IL NUOVO CIMENTO **38 C** (2015) 102
DOI 10.1393/ncc/i2015-15102-6

Colloquia: GIREP/MPTL 2014

# Investigation of a reflective pedagogy to encourage pre-service physics teachers to explore argumentation as an aid to conceptual understanding

Greg Lancaster(*) and Rebecca Cooper(**)
*Science Education Research Group, Faculty of Education, Monash University Clayton, Australia*

received 26 October 2015

**Summary.** — An emerging focus of recent science education research advocates the benefits of using argumentation as an approach in which teachers can better engage students in a more authentic experience of the epistemic work of scientists (Bricker and Bell, 2008). Logical argument and critical thinking are considered essential skills for an effective and successful undertaking of scientific inquiry and analysis. Early research suggests the practise of encouraging students to engage in scientific discourse in the classroom (Kuhn, 2010) can provide rich experiences for students and teachers to hone their cognitive abilities. This paper explores the use of critical 'discussion problems' purposefully designed for pre-service physics teachers to investigate their own alternative conceptual understandings of key physics ideas. It also discusses how these problems are then used to generate classroom discourse which focuses on the importance of developing effective pedagogical content knowledge (See Shulman, 1986 for a detailed explanation of pedagogical content knowledge) rather than just mastery of scientific content and its mathematical applications. Further, the paper will detail a preliminary study in which pre-service physics teachers were introduced to a number of discussion problems via an online learning environment and asked to first consider the problem and post a solution in isolation from their peers. A considerable challenge was persuading the pre-service teachers to resist the common practice of "Googling the answer" via the internet before posting their solution attempt. Although most students initially appeared to believe that posting "the correct" answer was the main task objective, the vast majority eventually came to realise that discussing the range of unresearched solutions was much more beneficial for their conceptual understanding and professional practice. Over time, this approach generally encouraged students to post original ideas and to be less influenced by the arguments or analysis of other students. Following the completion of the online posts, the range of ideas included in the postings were then explored during a face to face workshop where the ideas were debated and frequently defended and the implications for pedagogy and their students learning discussed. The initial feedback from the pre-service teachers during this preliminary study is encouraging and suggests there is merit in exploring the benefits of argumentation for pre-service teachers and their students in a subsequent expanded study.

(*) E-mail: greg.lancaster@monash.edu
(**) E-mail: rebecca.cooper@monash.edu

 

## 1. – Introduction

Jerry Wellington and Jonathan Osborne in their book (Wellington and Osborne, 2001) on the use of language in science education, identify at the outset a fundamental premise which underpins their notion of what constitutes a quality science education. They view learning the language of science as a key objective ("if not *the* major part", p2) of the purpose of science education. Further to this they propose that science educators should embrace the notion that "every science lesson is a language lesson". It is during rhetorical communication that students are more likely to realise the strengths and shortcomings of their current science understandings (Bell and Linn, 2000). This view that students need to become proficient in their use of scientific language is an emerging focus of recent science education research (Duschl and Osborne, 2002; Norris and Phillips, 2003; Sampson and Clark 2008; Osborne, 2012;) and has provided impetus to the notion of developing scientific literacy in all citizens to ensure that they are skilled sufficiently to fully participate in an increasingly technologically focused society.

Since the term scientific literacy was coined in the late 1950s it has remained nebulous and researchers have continued to struggle to achieve a widely accepted definition. Some fifty years after its emergence, Rüdiger Laugksch (Laugksch, 2000, p. 71) in his comprehensive analysis of the term still described it as an "ill-defined and a diffuse concept". Although the complexities of scientific literacy continue to be debated by researchers (Shamos, 1995; Bybee, 1997; Driver, Newton and Osborne, 2000) there are essential inquiry skills and knowledge about the nature of science and how it is undertaken which are increasingly seen by many educators as essential competences for a scientifically literate citizen. Theses competencies are important in order to equip citizens to make the scientifically informed and socially responsible decisions required to engage successfully in a 21st century world. Critical to the foundation of an understanding of scientific literacy is the knowledge of the social construction of science and the many practices and processes of science that inspire debate and disagreement from both within scientific communities, the media and the political arena. Being able to participate in logical debate, construct coherent arguments and appraise the arguments of others is an increasingly important skill. Hence, the skill of argumentation is seen by many science educational researchers as an essential component of a quality science education and further, the development of scientifically literate citizens.

## 2. – What is argumentation?

Van Eemeren and Grootendorst (2004) define argumentation as "[...] a verbal, social, and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of propositions justifying or refuting the proposition expressed in the standpoint" (p. 1). This definition has met with wide acceptance however the use of the word "verbal" is commonly associated with spoken language but can arguably be regarded to include written, graphical and mathematical communication. The term "social" is particularly pertinent as the approach most frequently practiced (but not exclusively) is a dialogue between two or more people. Argumentation is also "rational" in that "it is aimed at defending a standpoint in such a way that it becomes acceptable to a critic who takes a reasonable attitude" (Van Eemeren, Grootendorst, and Henkemans, 2002, p. 11). Initially, the use of the term "reasonable" appears to lack the clarity one would aspire for

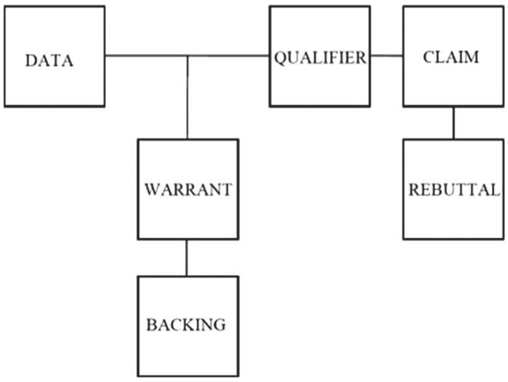


Fig. 1. – Toulmin's argument schema.

however when one considers the very social nature of the task, what may be accepted as logical and reasonable by one person may remain confusing and unreasonable for another.

Van Eemersen and Gootendorst (2004) propose that argumentation is fundamentally different from other forms of discourse, such as instruction, explanation or clarification because argumentation includes the notion of a positional standpoint. They argue that other forms of discourse involve either an overt or covert mutual acceptance of key propositional ideas that are never disagreed with or challenged. Alternatively, the purpose of argumentation is to deliberately challenge or defend a standpoint whose correctness can eventually be agreed upon through use of a logical evidence based rhetorical argument. Although this distinction is seen as helpful by many, it has prompted some disagreement by those who see that explanation based discourse can also include disagreement and hence involve elements of argumentation as well (Simosi, 2003).

In his influential work on the structural analysis of argument Stephen Toulmin (Toulmin, 1958) proposed a radically new framework (fig. 1.) that replaced the use of the traditional terminology of "premise" and "conclusion" with a new schema. His study of the way people argue in natural settings gave rise to a range of new terms such as; data, claim, warrant, rebuttal and backing. Firstly in his proposal the claim is equivalent to the conclusion whose merit is to be established by the claimant. The data is considered to be the evidence or facts that lay foundation to the claim to be established. The warrant is then used to bridge or link the data or evidence with the claim. If the warrant is not considered to be strongly convincing then an additional backing point is used to support or credential the warrant. In addition a qualifier can be used by the claimant to indicate the strength of their conviction or the degree of certainty with which they advocate the claim. A rebuttal is sometimes also used to qualify the claim in recognition of restrictions dependant on context. The claim (conclusion), data (evidence) and the warrant are considered to be essential elements of Toulmin's framework. His approach attempts to decontextualise the process providing an analytical framework with which to argue rationally or scientifically. Although there have been many subsequent amendments proposed to Toulmin's original work it continues to provide a framework which still provides a valid model today although a substantial limitation is that it does not lead to judgments about the correctness or quality of the argument. Assessments on the quality and correctness of an argument clearly demand expert content knowledge to gauge the validity of the data and its logical application within the context.

## 3. – Reported benefits

Effective argumentation is an approach that requires critical thinking, logical construction and evaluation of argument. Although these skills are by no means unique to the domain of science there is no doubt that they are critical to how the scientific community uses skilled scientific arguments to support or challenge the creation of new knowledge and to logically scrutinise the merit of evidence with peers. An increasing number of science educators now view argumentation as an important instructional approach that provides science students with authentic opportunities to investigate how scientists use skilled scientific arguments to undertake the social construction and consolidation of new knowledge; the core epistemic work of scientists (Bricker and Bell, 2008). Previous classroom research has shown that teacher intended student classroom discourse occupies very little class time. Findings in the US from Goodlad (1984), found that open discussion occupied an average of 4–7% of total class time. This compares similarly with more recent research in 1997 in the UK by Newton *et al.* (1999), where their study of 34 lessons revealed that on average 2% or less of class time was spent on student collaborative discussion. With the growing adoption of inquiry based learning and the use of collaborative practical investigations one would be hopeful that these numbers have increased in recent times. However, they do highlight how important it is that greater attention is given to the processes of planning, analysis and interpretation with argumentation being acknowledged as an integral part of these processes (Kuhn and Pease, 2008).

As a consequence of her extensive research in this area, Deanna Kuhn (1991, 2010) concludes that providing opportunities for students to engage in scientific discourse in the classroom can provide rich authentic experiences for students and teachers to engage in scientific reasoning and the construction and analysis of logical argument. In one study she explored the capacity of 160 individuals ranging from primary school students to adults to use reasoned argument when considering problematic social issues. Her findings suggest that both children and adults (particularly those with limited formal education) were very poor at co-ordinating and constructing the essential relationships between, Toulmin's "data" (evidence) and "claim" (conclusion) for a logically reasoned argument. She advocates that students need to be taught that "data" (evidence) is qualitatively different from theory and that evidence is critical in supporting or disproving a theory.

Kuhn and Reiser's (2005) findings have been cited as evidence by many education researchers that the majority of people struggle to demonstrate effective argumentation skills and that students should be provided with more opportunities to engage in the construction and analysis of reasoned arguments. Teaching science using an argumentation frame is seen by many educators as an essential approach with which to engage students in an experience of science more representative of the formal cognitive work undertaken by scientists.

## 4. – Research methodology

Given the potential benefits of an argumentation framework as highlighted in the literature, the researchers were keen to explore how the practice of argumentation could be introduced to pre-service physics teachers and the potential benefits explored within the tight time constraints of a teacher education course. The approach trialled was to establish a small pilot study during a second semester unit and to introduce the ideas on multiple occasions rather than a single workshop. It was anticipated that revisiting the ideas would create opportunities to progressively develop the notion of argumentation and to gauge the effectiveness of the approach in shaping the thinking and professional practice of pre-service science teachers.

Four purposefully designed "discussion problems" were introduced using an online discussion forum in which the pre-service teachers ($N = 23$) could post brief solutions ($\sim$150 words) with an accompanying argument. This forum would also provide the pre-service teachers with data for a meta-analysis of their alternative conceptual understandings of the "key" physics ideas underpinning the problems and provide an opportunity to make the different understandings of their peers more explicit. After posting their solution online, the discussion problem and the range of views were then discussed in subsequent face to face workshops conducted the following week. During these workshops individuals were invited to discuss, defend and argue the merits of their solutions with the collective intent of arriving at an explanation acceptable to all. It was envisaged that these workshops would provide an opportunity for the pre-service teachers to explore the benefits of argumentation in achieving both rational solutions to the problems using a dialogic process and to clarify each other's conceptual understanding of the key physics ideas. This approach would also introduce a collegial learning model and encourage the investigation of related pedagogies which they may choose to explore further in their own practicum experiences.

The online discussion forum was established using a Moodle (Virtual Learning Environment) and required the pre-service teachers to post their solutions to the forum before accessing those of their peers. This restriction was adopted by the researchers as it was felt that it would help create a low threat environment where the pre-service teachers were able to take the time they needed to formulate an individual considered response. It also encouraged every class member to undertake some degree of preliminary thinking about the problem before engaging in a dialogic analysis of the problem during the workshop debrief.

Experience with many past physics method pre-service teachers suggests that a high proportion are mature age and academically high performing (many possess post graduate or doctoral qualifications). Maybe more than most students, the physics graduates demonstrate a reluctance to be seen as "incorrect" amongst their peers and lecturers, and so are frequently slow in volunteering possible solutions which they are unsure of, or opinions which they hold but know to be incorrect or inconsistent with the accepted scientific view. The pre-service teachers were instructed not to "Google" or research problem solutions before posting their initial attempts because achieving the "correct" answer was not the most beneficial outcome. It was explained to the pre-service teachers that their unresearched solutions were much more likely to provide insights into commonly held alternative conceptions and appropriate pedagogical approaches that could be used to shift their students towards an understanding consistent with the current scientific view.

Four qualitative discussion problems were initially designed to loosely target the Victorian state senior physics curriculum and provide a range in difficulty and context. Each problem although capable of numerical analysis did not require the students to provide more than a qualitative explanation of the solution with the possible addition of suitable evidence to support their thinking. However, in this pilot study students were

Fig. 2. – Two connected balloons.

deliberately given no instructions or models on how to compose or argue a convincing solution for their forum posts or for use in the face to face workshops.

## 5. – Discussion problems

Two of the four discussions problems used in the pilot study are included below with some analysis.

**5**˙1. *Discussion problem* (1) — *Two connected balloons*. – Two balloons with similar properties are inflated to different diameters and connected by a short length of tube as shown below (fig. 2). The tube is initially clamped tight to prevent any air flow but then released. Both balloons are free to expand or reduce to accommodate a change in volume as needed. Will there be any change in the balloons when the air is able to flow freely between them? Describe what will happen. What do you think your students would predict will happen and why?

**5**˙2. *Discussion problem* (2) — *Weighing your finger in a glass of water*. – A beaker containing a small measure of water is placed on an electronic balance. The weight is recorded and a finger is lowered into the beaker until it is partially submerged but not touching the beaker as shown in fig. 3 below. Will the weight of the beaker stay the same or change and if so how? Discuss how you arrive at your solution. What do you think your students would predict and why?

**5**˙3. *Preliminary findings and analysis of online posts*. – As stated, this research was undertaken in the form of a small pilot study consisting of just four discussion problems for use with 23 pre-service teachers. The anecdotal evidence used to gauge the impact of this approach is based on an analysis of 87 solutions posted to the online forum and the interpretation of the lively discourse generated during the four face to face workshops (approx. one hour of discussion in total) where the solutions were debated and defended by many of the pre-service teachers. In addition, the students were asked to complete written reflections on their learning at three points throughout the 12 week unit and many of these contained comments about their experiences with the problems. As a consequence of research ethics compliance, none of the pre-service teacher responses from the study will be quoted, however their general analysis by the researchers will be used to assess the impact of the argumentation approach trialled and to shape the design of a more qualitative research methodology for future study.

Fig. 3. – Weighing your finger in a glass of water.

**5**˙4. *Discussion problem* (1) — *Two connected balloons*. – The task was new and understandably many of the pre-service teachers described feeling unsure about the format of their online response. The average response was 160 words with 16 pre-service teachers posting correct and 10 posting incorrect solutions to the problem. Of the 16 correct solutions, 13 constructed arguments that were consistent with Toulmin's argument schema, in which they included a claim (*e.g.* the small balloon would reduce in size while the large balloon would increase), evidence (*e.g.* it is harder to blow up a small balloon because the internal pressure is higher than in a larger balloon) and a supporting warrant (*e.g.* identifying the Young-Laplace or Laplace's pressure equations for gas bubbles in a liquid) to construct their argument. All 10 incorrect proposals were poorly constructed with a tentative, incorrect or ambiguous claim. A number of these also attempted to use a warrant instead of evidence to support the claim or used a warrant which identified an alternate physics law which was not applicable to the context.

**5**˙5. *Discussion problem* (2) — *Weighing your finger in a glass of water*. – Most pre-service teachers posted succinct online responses to the second problem. The average response was 136 words with 18 pre-service teachers posting correct solutions stating that the weight of the beaker increases, compared with just four posting incorrect or confused responses with no clear claim. The 18 correct solutions all appeared to reflect reasoning consistent with Toulmin's argument schema and many showed greater attention to the choice of relevant evidence (*e.g.* identifying the existence of reaction forces) and relevant warrants (*e.g.* buoyancy forces, Archimedes principle or Newton's third law) compared with the previous problem. The majority of solutions were better constructed and argued than in the previous problem with a higher proportion achieving a correct solution compared with the first problem. This improvement may reflect a problem which is less counterintuitive than the first or it may be more likely the result of improved efforts to research the answer in an attempt to ensure an improved chance of a correct solution. A small number of the pre-service teachers admitted to investigating the solution at home using kitchen scales and a glass of water to explore the answer before attempting the online posting.

**5**˙6. *Preliminary findings — analysis of workshops and reflective comments*. – The vast majority of pre-service teachers reported finding the problems highly engaging and they particularly welcomed the opportunity for a follow up face-to-face workshop to debate the range of alternate arguments posted online. Several pre-service teachers described the discussion problems and their analysis as one of the highlights of the unit with more than half the cohort acknowledging their benefits in their reflective comments. No negative comments regarding their use were recorded and only a few students remained ambivalent to their inclusion in the unit. Anecdotal comments made during the workshops suggested that many of the pre-service teachers admitted to undertaking some cursory internet research to investigate the problems before posting their solutions to ensure their attempted answers were "on track". Given the nature of ubiquitous Wi-Fi and easy access to mobile devices it remains unclear how this form of investigation could be completely discouraged other than by rationalising the intent of the exercise as was attempted.

Approximately half of the pre-service teachers acknowledged in their reflective comments the benefits of the workshop discussion in making explicit the range of alternative conceptions relevant to the problem contexts. Many reported that they felt these insights would enable them to make better informed pedagogical choices and equip them to more skilfully address the range of alternate views likely to be encountered in their classrooms. Some pre-service teachers recounted how they had introduced some of the problems into their practicum classrooms where they had caused considerable debate and discussion to the interest of their teacher mentors. The comments and feedback from the pre-service teachers suggests that the face-to-face workshops were instrumental in providing them with highly interactive forums in which they could construct logical arguments and verbally present them to their peers for critical comment. Several pre-service teachers reported that they welcomed the opportunity to test their thinking against the expert knowledge of other physics content specialists. Several pre-service teachers also remarked that their introduction to an argumentation framework was valuable and not something that they recall encountering during their undergraduate or post graduate studies in science.

The face-to-face workshops provided valuable opportunities for the pre-service teachers to present and refine ideas and develop their skills in the construction and critique of logical arguments. During the first two workshops the pre-service teachers were comfortable with contributing ideas and analysis in a general class discussion managed largely by one of the researchers. However, in the final two workshops, several individuals volunteered to present their solutions as a starting point for class critique and this learner centred approach appeared to generate engaging discussion resulting in more polished and logical argument development. Eventually, the vast majority of the class members appeared to be quite satisfied with the solutions, which were improved through a process of class consensus.

## 6. – Conclusions and opportunities for further research

The preliminary findings suggest that the use of discussion problems can act as a positive stimulus for pre-service science teachers to consider the merits of adopting an argumentation framework in their professional practice. In addition, the careful choice of suitable problems can promote considerable debate and assist pre-service teachers to reflect on the potential range of alternative conceptions they are likely to encounter among their students for specific physics contexts. Equally important for the preparation of skilled science teachers is the development of their pedagogical content knowledge and a growing awareness of how skilled pedagogical choices can successfully challenge and shift their students' understanding to better reflect the current scientific explanation. Critical to the success of this approach is the fostering of trusting relationships within the class where pre-service teachers can feel at ease in sharing their alternate understandings with their peers without the pressure to always be seen as "correct". Although the researchers acknowledge the limited nature of this pilot study, they are encouraged by the preliminary findings and suggest that an expanded investigation that considers alternate instructional approaches and the use of rich technology may better promote the use of productive argumentation in science classrooms.

## REFERENCES


[1] Bell P. and Linn M., *Int. J. Sci. Educ.*, **22** (2000) 797.
[2] Bricker L. A. and Bell P., *Sci. Educ.*, **92** (2008) 473.
[3] Bybee R. W., *Achieving scientific literacy: From purposes to practices*, Vol. **88** (Heinemann,Portsmouth NH) 1997.
[4] Driver R., Newton P. and Osborne J., *Sci. Educ.*, **84** (2000) 287.
[5] Duschl R. A. and Osborne J., *Stud. Sci. Educ.*, **38** (2002) 39.
[6] Goodlad J. L., *A place called school: Prospects for the future* (McGraw-Hill, NY) 1984.
[7] Kuhn D., *Sci. Educ.*, **94** (2010) 810.
[8] Kuhn D., *The skills of argument* (Cambridge University Press, Cambridge UK) 1991.
[9] Kuhn L. and Reiser B., *Students constructing and defending evidence-based scientific explanations in Annual meeting* (National Association for Research in Science Teaching, (NARST), Dallas, USA) 2005.
[10] Kuhn D. and Pease M., *Cognition Instruct.*, **26** (2008) 512.
[11] Laugksch R. C., *Sci. Educ.*, **84** (2000) 71.
[12] Newton P., Driver R. and Osborne J., *Int. J. Sci. Educ.*, **21** (1999) 553.
[13] Norris S. P. and Phillips L. M., *Sci. Educ.*, **87** (2003) 224.
[14] Osborne J., *Stud. Sci. Educ.*, **48** (2012) 119.
[15] Sampson V. and Clark D. B., *Sci. Educ.*, **92** (2008) 447.
[16] Shamos M. H., *The myth of scientific literacy* (Rutgers University Press, New Brunswick, NJ) 1995.
[17] Shulman L. S., Those who understand: Knowledge growth in teaching, *Educ. Res.*, **15** (1986) 4.
[18] Simosi M., *Argumentation*, **17** (2003) 185.
[19] Toulmin S., *The layout of arguments*, in *The Uses of Argument.*, edited by Toulimin S. (Cambridge University Press, Cambridge) 1958, pp. 94–145.
[20] Van Eemeren F. H. and Grootendorst R., *A systematic theory of argumentation: The pragma-dialectical approach*, Vol. **14** (Cambridge University Press, Cambridge UK) 2004.
[21] Van Eemeren F. H., Grootendorst R. and Henkemans A. F. S., *Argumentation: Analysis, evaluation, presentation* (Routledge, London) 2002.
[22] Wellington J. and Osborne J., *Language and literacy in science education* (Open University Press, Buckingham UK) 2001.