well as the work their students produce (Berland & McNeill, 2010; Zembal-Saul, 2009).

To help pre-service and in-service teachers to develop self-efficacy, science teacher educators must continue to work on developing effective professional development models to address science teachers' professional needs (Zohar, 2008). Some colleagues, Simon, Erduran & Osborne (2006) and McNeill & Knight (2013), have developed and implemented effective professional development models. Similarly, some colleagues have developed curriculum resources (Osborne et al., 2004; Sampson et al. 2014) in support of teaching science through argumentation. Wide adoption of these successful practices and resources can increase science teachers' self-efficacy to teach science through argumentation and thus help make argumentation a prevalent practice in science classrooms across grade levels.

Several conclusions can be drawn from this study. First, pre-service teachers can develop self-efficacy to teach science through argumentation. However, it must be noted that in order for this to happen, researchers should focus both on

teachers' understanding of argumentation as a scientific practice and argumentation as a pedagogical tool. Second, in order for teachers to develop self-efficacy, they must engage in mastery experiences such as constructing, evaluating arguments, and teaching through argumentation. Third, prolonged engagement with mastery practices and collective reflection upon experience may be a key to increased self-efficacy.

Limitations

As it is the case with many educational research studies, this study is not immune to some limitations. First, this study took place in a specific teacher education program and with a limited number of participants. Therefore, these results may not be generalizable to other pre-service science teachers and contexts. Second, while these experiences have contributed to participants' increased self-efficacy to teach science through argumentation, it would be hard to make strong claims about the sustainability of this self-efficacy without administering the same self-efficacy survey to the participants after 1 year of teaching in actual classrooms. Finally, Cronbach alpha values for planning (0.445) and assessment (0.474) components of our survey are below the commonly accepted standard value of 0.6. This is most likely due to the lower number of questions in these two categories, our small sample size as well as the context in which this study took place (McCrae, Kurtz, Yamagata & Terracciano, 2011). However, as we continue to collect more data with this instrument in the future, and improve the scale based on feedback from our studies and colleagues, we hope to address this issue.

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