Science Education International
Vol. 24, Issue 3, 2013, 254-281

An examination of preservice primary teachers' written arguments in an open inquiry laboratory task

Christine V. McDonald[*†]

ABSTRACT: This study assessed the quality of preservice primary teachers' written arguments in an open inquiry laboratory task. An analysis of the features of the laboratory task was also undertaken to ascertain the characteristics of the task that facilitated or constrained the development of participants' written arguments. Australian preservice primary teachers (n=12) took part in a chemistry content course incorporating an inquiry oriented learning environment, explicit argumentation instruction, and numerous opportunities to engage in argumentation. Data sources included group written artefacts from an open inquiry laboratory task, and results indicated that two of the three groups failed to produce quality arguments in the written task. Data analysis indicates that a myriad of factors may have mediated groups' argument quality in the laboratory task including the adequacy of individual participants' background science conceptual knowledge, a lack of argumentation scaffolds in the task, the non-provision of alternative data, viewing the data as self-evident, a reliance on traditional reporting genres, and the non-inclusion of critical discussions. The laboratory task included a number of cognitive and epistemological features which were not aligned with authentic scientific inquiry including limited opportunities for extensive data transformation, complex theory-data coordination, utilisation of complex methods, multiple types of reasoning, generalisation of results to other contexts, and engaging in the review of 'expert research'. Implications of these findings highlight the importance of scrutinising the inquiry tasks learners engage with, in the chemistry laboratory context, to ensure they promote authentic scientific reasoning.

KEY WORDS: scientific argumentation, open inquiry, pre-service

INTRODUCTION

The inclusion of argumentation in the curricula is an important component of contemporary science education in many countries (e.g., AAAS, 1993; Australian Curriculum, Assessment and Reporting Authority [ACARA], 2012; NRC, 1996). Despite the worldwide trend to incorporate the teaching of argumentation in science classrooms via recent reform recommendations

* Corresponding Author: c.mcdonald@griffith.edu.au
† Griffith University, Australia

and curriculum developments (Jimenez & Erduran, 2007), and the recommendations stemming from recent research viewing argumentation as an important instructional strategy and educational goal for science education (Bricker & Bell, 2008); both early (e.g., Driver, Newton, & Osborne, 2000), and more recent (e.g., Berland & Reiser, 2009; Simon, Erduran, & Osborne, 2006) empirical research indicates argumentation is rarely effectively incorporated in science classrooms. Various researchers (e.g., Clark & Sampson, 2006; Duschl, 1990) have highlighted the limitations of presenting scientific knowledge in a transmissive manner, which not only provides learners with an inaccurate image of the nature of science, but also fails to encourage an exploration of how scientific ideas have developed and changed over time. Thus, learners may not appreciate the purpose of discussing and critiquing these ideas, and are less likely to engage in argumentative discourse about how these ideas are developed and validated by the scientific community.

An inquiry-based approach to teaching science has been proposed as an effective mechanism for enabling learners to carry out classroom activities that more closely align with authentic science practices (AAAS, 1993; ACARA, 2012; NRC, 1996), and a widely accepted definition promoted by the AAAS (1993) defines scientific inquiry as an attempt to develop explanations about the natural world using evidence and logic. Importantly, the classroom inquiry tasks learners engage with must also promote the central role of argumentation in the development of scientific knowledge. Chinn and Malhotra (2002) examined the cognitive and epistemological differences between authentic scientific tasks (e.g., research carried out by scientists) and simple inquiry tasks (e.g., straightforward experiments, observation of objects, stepwise procedures) in a comprehensive review of 468 textbook inquiry tasks commonly used in schools, and 26 researcher-designed inquiry tasks. Results indicated few parallels between the reasoning processes induced by the textbook tasks and the processes utilised during authentic scientific inquiry. They state that most science inquiry tasks students engage with in schools are not epistemologically aligned with the research conducted by scientists, and thus do not reflect the central features of authentic scientific reasoning. As such, engaging students in these simple inquiry tasks does not promote the effective implementation of quality argumentation in the science classroom. Implications stemming from this research highlight the importance of examining the inquiry tasks utilised to promote engagement in argumentation, to ensure they are aligned with authentic scientific inquiry.

Thus, strategies to increase the successful uptake and implementation of argumentation in school science are necessary, and this study will analyse an inquiry task to determine whether it is aligned with authentic scientific inquiry, and thus promotes engagement in

argumentation. In addition, only a few studies have examined the science laboratory as a context for facilitating and/or developing learners' argumentation. This study will contribute to this gap in the literature by examining learners' written arguments produced after engagement in a laboratory task. As the laboratory provides an optimal environment for inquiry-based teaching, it is important to examine its effectiveness as a context for engaging learners in scientific argumentation.

The laboratory as a context for scientific argumentation

Historically, learning science in the laboratory is considered to be a central cornerstone of school science (Abrahams & Millar, 2008; Hodson, 1993; Hofstein & Lunetta, 2004). In theory, the school science laboratory affords many educational advantages to students including the development of metacognitive skills, critical thinking skills, collaborative skills, communication skills, and the opportunity to learn science by 'doing' (Katchevich, Hofstein, & Mamlok-Naaman, in press). Many researchers have investigated the potential of the laboratory context to facilitate the development of students' cognitive abilities and practical skills (e.g., Abrahams & Millar, 2008; Berry, Mulhall, Loughran, & Gunstone, 1999; Hodson, 1990, 1996). In addition, an extensive body of research examining the effectiveness of the laboratory as a context for learning in science has been conducted over the past 40 years (please refer to Hofstein & Lunetta, 1982, 2004; Hodson, 1993; Lazarowitz & Tamir, 1994 for reviews of the field). Findings from this body of research highlight the nature of the relationship between laboratory experiences and science learning is complex, with many studies indicating that the perceived benefits have not been realised. Hofstein and Kind (2012, p. 189) suggest that "the aimed-for ideal of open-ended inquiry, in which students have opportunities to plan an experiment, to ask questions, to hypothesise and to plan an experiment again to verify or reject their hypothesis, happens more rarely – and when it does, the learning outcome is much discussed". Thus, it is important to consider the differences between the types of tasks students may participate in school science laboratory contexts.

Laboratory tasks have been categorised by researchers in various ways. In general, a four component categorisation is common, comprising confirmatory (or traditional expository), guided inquiry (or discovery), problem-based, and open inquiry (or inductive). The majority of so-called 'recipe-style' experiments fall under the umbrella of confirmatory/traditional expository tasks, and these types of tasks constitute the bulk of laboratory work in school science (Kind, Kind, Hofstein, & Wilson, 2011). These tasks are typically governed by naive epistemological orientations which incorporate a linear, stepwise scientific method directing students to 'find' the correct data to fit a pre-determined

conclusion. Students tend to focus on the given procedures and typically do not challenge methods or critically analyse their data in these types of tasks. Recipe-style tasks fail to encourage discussion amongst students as the primary focus of the task is following teacher instructions, or textbook procedures. By contrast, open inquiry tasks require students to develop research questions, decide on methods, collect and analyse data, deal with ambiguities in their data, and present their conclusions. By participating in this inductive process, students come to appreciate that the scientific method is neither linear, nor stepwise, as participating in the process often requires students to reflect on, and adapt their methods, and re-interpret new and/or existing data. Open inquiry tasks encourage group discussion as students attempt to make sense of their developed methods, and the analysis of their findings. Importantly, the incorporation of these types of laboratory tasks in school settings is constrained by various external pressures such as assessment requirements, curriculum constraints, and time allocations (Kind et al., 2011), in addition to changing existing teacher practices (Hofstein & Lunetta, 2004).

Few studies have examined the science laboratory as a context for argumentation, and no consensus exists in the literature regarding the effectiveness of the laboratory to promote scientific argumentation (Katchevich et al., in press). As stated earlier, the majority of science inquiry tasks students engage with in schools are not epistemologically aligned with the research conducted by scientists, and thus do not reflect the central features of authentic scientific reasoning. In the laboratory context, these types of tasks typically include recipe-style experiments. Conversely, authentic scientific inquiry tasks have been shown to promote the development of scientific reasoning (Chinn & Malhotra, 2002), and in the laboratory context, these types of tasks typically include open inquiry experiments. Thus, one could posit that engaging students in open inquiry experiments may provide an optimal environment for engaging in scientific argumentation. The following section will review studies conducted in laboratory settings which have focused on argumentation.

Laboratory argumentation studies in chemistry contexts

A review of the literature revealed four studies which have been conducted in chemistry contexts focusing on argumentation in laboratory settings. All of these studies are reported post-2010 and were conducted with middle school students, high school students, and undergraduate science students. Kind et al. (2011) examined the quality of middle school students' oral argumentation as they engaged in three different laboratory tasks. Two of the tasks involved students collecting and analysing their own data after engaging in experimentation, and the third task required students to discuss pre-collected laboratory data in a paper-based task. Findings indicated

engaging in the paper-based task generated the highest amount of argumentation, and argumentation was brief during the experimental tasks. During the experimental tasks, students were observed to focus the majority of their time on data gathering, as opposed to analysing or discussing evidence, and reliance on data was seen to be paramount. Findings also indicated that students did not question measurements, and put aside their personal beliefs to accept data unequivocally. The authors conclude that if students view the data as 'true', there is no impetus for them to engage in argumentation, and recommend explicitly addressing and teaching argumentation in the classroom. In another recent study, Katchevich et al. (in press) explored the processes by which high school students construct arguments during experimentation in the chemistry laboratory. Data sources included audio-taped laboratory discourse, written laboratory reports, and semi-structured student interviews. Students engaged in both confirmatory-type experiments and open inquiry-type experiments, and no explicit argumentation instruction was provided. Findings indicated that student discourse during open inquiry-type experiments contained numerous arguments, whereas discourse during confirmatory-type experiments contained few arguments. The authors conclude that open inquiry-type experiments have the potential to provide an effective context for formulating and promoting student argumentation.

Two studies conducted by Sampson and colleagues in the US have also reported favourable outcomes for student argumentation. Sampson, Grooms and Walker (2011) designed a suite of laboratory activities underpinned by a new instructional model entitled 'Argument-Driven Inquiry (ADI)' to promote student engagement in scientific argumentation. In addition to providing opportunities for students to develop methods, and design investigations, the ADI model provides opportunities for students to participate in scientific argumentation, and the peer review process. The authors propose that engaging students in these authentic scientific practices allows them to appreciate the norms of the scientific community. High school students took part in an 18 week intervention which included 15 ADI laboratory activities and explicit argumentation instruction, during a 10th grade chemistry course. Findings indicated that the students produced better quality written arguments after engaging in the ADI activities. In a more recent study, Sampson and Walker (2012) examined undergraduate science students' argumentation as they engaged in six laboratory activities underpinned by the ADI model over 15 weeks of a general chemistry laboratory course. Students also took part in explicit argumentation instruction during the study, and results indicated that the quality of participants' written argumentation improved over the duration of the study. The authors propose that teachers and instructors provide explicit modelling, scaffolding, and coaching of writing practices such as

crafting an argument, and engaging in peer review, with students to ensure they develop these crucial conceptual understandings and skills.

Implications drawn from the findings of these four studies highlight the importance of incorporating explicit argumentation instruction in the laboratory context to facilitate engagement in argumentation. Explicit instruction in this context refers to the direct teaching of various aspects of argumentation including instruction pertaining to the various definitions, structure, function, and application of arguments, and the criteria used to assess the validity of arguments. In addition, open inquiry laboratory tasks were found to be more effective than confirmatory laboratory tasks in providing a context for promoting argumentation in the reviewed studies.

Laboratory argumentation studies with preservice teachers

Few studies have focused on the assessment and/or development of preservice teachers' understanding of scientific argumentation (e.g., Osana & Seymour, 2004; Zembal-Saul, 2004; Zembal-Saul, 2005; Zembal-Saul, 2007; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2002), and only one published study has been identified in the literature which has examined teachers' scientific argumentation in a laboratory setting (Ozdem, Ertepinar, Cakiroglu, & Erduran, in press). Ozdem and colleagues examined 35 preservice elementary teachers' scientific argumentation as they performed inquiry-oriented laboratory tasks set in a middle school context. Data sources included video- and audio-recordings of discussions during six inquiry-based laboratory sessions. No explicit argumentation instruction was incorporated in the sessions, which were drawn from a range of disciplines, including biology, chemistry and physics. The argumentative inquiry-oriented laboratory context consisted of two stages: the experimentation stage (providing a context for the construction of knowledge claims), and the critical discussion stage (providing opportunities to evaluate claims, counterclaims and evidence). Results indicated that preservice teachers generated different numbers and kinds of arguments, many of which were considered 'scientific' in nature, and the inquiry-oriented laboratory context provided opportunities for participants to engage in productive scientific argumentation. Participants engaged in argumentation during both the experimentation stage, and the critical discussion stage, although the number of arguments generated during the critical discussion stage was higher. The authors conclude that this finding supports the crucial role of the critical discussion stage in providing a context for teachers to consider plural accounts of phenomena (Duschl & Osborne, 2002). Implications of this research indicate that inquiry-centred laboratory contexts are effective in engaging preservice teachers in argumentation, and engaging preservice teachers in critical discussions

after engaging in experimental work provides important opportunities to engage in productive argumentation.

Summary and Aim of the Study

The previous review has highlighted that teachers generally do not possess adequate skills to teach argumentation to their students, and most classrooms are teacher dominated with students given few opportunities to learn about, or engage in argumentation. Consequently, most science inquiry tasks students engage with in schools do not reflect the central features of authentic scientific reasoning, and do not promote the effective implementation of quality argumentation in the science classroom. Although the laboratory provides an optimal environment for inquiry-based teaching, only a few studies have examined the science laboratory as a context for facilitating and/or developing learners' argumentation. Findings from these studies highlight (1) the importance of incorporating explicit argumentation instruction in the laboratory context to facilitate engagement in argumentation, (2) the effectiveness of open inquiry laboratory tasks in providing a context for promoting argumentation, and (3) the role of critical discussions to support engagement in productive argumentation.

Thus, more research is needed to assess inquiry tasks utilised in laboratory settings to ascertain whether these tasks promote authentic scientific reasoning, in addition to further studies on preservice teachers' scientific argumentation. This research is part of a larger study exploring preservice primary teachers' epistemological views and argumentation in scientific and socioscientific contexts (see McDonald, 2010). This paper focuses on participants' written arguments in the open inquiry laboratory task. The quality of the preservice primary teachers' written arguments produced from engagement in the task will be evaluated (using a framework adapted from Zohar & Nemet, 2002). In addition, the features of the argumentation task will be examined (using a framework developed by Chinn & Malhotra, 2002, which examines the epistemological authenticity of the task) to identify the characteristics of the task that facilitated or constrained the development of participants' written arguments. The specific research questions examined in this paper are:

1. What is the quality of preservice primary teachers' written arguments in the open inquiry laboratory task?
2. What features of the open inquiry laboratory task facilitated or constrained the development of participants' written arguments?

METHOD

Participants

This study was conducted with preservice primary teachers enrolled in a chemistry content course conducted at a large urban university in Queensland, Australia. The majority of the preservice teachers entered the course having studied science to upper secondary levels with varying degrees of success, and were predominantly of Caucasian descent, and middle class socio-economic status. All preservice teachers were enrolled in their second or third year of a four-year Bachelor of Education undergraduate degree (focused on the education of 5-12 year old students). Sixteen of the seventeen preservice teachers enrolled in the course consented to participate in the study, and these teachers formed five groups (self-selected) to complete the open inquiry task in this study. Data for this paper was obtained from three of the five groups, as although all five groups produced written laboratory reports, only three of the groups fully attended all laboratory sessions. As such, rich information was not able to be obtained from the two groups where individual group members were absent during various stages of the task.

Context

The chemistry content course is one of a set of three science electives recommended for preservice primary teachers who wish to specialise in primary science teaching at the end of their degrees. Classes were held weekly in three-hour sessions, covering an 11-week teaching period. The course incorporated an inquiry-oriented learning environment where core chemistry concepts were taught through a variety of inquiry-based methods such as engagement in laboratory-based investigations (confirmatory and open inquiry), evaluating case studies, questioning and evaluating scientific claims, analysing primary data, and engaging in discussions of controversial issues (ACARA, 2012). As part of the larger study, a series of course components were specifically embedded within the inquiry-oriented learning environment to provide opportunities for developing and applying preservice teachers' epistemological views, developing their understandings of argumentation, and to provide opportunities for preservice teachers to engage in argumentation. Argumentation instruction was explicitly implemented during weekly classroom teaching sessions by incorporating teaching materials developed from the Ideas, Evidence and Argument in Science Project 'IDEAS' (Osborne, Erduran, & Simon, 2004a). Through explicit instruction, participants' developing understandings of argumentation were scaffolded by engaging them in activities such as evaluating evidence sources, examining the quality of data/evidence, discussing differences between counterclaims and counter-

arguments, and using writing frames to effectively structure arguments. Participants were provided with opportunities to practice their evolving understandings of argumentation during these explicit argumentation sessions, and also whilst engaged in a series of five argumentation scenarios situated in scientific and socioscientific contexts, throughout the course. Participants also engaged in a global warming task which provided opportunities for participants to develop and apply their skills of argumentation in a socioscientific context, and provided opportunities for participants to apply their epistemological views to their reasoning about the task. Concurrently, participants engaged in an open inquiry laboratory task in small groups. This task provided opportunities for participants to develop and apply their understandings of argumentation in a scientific context, and provided opportunities for participants to apply their epistemological views to their reasoning about the task. The open inquiry laboratory task is the focus of the present paper.

Data sources

Participants were required to work in groups to design and implement an open inquiry laboratory task concerned with determining the most efficient substance for melting ice. The laboratory task was an adaptation of a science fair project by Bochinski (1991), originally designed for middle and high school students. In this study the original idea was modified and presented as an open-ended problem for participants to attempt to solve (refer to Figure 1).

The captain of a fishing trawler has approached your research group with a problem. He has a build-up of ice approximately 2 cm thick on the bottom of an aluminium ice box used to store fresh fish. He needs to be able to melt the build up of ice without damaging the aluminium. Your task is to determine what would be the most effective substance to carry out this process. You will need to consider factors such as speed, cost and efficiency in your recommendation.

The following conditions are noted:

1. Outside air temperature is in the range of 18-25 degrees C.
2. No outside heat sources may be used (it is assumed there is no electricity available on the trawler).
3. No mechanical agitation of the ice is permitted (e.g., grinding, breaking up, agitating, etc.).
4. All groups will be provided with six aluminium baking pans and will have access to a very limited amount of freezer space.

Figure 1. Laboratory Project Brief (Adapted from Bochinski 1991)

Consistent with an open inquiry pedagogical approach (Banchi & Bell, 2008), participants were required to work in groups to design and

conduct their experiments, and analyse their findings. They were required to devise their own experimental procedures, and determine which materials they would need to conduct their tests. They were also required to justify the use of their data, and deal with the ambiguity of their data during analysis. Participants self-selected the composition of their groups with Group 1 consisting of four preservice teachers, Group 2 consisting of five preservice teachers, and Group 3 consisting of three preservice teachers. Group composition was varied, with a mix of gender, age, prior experience, and scientific background within each group.

The data collection aspect of the task was carried out in the class laboratory over a three week period during Weeks 8-10. The open inquiry task was designed to allow groups to research and test a range of chemicals to determine the most suitable chemical to solve the problem, thus providing a context for participants to engage in scientific argumentation by evaluating information, providing justifications for their choices, and offering rebuttals and counterarguments. Importantly, groups were not explicitly directed to test a range of chemicals in the written criteria, although this was an implicit expectation of the task based on the Laboratory Project Brief (refer to Figure 1). The task also did not utilise written or verbal prompts to encourage groups to engage in argumentation. Again, an implicit expectation of the task was premised on the assumption that groups would evaluate the results of trials using different chemicals to break down the ice, and then provide an argument to support their choice of chemical. In the final week of the course (Week 11) each group presented an informal oral summary of their findings to the class, and groups were then required to present their findings, and their recommendations to solve the problem, in a written scientific report. The written scientific report contributed 40% towards the final semester grade.

Data analysis

Data analysis was conducted after the conclusion of the study. All of the groups' written arguments in their laboratory reports were coded, in addition to analysing the features of the open inquiry task. To ensure that the results were consistent with the evidence gathered, an assessment of the reliability methods for coding the data was required. In order to achieve inter-rater reliability, a second science educator experienced in argumentation analysis independently coded all of the groups' written arguments, in addition to evaluating the features of the open inquiry task. Inter-rater agreement was reached in all cases through a process of initial coding, discussion, re-evaluation and resolution of discrepancies, and final consensus.

Quality of argumentation

The quality of group's written arguments in this study were evaluated using a framework adapted from Zohar and Nemet (2002), and this analysis provided evidence to address the first research question. Zohar and Nemet define better quality arguments as those which consist of multiple justifications and conceptually accurate scientific information. Poor arguments are characterised by the presence of weak or irrelevant justifications, and claims which are not supported by any justification are not categorised as arguments. The criterion for argument formulation was whether the written responses included a conclusion with at least one relevant justification. Justifications were scored according to their number and structure. The score range for the number of justifications was 0-2 (0=no justification, 1=one valid justification, 2= two or more valid justifications). The score range for argument structure also ranged between 0 and 2 (0=no valid justification, 1=a simple structure consisting of a conclusion supported by at least one reason, 2=a composite structure, in which the justification is supported in turn by another reason, usually explaining why the first reason should be accepted). Thus, a score between 0 and 4 is possible for each developed argument, counterargument or rebuttal (i.e., the sum of the number of justifications and argument structure scores). A total score ranging between 0 and 12 is possible for the task in this study as the task consisted of all three argumentation components (i.e., arguments, counter-arguments and rebuttals). Refer to Table 1 for exemplars of scoring arguments, counter-arguments and rebuttals for the task.

Another important aspect of Zohar and Nemet's framework is a consideration of whether learners' incorporate scientific conceptual knowledge into their arguments. They utilised four categories of analysis to determine the extent to which scientific knowledge is considered in developed arguments: (a) no scientific knowledge is considered, (b) incorrect scientific knowledge is considered, (c) non-specific scientific knowledge is considered, and (d) correct, specific scientific knowledge is considered. Higher quality arguments are characterised by the inclusion of correct, specific scientific knowledge. These criteria were also followed in this study. Refer to Table 2 for examples of scientific conceptual knowledge categories of analysis for the task.

In addition to Zohar and Nemet's consideration of the quality of arguments, counterarguments, and rebuttals, and the incorporation of scientific knowledge, an additional criterion was utilised to assess the quality of groups' arguments in this study. The consideration of alternative sources of evidence, and the subsequent coordination of claims with available evidence, is an important aspect of high quality argument formation not assessed using the framework developed by Zohar and

Table 1. Exemplars of scoring arguments, counterarguments and rebuttals in the open inquiry task (Adapted from Zohar and Nemet 2002)

Examples of arguments, counterarguments and rebuttals	Justification (single or multiple)	Structure (simple or composite/extended)
Argument – Sodium chloride is the most effective substance for melting the ice	*Single* – Sodium chloride is a strong electrolyte. A strong electrolyte will have a greater effect upon the melting point of water	Extended
Argument – Magnesium chloride is the most effective substance for melting the ice	*Multiple* – Experimental results showed that magnesium chloride produced a melt rate of 40 mL/10 min There was little discernable damage to the surface on application Magnesium chloride can be mixed with a corrosive inhibitor to further reduce corrosive effects	Extended
Counterargument – Calcium chloride is the most effective substance for melting the ice	*Single* – Experimental results showed that calcium chloride produced a melt rate of 56.7 mL/10 min	Simple
Rebuttal – Calcium chloride caused damage to the surface	*Single* – Calcium chloride was highly corrosive and caused major damage to the surface Long term application of corrosive substances will have economic implications for the trawler	Extended

Nemet. This criterion is significant as learners may develop arguments, counterarguments and rebuttals supported by justifications, and incorporate relevant scientific knowledge, but fail to consider other possible sources of evidence, or not utilise available evidence when developing their arguments. Thus, a high quality argument is characterised by the presence of arguments, counterarguments and rebuttals supported by multiple justifications and an extended argument structure; a consideration of accurate and specific scientific knowledge; and the coordination of claims with all available evidence.

Table 2. Examples of categories of analysis of science conceptual knowledge in the open inquiry task (Adapted from Zohar and Nemet 2002)

Consideration of science conceptual knowledge	Examples of arguments in the scientific task
No scientific knowledge is considered	We would choose water as chemicals are bad for the environment
Incorrect scientific knowledge is considered	We would not choose sodium chloride is it is insoluble in water
Non-specific scientific knowledge is considered	We would not choose calcium chloride as it has environmental influences
Correct, specific scientific knowledge is considered	We would not choose potassium acetate as although it is not corrosive, it is a diuretic which may lead to possible health implications

Open inquiry laboratory task features

An analysis of the epistemological authenticity of the open inquiry task in this study was conducted using an analytical framework developed by Chinn and Malhotra (2002). This analysis provided evidence to address the second research question by identifying the features of the task that mediated the development of groups' written arguments. Chinn and Malhotra's analytical framework outlines differences between authentic scientific inquiry and simple inquiry tasks, based on the *cognitive processes* employed when engaged in reasoning about the tasks, and the *epistemological dimensions* emphasised in the different tasks. In this study, the nature of the inquiry task utilised is more closely aligned with a 'simple experiment', than a 'simple observation' or 'simple illustration,' and as such, the 'simple observations' and 'simple illustrations' tasks from the original tables (Chinn & Malhotra, 2002, pp. 180-182, 188) have been omitted from the information presented in Tables 3 & 4. These tables summarise the key differences between authentic inquiry tasks and simple experiments and form the analytical framework utilised in this study.

Features of the open inquiry task were scrutinised and mapped to the framework presented in Tables 3 and 4 to enable an analysis of the cognitive processes and epistemological dimensions of the task to be ascertained. In this study, the task was considered to be *epistemologically authentic* if the majority of task features aligned with the features of *authentic inquiry* for both the cognitive processes and the epistemological dimensions.

Table 3. Cognitive processes of authentic scientific inquiry tasks and simple inquiry tasks (from Chinn and Malhotra 2002, pp. 180-182)

Cognitive process	Type of Reasoning Task	
	Authentic Inquiry	Simple Experiments
Generating research questions	Scientists generate their own research questions.	Research question is provided to students.
Designing studies		
• Selecting variables	Scientists select and even invent variables to investigate. There are *many* possible variables.	Students investigate one or two provided variables.
• Planning procedures	Scientists invent complex procedures to address questions of interest. Scientists often devise analog models to address the research question.	Students follow simple directions on how to implement a procedure.
• Controlling variables	Scientists often employ multiple controls. It can be difficult to determine what the controls should be or how to set them up.	There is a single control group. Students are usually told what variables to control for and/or how to set up a controlled experiment.
• Planning measures	Scientists typically incorporate multiple measures of independent, intermediate, and dependent variables.	Students are told what to measure, and it is usually a single outcome variable.
Making observations	Scientists employ elaborate techniques to guard against observer bias.	Observer bias is not explicitly addressed, although measuring devices such as rulers are used.
Explaining results		
• Transforming observations	Observations are often repeatedly transformed into other data formats.	Observations are seldom transformed into other data formats except perhaps straightforward graphs.
• Finding flaws	Scientists constantly question whether their own results and others' results are correct or artifacts of experimental flaws.	Flaws in experiments are seldom salient.
• Indirect reasoning	Observations are related to research questions by complex chains of inference. Observed variables are not identical to the theoretical variables of interest.	Observations are straightforwardly related to research questions. Observed variables are the variables of interest.
• Generalisations	Scientists must judge whether to generalise to situations that are dissimilar in some respects from the experimental situation.	Students usually generalise only to exactly similar situations.
• Types of reasoning	Scientists employ multiple forms of argument.	Students employ simple contrastive reasoning.

Table 3 continued. **Cognitive processes of authentic scientific inquiry tasks and simple inquiry tasks (from Chinn and Malhotra 2002, pp. 180-182)**

Cognitive process	Type of Reasoning Task	
	Authentic Inquiry	Simple Experiments
veloping theories		
• Level of theory	Scientists construct theories postulating mechanisms with unobservable entities.	Students usually uncover empirical regularities, not theoretical mechanisms.
• Coordinating results from multiple studies	Students coordinate results from multiple studies.	Students do just a single experiment.
	Results from different studies may be partially conflicting, which requires use of strategies to resolve inconsistencies.	Not applicable
	There are different types of studies, including studies at the level of mechanism and studies at the level of observable regularities.	Not applicable
dying research reports	Scientists study other scientists' research reports for several purposes.	Students do not read research reports.

Table 4 **Epistemological dimensions of authentic scientific inquiry tasks and simple inquiry tasks (from Chinn and Malhotra 2002, p. 188)**

Dimension of Epistemology	Type of Reasoning Task	
	Authentic Inquiry	Simple Experiments
Purpose of research	Scientists aim to build and revise theoretical models with unobservable mechanisms.	Students aim to uncover a simple, surface-level regularity.
Theory-data coordination	Scientists coordinate theoretical models with multiple sets of complex, partially conflicting data. Scientists seek global consistency.	Students coordinate one set of observable results with conclusions about those observable results. Students seek at most local consistency.
Theory-ladenness of methods	Methods are partially theory-laden.	Methods are not theory-laden.
Responses to anomalous data	Scientists rationally and regularly discount anomalous data.	There is little scope for students to rationally discount data.
Nature of reasoning	Scientists employ heuristic, nonalgorithmic reasoning. Scientists employ multiple acceptable argument forms. Reasoning is uncertain.	Students employ algorithmic reasoning to derive a conclusion from an experiment. Students employ simple contrastive arguments. Reasoning is certain.
Social construction of knowledge	Scientists construct knowledge in collaborative groups. Scientists build on previous research by many scientists. Institutional norms are established through expert review processes and exemplary models of research.	Students construct knowledge in collaborative groups. Students seldom build on any previous research. There are no institutional norm-setting processes.

RESULTS AND DISCUSSION

Quality of Argumentation

This section will provide evidence to address the first research question - What is the quality of preservice primary teachers' written arguments in the open inquiry laboratory task? Results indicated that two of the three groups (Groups 1 & 2) failed to produce quality written arguments. Group 3 developed a high quality argument for their choice of chemical by providing arguments, counterarguments and rebuttals supported with multiple justifications and an extended argument structure; the incorporation of specific and accurate scientific knowledge; and evidence of the coordination of claims with all available evidence. The other groups did not produce quality arguments, as although they provided a claim for their choice of chemical supported by one justification, they did not coordinate their claims with other possible sources of evidence by failing to provide counterarguments examining other alternative chemicals, or rebuttals to refute the possible selection of these chemicals. Refer to Table 5 for an overview of the scoring of argument/counterargument/rebuttal development and justification; consideration of scientific knowledge; and the coordination of claims with evidence, for the open inquiry task.

Group 1 chose sodium chloride as the most effective chemical to solve the problem. They presented accurate and specific scientific background knowledge on the properties of sodium chloride, and supported their choice of chemical with one relevant justification in the concluding section of their report:

> In conclusion, the most time- and cost-effective substance found to melt the build-up of ice without damaging the aluminium trays or using force or heat was salt with water. It is therefore our recommendation to the captain that he pour salt onto the build-up of ice and pour over water, to melt the ice within 30 minutes and leave no harmful residue of damage (Written laboratory report, Group 1, p. 7).

They did not conduct background research any other chemicals, and subsequently only tested sodium chloride in their project stating "Through research it has been found that the common substance sodium chloride has proven to be a cost effective and efficient way to melt ice (Malone, 1997)" (Written laboratory report, Group 1, p. 4). These findings indicate that this group had already made up their minds about the most effective chemical prior to conducting their project. This lack of consideration of alternative chemicals did not allow this group the opportunity to coordinate their claim with available evidence, and subsequently produce a quality argument.

Table 5. Scoring of argument quality for the open inquiry task (Adapted from Zohar and Nemet 2002)

Group	Arguments		Counter-arguments		Rebuttals		Total score /12	Consideration of scientific knowledge				Coordination of claims	
	J* /2	S#/ 2	J* /2	S#/ 2	J* /2	S #/ 2		None	Incorrect	Non-specific	Correct specific	Consideration of alternatives	Coordination of claims with evidence
Group 1	1	1	0	0	0	0	2				√	×	√
Group 2	1	1	0	0	0	0	2			√		√	×
Group 3	2	2	2	2	2	2	12				√	√	√

Note: J* - Justifications S# - Structure

Group 2 chose water as the most effective chemical to melt the ice, and supported this choice of chemical with one relevant justification (refer to transcript below). Interestingly, this group did not test 'water' as a possible chemical to solve the problem during the experimental phase of the project. Instead, after conducting background research on effective chemicals used to melt ice, the group chose to test the following three chemicals - sodium chloride, potassium chloride and calcium chloride. Although results were obtained and analysed for each of these three chemicals, this information did not appear to be considered in the decisions presented in the written report. The following statements were made in the 'Concluding statements and recommendations' section:

> Overall the experiments conducted were reasonable successful in determining which chemical was the most effective in melting ice without corroding the ice trays. ...From the results obtained, we would recommend to the captain of the fishing trawler to use water to degrade the ice. Water is cost effective, readily available, environmentally friendly and most effective in melting the ice… The other chemicals tested would be less effective and pose environmental, safety, cost and storage issues (Written laboratory report, Group 2, p. 11).

Thus, although Group 2 collected and analysed data from the application of three chemicals, they did not use this information to arrive at their decision to use water to degrade the ice in their written report. They simply presented the result of their trials and did not attempt to interpret the relative effectiveness of one chemical over another. The justification offered to support their final choice was not derived from the results of their experiment, and their broad claim regarding the effectiveness, safety, cost, environmental impact and storage of the three tested chemicals were not justified. In addition, this group did not present specific scientific knowledge to support their claims. Similarly to Group 1, the lack of consideration of the alternative sources of evidence did not enable Group 2 the opportunity to coordinate their claim with available evidence, and subsequently produce a quality argument.

Conversely, Group 3 provided a high quality argument to support their choice of chemical to solve the problem in their written report. This group incorporated specific, scientifically accurate knowledge, and provided an extended argument structure which included multiple justifications in their report. Group 3 chose to test two sets of chemicals – the chlorides and organic materials. In total, seven chemicals were tested. Interestingly, this group did not provide an overview of the properties of these chemicals in the background science section of the written report, nor did they provide a rationale for why they chose to test the selected chemicals, although a general overview of phase changes and properties of water were provided. Results for each trial for all seven chemicals were comprehensively recorded and provided in the written

report. The 'Analysis of Results' section provided evidence of engagement in scientific argumentation, with the group's choice of chemical supported with multiple justifications. Several counterarguments were provided whilst examining the other alternative chemicals which were also supported with multiple justifications, and rebuttals were provided to refute the selection of alternative chemicals which were also supported with justifications. This group chose magnesium chloride as the most effective chemical to melt the ice:

> Our results pointed towards calcium chloride but given the environmental, corrosive and expense of the products it was decided to make the final decision to recommend the powdered application of magnesium chloride (mixed with a corrosive inhibitor) to the affected hold to breakdown and melt the ice. However there would be an addendum to this that would recommend that periodically that the skipper use the sea water method every third or fourth melt cycle (Written laboratory report, Group 3, p. 14).

This choice was made after the group compared and contrasted the results of trials for each chemical tested. For example, counterarguments and rebuttals were provided for sodium chloride and calcium chloride as although they were shown to be efficient at melting the ice rapidly, they are highly corrosive substances (which may lead to long-term damage to the fishing trawler). Counterarguments and rebuttals for sodium acetate, urea, ammonium sulphate and potassium acetate were also provided which were also supported with multiple justifications. The following excerpt is a typical example:

> Week three focused on non-corrosive compounds that were freely available and efficient. The results lead us to believe that potassium acetate was a better alternative than the industrial salts, for there is no corrosive element to be factored into the final solution, as well as no discernable short or long term harmful side effects. However there is the consideration that this substance is a diuretic, which in turn may lead to diarrhoea, nausea and severe headaches. Given that this hold is to contain fish for human consumption then the possibility of contaminating the catch with potassium acetate needs to be weighed against the financial viability and effectiveness of the chemical (Written laboratory report, Group 3, p. 13).

Thus, the argument presented in the written report from Group 3 fulfilled all three criteria of a high quality argument.

A possible explanation for the differing results obtained in the laboratory task may relate to participants' background science conceptual knowledge. Information obtained from the interviews indicated that many of the group members from Group 1 and 2 did not possess strong background science conceptual knowledge which may have been inhibited their ability to select appropriate chemicals to test, and/or interpret information obtained from the trials of their experiments. On the other hand, one of the members from Group 3

possessed relatively strong background science content knowledge and appeared to draw on this knowledge during the laboratory task, selecting a variety of appropriate chemicals to test, and accurately interpreting information obtained from the trials of their experiments. This group member was observed to be a dominant figure during laboratory sessions, and predominantly led the investigation. Interestingly, one of the members of Group 1 also possessed relatively strong background science content knowledge, and she was also a dominant figure in her group. Although her group did not select and test a number of alternative chemicals, she did encourage her group to include specific and accurate scientific knowledge about the single chemical selected. Osborne et al. (2004b) propose that argumentation in scientific contexts requires the application of relevant scientific knowledge to enable participants to support and justify their arguments, with findings from this study indicating that participants with relatively weaker science conceptual knowledge may have benefited from the inclusion of relevant background information about appropriate chemicals embedded within the task.

Importantly, no argumentation scaffolds were utilised in the laboratory task as written assessment criteria did not explicitly ask groups to develop an argument and counterargument to support and justify their position. Results indicated that two of the three written reports simply presented empirical data with minimal scientific interpretation, and little attempt to convince the reader of why one chemical was more effective than another chemical. The failure to consider the possibility of alternative data or explanations has been reported in previous studies (e.g., Bell & Linn, 2000; Kuhn, 1991, 1993), and suggests that these participants may have engaged in the argumentative nature of the laboratory task if it had been designed to allow competing ideas to be tested. For example, groups could have been provided with a list of alternatives (chemicals) and asked to research and test the chemicals, and then to provide an argument as to why chemical A, was more effective than chemical B, or chemical C, etc.

Another possible explanation for this finding could be that group members may have believed that the data were self-evident, and did not require interpretation, or justification; or alternatively they may have believed the instructor already knew why the data were important, and therefore it only mattered to include the data. These possibilities have been discussed in previous studies (Kuhn & Reiser, 2006; Sandoval & Millwood, 2005), and indicate that engagement in argumentation in this task may have been influenced by whether groups perceived a need to explain their data. Further, Berland and Reiser (2009) highlight the tension between the traditional norms of the classroom where learners are expected to report the 'right answers' and the goals of argumentation where learners are expected to persuade the reader of their position. As such, participants may have responded to the task in a manner that was familiar to them – in the genre of a traditional written laboratory report.

Katchevich and colleagues (in press) recently utilised the Science Writing Heuristic (SWH) to enable students to participate in the construction of knowledge during laboratory activities (Hand & Keys, 1999). The SWH has a semi-structured format and provides written guidelines to enable learners to make connections during all stages of the inquiry process, via inquiry questions which aid learners in constructing claims to support their data. An integral part of this process is engagement in classroom discussions in a non-critical atmosphere where learners feel free to express their views openly. In the present study, this scaffold was not provided, nor were classroom discussions held at the conclusion of weekly laboratory activities.

Open inquiry laboratory task features

This section will provide evidence to address the second research question - What features of the open inquiry laboratory task facilitated or constrained the development of participants' written arguments? An analysis of the features of the laboratory task indicated that the task was not considered to be epistemologically authentic as all of the task features aligned with the features of *simple experiments* for the epistemological dimensions, and many of the task features aligned with the features of *simple experiments* for the cognitive processes. These features are discussed in more detail in the following sections.

Cognitive processes

Many of the features of the laboratory task aligned with the features of *simple experiments* for the cognitive processes. For example, in the task, the research question was provided to groups, which runs contrary to authentic scientific research where scientists develop their own research questions to solve a problem or investigate a phenomenon. Although groups employed techniques to minimise measurement errors (e.g., using rulers to measure changes in height of ice, and stopwatches to record melt time), techniques to minimise observer bias were not explicitly discussed in the task. Importantly, there were some weak alignments with authentic inquiry in some aspects of the laboratory task. Unlike most simple experiments, groups in this task were not told which variables to investigate. There were a variety of possibilities to choose from, although the task did not require groups to construct conceptually-embedded theoretical variables. Groups were also not provided with a recipe-style procedure to follow. They were required to invent their own procedure, although the procedures developed were not complex in nature. In addition, groups were not told which variables to control, and there was often more than one control group, although it is important to note that the controls utilised in the task were intuitive and easy to implement.

The laboratory task did not provide opportunities for extensive data transformation as the observations were generally straightforward, although some groups chose to graph their results. As the task did not require the incorporation of complex methods, there was little opportunity to find flaws in the methods employed. The task also did not provide opportunities for groups to appreciate the indirect nature of reasoning as the theoretical variables of interest were identical to the variables manipulated in the task. For example, typical variables manipulated in the task were the various chemicals tested (e.g., sodium chloride, magnesium chloride, potassium acetate) – the independent variables, and the rate of melting - the dependent variable. These variables were also the theoretical variables in the task. The task did not require the incorporation of multiple types of reasoning to derive conclusions. Groups 1 and 2 typically carried out their trials and then employed simple forms of contrastive causal reasoning to arrive at their conclusions. Due to the localised nature of the task, groups were not required to generalise their results to other contexts or situations, either similar or dissimilar in nature.

Groups were not required to develop theories as a result of engaging in the laboratory task. Regarding the aspect of coordinating results from multiple studies, this aspect was not applicable to the task as groups were only required to perform one set of experiments (a single study) on the topic of interest. Little or no reading of other scientists' research reports took place with most groups engaging in a brief review of possible chemicals from chemical databases, textbooks etc, and then conducting their own research.

Epistemological dimensions

The purpose of the research in the laboratory task focused on revealing observable regularities between variables, as opposed to generating theories. Groups were not required to engage in complicated theory-data coordination in the laboratory task, as the task sought to find a solution to a relatively simple, localised problem. As such, there were few opportunities for groups to view data as tentative and conflicting as the task encouraged participants to view theory and methods as independent processes, and promoted the view that if procedures are followed accurately, then methods can be thought to be trustworthy. Due to the uncomplicated nature of the task, groups were provided with few opportunities to rationally eliminate data. The laboratory task tended to promote the incorporation of simple reasoning strategies, for example, Groups 1 and 2 simply tested a range of different chemicals (or concentrations of chemicals) whilst controlling all other variables (amount of ice, temperature, amount of chemical, etc.), and chose the chemical that melted the ice in the fastest time to solve the problem. Group 3 was the only group that did not apply simple contrastive arguments as they considered not only the experimental results

obtained (related to rate of melting), but also evidence related to safety, cost, environmental factors, etc. This consideration of multiple data sources allowed members of Group 3 to appreciate the uncertain nature of reasoning. Finally, although participants were required to work in groups as scientists do, most participants did not engage in reviewing previous research in the area. As such, the study of 'expert research' in the task was almost non-existent.

CONCLUSION AND RECOMMENDATIONS

Previous research has highlighted that teachers generally do not possess adequate skills to teach argumentation to their students, and most science inquiry tasks students engage with in schools do not reflect the central features of authentic scientific reasoning. Although the laboratory provides an optimal environment for inquiry-based teaching, few studies have examined the chemistry laboratory as a context for facilitating and/or developing learners' argumentation. This study was designed to assess the quality of preservice primary teachers' written arguments in an open inquiry laboratory task, in addition to examining the epistemological authenticity of the task to identify the characteristics that facilitated or constrained the development of groups' written arguments. Participants took part in a chemistry content course incorporating explicit argumentation instruction, and numerous opportunities to engage in argumentation. Results indicated that two of the three groups failed to produce quality arguments in the laboratory task. Data analysis indicates that a myriad of factors may have mediated groups' argument quality in the laboratory task including the adequacy of individual participants' background science conceptual knowledge, a lack of argumentation scaffolds in the task, the non-provision of alternative data, viewing the data as self-evident, a reliance on traditional reporting genres, and the non-inclusion of critical discussions. The laboratory task included a number of cognitive and epistemological features which were not aligned with authentic scientific inquiry including limited opportunities for extensive data transformation, complex theory-data coordination, utilisation of complex methods, multiple types of reasoning, generalisation of results to other contexts, and engaging in the review of 'expert research'.

Implications of these findings highlight the importance of scrutinising the inquiry tasks learners engage with, in the chemistry laboratory context, to ensure they promote authentic scientific reasoning. A consideration of learners' background science knowledge, and the inclusion of critical discussions is also recommended to maximise engagement in argumentation. In addition, the integration of non-traditional reporting genres is suggested to shift learners away from the traditional norms of reporting the 'correct answers' to formats which promote persuasion and argumentation. This study has made an original

contribution to literature in the field by exploring the epistemological authenticity of an open inquiry laboratory task, and the quality of the preservice primary teachers' written arguments emerging from engagement in the task. Importantly, the results of this study are applicable to the 12 participants selected for investigation in this study. As such, the findings should not be generalised to other populations. Future studies utilising larger samples are needed to ascertain if these findings are representative of other groups.

REFERENCES

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. International Journal of Science Education, 30, 1945-1969.

(AAAS) American Association for the Advancement of Science (1993). Benchmarks for science literacy: A Project 2061 Report. New York: Oxford University Press.

(ACARA) Australian Curriculum, Assessment and Reporting Authority (2012). Australian Curriculum: Science F-10 Version 3.0. Commonwealth of Australia: Sydney, NSW.

Banchi, H., & Bell, R. (2008). The many levels of inquiry. Science & Children, 46(2), 26-29.

Bell, P., & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. International Journal of Science Education, 22(8), 797-817.

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. Science Education, 93(1), 26-55.

Berry, A., Mulhall, P., Loughran, J. J., & Gunstone, R. F. (1999). Helping students learn from laboratory work. Australian Science Teachers Journal, 45, 27-31.

Bochinski, J. B. (1991). The complete handbook of science fair projects. New York: Wiley.

Bricker, L. A., & Bell, P. (2008). Conceptualisations of argumentation from science studies and the learning sciences and their implications for the practices of science education. Science Education, 92, 473-498.

Chinn, C. A., & Brewer, W. F. (1998). An empirical test of a taxonomy of responses to anomalous data in science. Journal of Research in Science Teaching, 35(6), 623-654.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. Science Education, 86, 175-218.

Clark, D., & Sampson, V. (2006, April). Characteristics of students' argumentation practices when supported by online personally-seeded

discussions. Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST), San Francisco, CA.
Crawford, T. (2005). What counts as knowing: Constructing a communicative repertoire for student demonstration of knowledge in science. Journal of Research in Science Teaching, 42(2), 139-165.
Dawson, V., & Venville, G. J. (2009). High-school students' informal reasoning and argumentation about biotechnology: An indicator of scientific literacy? International Journal of Science Education, 31(11), 1421-1445.
Dawson, V. M., & Venville, G. (2010). Teaching strategies for developing students' argumentation skills about socioscientific issues in high school genetics. Research in Science Education, 40(2), 133-148.
Denzin, N. (1984). The research act. Englewood Cliffs, NJ: Prentice Hall.
Denzin, N. K., & Lincoln, Y. S. (2000). Handbook of qualitative research (2nd ed.). Thousand Oaks, CA: Sage.
Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. Science Education, 84, 287-312.
Duschl, R. A. (1990). Restructuring science education: the importance of theories and their development. New York: Teachers College Press.
Duschl, R. A. & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. Studies in Science Education, 38, 39-72.
Guba, E. G., & Lincoln, Y. S. (1989). Fourth generation evaluation. CA: Sage.
Hand, B., & Keys, C. W. (1999). Inquiry investigation: A new approach to laboratory reports. The Science Teacher, 66, 27-29.
Hodson, D. (1990). A critical look at practical work in school science. School Science Review, 70, 33-40.
Hodson, D. (1993). Re-thinking old ways: toward a more critical approach to practical work in school science. Studies in Science Education, 22, 85-142.
Hodson, D. (1996). Practical work in school science: Exploring some directions for change. International Journal of Science Education, 18, 755-760.
Hofstein, A. & Kind, P.M. (2012). Learning in and from science laboratories. In B. J. Fraser, K. G. Tobin, & C. J. McRobbie (Eds), Second International Handbook of Science Education (pp. 189-207). Dordrecht: Springer.
Hofstein, A., & Lunetta, V. N. (1982). The role of the laboratory in science teaching: Neglected aspects of research. Review of Educational Research, 52, 201-217.
Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: foundation for the 21st century. Science Education, 98, 28-54.
Jimenez-Aleixandre, M.-P., Bugallo Rodriguez, A., & Duschl, R. A. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. Science Education, 84, 757-792.
Jimenez-Aleixandre, M.-P., & Erduran, S. (2007). Argumentation in science education: An overview. In S. Erduran and M.-P Jimenez-Aleixandre

(Eds.). Argumentation in science education: Perspectives from classroom-based research (pp. 3-27). Dordrecht: Springer.
Katchevich, D., Hofstein, A., & Mamlok-Naaman, R. (in press). Argumentation in the Chemistry Laboratory: Inquiry and Confirmatory Experiments. Research in Science Education.
Kind, P. M., Kind, V., Hofstein, A., & Wilson, J. (2011). Peer argumentation in the school science laboratory – Exploring effects of task features. International Journal of Science Education, 33(18), 2527-2558.
Kuhn, D. (1991). The skills of argument. Cambridge: Cambridge University Press.
Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. Science Education, 77(3), 319-337.
Kuhn, L., & Reiser, B.J. (2006). Structuring activities to foster argumentative discourse. Paper presented at the Annual Meeting of the American Educational Research Association (AERA), San Francisco, CA.
Lazarowitz, R., & Tamir, P. (1994). Research on using laboratory instruction in science. In D. L. Gabel (Ed.), Handbook of research on science education (pp. 94-130). New York: Macmillan.
McDonald, C. V. (2010). The influence of explicit nature of science and argumentation instruction on preservice primary teachers' views of nature of science. Journal of Research in Science Teaching, 47(9), 1137-1164.
(NRC) National Research Council (1996). National Science Education Standards. Washington DC: National Academic Press.
Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. International Journal of Science Education, 21(5), 553-576.
Osana, H. P., & Seymour, J. R. (2004). Critical thinking in preservice teachers: A rubric for evaluating argumentation and statistical reasoning. Educational Research and Evaluation, 10, 473-498.
Osborne, J., Erduran, S., & Simon, S. (2004a). Ideas, Evidence and Argument in Science (IDEAS) Project. London: University of London Press.
Osborne, J., Erduran, S., & Simon, S. (2004b). Enhancing the quality of argumentation in school science. Journal of Research in Science Teaching, 41(10), 994-1020.
Ozdem, Y., Ertepinar, H., Cakiroglu, J., & Erduran, S. (in press). The nature of pre-service science teachers' argumentation in inquiry-oriented laboratory context. International Journal of Science Education.
Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. Journal of Research in Science Teaching, 41(5), 513-536.

Sampson, V., & Blanchard, M. R. (2012). Science teachers and scientific argumentation: Trends in views and practice. Journal of Research in Science Teaching, 49(9), 1122-1148.

Sampson, V., Grooms, J., & Walker, J. P. (2011). Argument-driven inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: An exploratory study. Science Education, 95, 217-257.

Sampson, V., & Walker, J. P. (2012). Argument-Driven Inquiry as a way to help undergraduate students write to learn by learning to write in chemistry. International Journal of Science Education, 34(10), 1443-1485.

Sandoval, W. A. & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. Cognition and Instruction, 23(1), 23-55.

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. International Journal of Science Education, 28, 235-260.

Simon, S., & Johnson, S. (2008). Professional learning portfolios for argumentation in school science. International Journal of Science Education, 30, 669-688.

Singer, S. R., Hilton, M. L., & Schweingruber, H. A. (2005). America's lab report: Investigations in high school science. Washington: National Academies Press.

Toulmin, S. E. (1958). The uses of argument. Cambridge: Cambridge University Press.

Zembal-Saul, C. (2004). Year 1: Teaching elementary school science as argument. Annual report to the National Science Foundation (NSF CAREER 0237922).

Zembal-Saul, C. (2005, April). Preservice teachers' understanding of teaching elementary school science as argument. Paper presented at the meeting of the National Association for Research in Science Teaching (NARST), Dallas, TX.

Zembal-Saul, C. (2007, August). Evidence and explanation as a lens for learning to teach elementary school science as argument. Paper presented at the meeting of the European Science Education Research Association (ESERA), Malmo, Sweden.

Zembal-Saul, C. (2009). Learning to teach elementary school science as argument. Science Education, 93, 687-719.

Zembal-Saul, C., Munford, D., Crawford, B., Friedrichsen, P., & Land, S. (2002). Scaffolding preservice science teachers' evidence-based arguments during an investigation of natural selection. Research in Science Education, 32(4), 437-463.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. Journal of Research in Science Teaching, 39(1), 35-62.