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A Critical Review of Scientific Argumentation in Science Education

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ABSTRACT

The use of argumentation in science education is associated with many benefits. Some of these include developing critical skills, promoting spirit of enquiry, enhancing conceptual understanding and improving academic performance of students. However, there are also some issues and challenges while using argumentation in science classrooms. This research will discuss the strength of using scientific argumentation in science education. The findings from other such studies will also be critically reviewed to seek an in-depth understanding of the use of argumentation in teaching and associated challenges. The research would help in improving the use of argumentation in teaching and exploring solution to problems and challenges associated with this method.

Keywords: argumentation, dialogic learning, improvement, performance, science teaching

INTRODUCTION

Argumentation is a social and dynamic process, involving individuals engaged in thinking, constructing and critiquing knowledge (Wegerif, 2007; Golanics & Nussbaum, 2008; Ford, 2008; Berland & Reiser, 2009; Osborne & Patterson, 2011). It encompasses a statement or a claim that is backed by at least one reason (Angell, 1964) and involves at least two individuals or more (Iordanou, 2013). It is imperative that the two persons involved in argumentation listen to each other as this would help in identifying weakness in opponent's argument followed by counter argument (Iordanou, 2013).

One of the goals of teaching science at school is to enable the students learn scientific concepts however; equally important is supporting them in learning scientific argumentation (Bricker & Bell, 2008). This seems to be an overestimated statement on argumentation. The research literature on the use of argumentation in teaching has momentously increased during recent decades (Driver, Newton, & Osborne, 2000; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Zohar & Nemet, 2002; Kelly & Takao, 2002; Erduran, Simon, & Osborne, 2004; Venvill & Dawson, 2010; Kaya, Erduran, & Cetin, 2012). As a novel method in teaching socio-scientific topics, it secured a place among the top cited articles since the beginning of the present century (Osborne, Christodoulou, Howell-Richardson, & Richardson, 2013; Erduran et al., 2004). Argumentation was found to improve students' conceptual understanding, helping them in making informed decisions and enabling them to work the scientist's way (von Aufschnaiter, Erduran, Osborne, & Simon, 2008; Sampson & Clark, 2009; Jimenez-Aleixandre & Pereiro-Munhoz, 2002; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Nussbaum & Sinatra, 2003; Faize, 2015). The benefits associated with argumentation increased, as more researchers undertook different dimensions and experimented with different models of argumentation (Toulmin, 1958; Walton, 1996; Foong & Daniel, 2010; Venvill & Dawson, 2010; Erduran et al., 2004). The findings and results of these studies though interesting and novel yet need to be scrutinized and analyzed critically.

This study would critically discuss and analyze the research literature on argumentation, with the aim to provide educational researchers a deeper understanding of the method and through its limitations, outline further areas of research on argumentation. In order to follow sequence of ideas in this paper, we begin with explaining the concept of argumentation, the structural problems, dialogic problems and application problems associated with the use of argumentation in education.

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Contribution of this paper to the literature

- This research would critically discuss various issues and problems in the use of scientific argumentation in education and would offer suggestions to tackle these problems.
- This study offers critical reflection on the use of scientific argumentation and encourages the need for developing new instructional models to scaffold argumentation in science teaching.
- The paper would help in identifying key questions in scientific argumentation that requires further exploration and research for promoting effective use of argumentation in teaching and learning.

UNDERSTANDING ARGUMENTATION

Argumentation in science education is quite different from the sense it is used in daily life. It is not a 'heated exchange' of opinions and emotions between two rivals aimed at defeating each other (Duschl, Scweingruber, & Shouse, 2007; "Scientific argumentation," 2013). In fact, it is a logical and rational discourse aimed at finding relationship between ideas and evidence (Duschl et al., 2007). Moreover, it involves development, evaluation and validation of scientific knowledge (Driver, Newton, & Osborne, 2000) and knowledge construction (Ford, 2008). The essence of scientific argumentation is thus to make a claim, refined and then supported on the basis of scientific evidences (Norris, Philips, & Osborne, 2007). The scientists consumes a great deal of time in assessing, critiquing and defending the evidences to convince others in favor of their argument (Sampson, Enderle, & Grooms, 2013). Thus, scientists have a developed potential to indulge in scientific argumentation. However, students require certain specific abilities in order to engage productively in scientific argumentation. The first is the ability to understand and use some sort of conceptual framework (theories, principles, laws, models etc.) while reasoning about a scientific issue or problem. Secondly, the use of correct epistemology for evaluating a claim. Lastly, the ability to construct and communicate knowledge as a social interaction process (Duschl, 2008). The issue here is: do majority of students really possess these abilities require for engaging in scientific argumentation. Unfortunately, the answer is 'no' especially for school students (National Research Council, 2008) making them struggle to find relevant data to support their claim and provide evidence (McNeill & Krajcik, 2007).

Jonassen and Kim (2010) explained the process of involving students in argumentation. The first thing is the provision of suitable and stimulating learning environment such as problem-based or project based learning environment. This may include socio-scientific issues that involve diverse responses and explanations. Secondly, the students should be provided with clear set of instructions and information about the structure/components of argumentation. Thirdly, the students should be encouraged to think and ask questions. Usually, controversial type of questions help more in setting the ground for discussion and cross-questions. This sets the pace for collaborative argument that encourages dialogic interaction and collaborative reasoning. Such kind of interaction make the students support their views through valid evidences and challenging opposite views with countering ideas.

Argumentation in education can be understood in structural and dialogic context. In structural context, it refers to a particular structure of discourse involving certain components (Toulmin, 1958; Sampson & Clark, 2009). This makes argumentation distinctive from explanation that focuses on causal description of an event involving certainty while, argumentation invites diverse opinions with both parties giving justifications for their claims (Ohlsson, 2002). The conclusion in argumentation unlike explanation is less certain (Osborne et al., 2011), tentative and is subject to criticism and refutation (Nussbaum, 2011). Students' involvement in argumentation require an explanation or decision to a research question which shall be supported by some evidences based on empirical data and include the use of scientific principles, theories, models etc. (Sampson, Grooms, & Walker, 2011). This is illustrated in **Figure 1**.

In dialogic context, argumentation refers to some interactive process between/among individuals convincing other side to accept/favor a particular stand (McNeill & Pimentel, 2010). This results in critiquing opponent's claim through counter arguments involving a dialogic interaction (McNeill & Knight, 2013). Thus, the main goal of argumentation is to support one's argument and to undermine the opponent's position through identifying weakness in the opponent's argument (Walton, 1989).

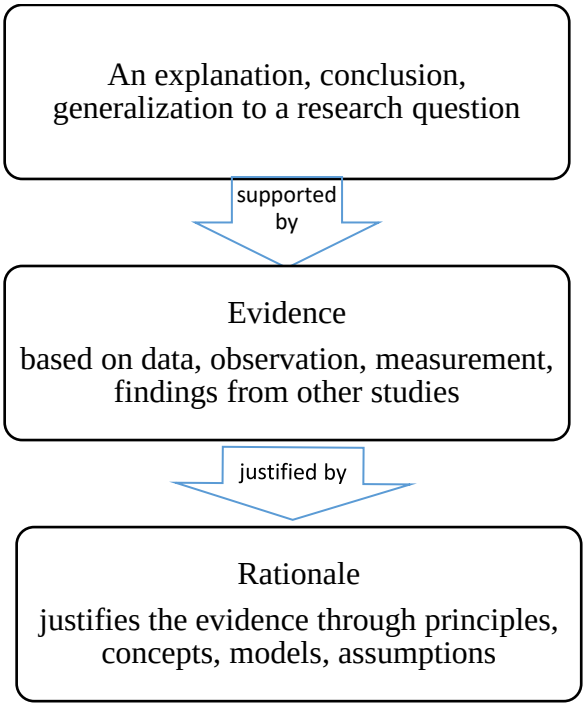

Figure 1. Concept of Argumentation adopted from Sampson, Grooms, and Walker (2011)

SCIENTIFIC ARGUMENTATION AS PROBLEM SOLVING

Another dimension of understanding argumentation which is quite different is the application side which describe argumentation as a scientific practice for solving problems and to advance knowledge (Duschl & Osborne, 2002).

This can be further explained with reference to two dimensions: argument constructed by students and argument constructed by scientists. The question here is: Are these two kinds of arguments of similar nature or they differ in any aspect. Considering this concept, it seems that students' argumentation as a process do not generate new information the way scientist construct knowledge. Scientific argumentation presented by a scientists are based on some specific experimental design and interpretation of data with reference to some theories (Druker, Chen, & Kelly, 1996). Another dimension of scientists' argumentation is its dissemination among public through conferences, research journals and media which helps in validating scientific argument and ensures quality control in science field unlike student's argumentation (Driver et al., 2000).

It is also important to distinguish between the 'natural world' and 'our knowledge' about that world. The natural world exists with its specific laws and properties which is independent of our understanding of that world as we don't have direct access to it. Thus, the scientists construct knowledge about the natural world which is a social construction to understand the hidden reality. Such kind of situation and opportunities can be created in science classrooms whereby a teacher may invite students towards different lines of rational thinking to construct knowledge through reasoned arguments like a scientist (Driver et al., 2000). However, a scientist might involve in a monologic and not a dialogic interaction to construct new information. This contradicts Wegerif (2007), Golanics and Nussbaum (2008), Ford (2008), Berland and Reiser (2009), and Osborne and Patterson (2011) that argumentation is a social and dialogic process. The question here is what about counter-argument and critiquing new knowledge for a scientist engaged in monologic interpretation. In this case, the role of critiquing knowledge is taken by the scientist him/herself to strengthen and validate one's claim/belief.

However, conducting argumentation with science students is impeded by the teacher centered classroom structure in which the teacher initiates a question to which the students respond in seconds with a single word or phrase. Such power relations do not encourage classroom discourse and dialogic interaction (Duschl & Osborne, 2002).

STRUCTURAL PROBLEMS IN ARGUMENTATION

Many of the research studies on scientific argumentation have focused on the structural context (Erduran et al., 2004; Osborne et al., 2004; Venville & Dawson, 2010; Foong & Daniel, 2010; Sadler & Fawler, 2006; Foong & Daniel, 2013). These studies also vary with respect to the number of components in an argument. According to Toulmin (1958), the pioneer on the work with argumentation, there are six components in a good argument. They are claim, data, warrants, qualifiers, backing and rebuttals. Claim is the statement that is being argued or simply it is making a decision or a conclusion. Data is the evidence used to assert the claim. Warrants are logical statements that link data with claim. Qualifiers impose conditions for the arguments to be true thus, it delimits the strength of an argument and sets its boundaries and intensity. Backing does not prove argument directly but rather it provides support to warrant. Rebuttal offers circumstances under which the person holding a particular claim may revise or give up one's claim. The person making a rebuttal challenges the opponent's view by pointing to certain weakness in the argument indicating high order thinking skills (von Aufschnaiter, Erduran, Osborne, & Simon, 2008; Toulmin, 1958).

A decision/claim is the simplest component and rebuttal is the most complex as well as the most significant element in determining the quality of an argument (Foong & Daniel, 2013). Rebuttal is valued as it indicates higher order thinking skills (Chang & Chiu, 2008; Lin & Mintzes, 2010). As rebuttal in an argument becomes more prominent and clear, the quality of argument improves, for it helps in assessing the validity and strength of the claim (Erduran et al., 2004). According to Kuhn and Pease (2006), a quality argument should concentrate on counter-argument and rebuttal. However, constructing a rebuttal is not easy and many studies have found that individuals struggled with constructing rebuttal even after repeated interventions (Osborne, Erduran, & Simon, 2004; Chang & Chiu, 2008; Simonneaux & Simonneaux, 2009; Lin & Mintzes, 2010; Topcu, Sadler, & Yilmaz-Tuzun, 2010; Ryu & Sandoval, 2012; Foong & Daniel, 2013).

These components also form the basis for analysing the quality of an argument in education (Jimenez-Aleixandre et al., 2000; Erduran et al., 2004; Venvill & Dawson, 2010; Zohar & Nemet, 2002). It is not necessary that all the six components are present in any argument (Toulmin, 1958). However, the more than the number of components, the more forceful and stronger would be the quality of an argument (Nussbaum, 2011).

One of the problem with Toulmin's components is that they are bleak and sometime it is very difficult to distinguish the components from one another, such as data, warrant and backing (Erduran et al., 2004; Erduran, 2008; Kaya, 2013). This problem was solved by Osborne, Erduran and Simon (2004) through collapsing data, warrant and backing into a single component named 'grounds'. However, a ground may be rich or poor depending upon the descriptions used in the ground for supporting a claim/decision. If the ground has no description, then it will be weak and thus will be given zero score to quantify the argument. The more the number of descriptions, elaborations/examples to support a claim, the stronger will be the ground and more score will be assigned to the argument (Chang and Chiu, 2008). Thus, the scheme presented by Osborne et al. (2004) elaborated three components in an argument; claim, grounds and rebuttal which offers a simple way of assessing quality of argumentation. This arises a question: how to assess the quality of information present in the grounds. The key question is how a teacher will determine the quality of arguments presented by two or more students containing the same number of grounds/components. According to Sampson and Clark (2008), Toulmin's scheme is unable to determine validity of an argument. Nevertheless, Toulmin's argumentation model is useful in the class room discourse by helping students to take a position of either support or refutation on an issue (Simon, 2008).

DIALOGIC PROBLEMS IN ARGUMENTATION

Confrontation and Biases

According to Berland and Reiser (2009), sense making and persuasion are the two goals of scientific argumentation. Here a problem might arise when students are attending to persuasion; they might stick to their own ideas, value them more and consistently refute the arguments and evidences presented by others. This would result in confirmation bias producing confrontational situations. The teacher may avoid such situations through legitimization of disparate ideas. The teacher guides the students to listen and honor the views of students whose ideas are to be abandoned to save them from facing embarrassment and then through consensus, the conflicting and fallacious ideas are revised (Berland & Lee, 2012). However, legitimization of disparate ideas will pose serious threat in classes with large strength resulting in wastage of time and discipline problems. Thus, this limitation of argumentation needs further research and explorations.

Another problem is how the class will know which idea or argument is correct. Pollock (1997) claims that an argument is warranted if it is undefeatable. However, an argument which is undefeatable might be due to lack of sufficient knowledge with other students. According to Zohar and Nemet (2002), more than 80% of students'

argument are incorrect in science classrooms. In such case, even a fallacious argument might stand warranted and unchallenged. The teacher role would be important here in directing argumentation towards right course and with minimum intervention (Zembal-Saul, 2009).

However, the teacher might not be competent in conducting and facilitating such kind of dialogic interaction (Sampson & Blanchard, 2012) due to lack of relevant training in conducting argumentation (Driver et al., 2000). This is coupled by a very limited research conducted on argumentation in pre-service teacher training (Aydeniz et al., 2012; Ozdem at al., 2013; Zohar, 2008; Kaya, 2013). Thus, argumentation may result in confrontational situations and discipline problems leaving a bitter experience to students as well as teacher.

The problems become more acute for school going students (Lu & Zhang, 2013) and low achievers (Sampson & Blanchard, 2012). Argumentation may be effective to some extent at college level or above due to availability of threshold level of prior information not possible at elementary level (Sadler & Fawler, 2006). This contradicts Mcneill and Krajcik (2006) findings that all students are capable of constructing arguments.

Issue of Knowledge Discovery

Involvement in argumentation offers scientists ways of engaging in critical thinking to improve and discover new knowledge (Passmore & Svoboda, 2012) and to engage in sense making (Lawson, 2003; Duschl, 2000; Bricker & Bell, 2008; Chim & Osborne, 2010).

However, it is worth arguing whether students' involvement in argumentation generate new ideas and knowledge just like scientists do. Students include information in their argument of which they have prior knowledge. According to Duschl and Osborne (2002), prior knowledge is an important factor that affects and scaffolds new learning. Scientific discourse require knowledge of scientific theories and related evidences for supporting claims (Osborne, Erduran, & Simon, 2004). Any exploration of new knowledge by students may be subject to verifiability and further testability.

However, students lacking relevant information might broaden their knowledge through dialogic sharing of ideas between students possessing prior understanding as Venville and Dawson (2010) observed that dialogic interaction between peers facilitate class understanding. In most cases, students hold deeply rooted ideas that are even in conflict with the established science practices and beliefs (Duit & Treagust, 2017). Thus, it is imperative to properly stimulate students' prior knowledge for developing understanding, otherwise it will not help in developing rational thinking in students. Further, engaging students in argumentation does not result in new knowledge rather, it consolidates prior knowledge and beliefs (von Aufschnaiter, Erduran, Osborne, & Simon, 2008).

ISSUES IN UNDERSTANDING

Engaging students in constructing arguments has assumed a greater significance in both science and humanities subjects (Lu & Zhang, 2013). One of the most cited benefit is the improvement in conceptual understanding of the content discussed through argumentation method (Newton, Driver, & Osborne, 1999; Venvill & Dawson, 2010; Zohar & Nemet, 2002; Kaya, Erduran, & Cetin, 2012; Duschl & Osborne, 2002; Nussbaum, 2011; Driver, Newton, & Osborne, 2000). This result is concluded by assuming that the degree of understanding influences the quality and complexity of an argument (Venville & Dawson, 2012). The increased level of understanding results in more justifications to support an argument (Sadler, 2004). In fact, it might be more appropriate to conclude that improvement in argumentation skills and improvement in the degree of understanding occur simultaneously as prior knowledge helps in constructing arguments and the use of argumentation further improves the level of understanding (Rudsberg, Öhman, & Östman, 2013).

Psychologists view that argumentation involves high order thinking skills (Nussbaum & Sinatra, 2003) resulting in superior quality answers by incorporating valid justifications and refuting alternatives (Iordanou, 2013). When students are involved through argumentation, they start thinking rationally and present various evidences to support their claim. Their justification is challenged by others through counter arguments and suggesting other alternatives. This is followed by further clarifications and supporting evidences resulting in conceptual change (Newton et al., 1999). As scientific concepts are evaluated and judged in comparison with various alternatives, the short comings of various held beliefs are modified in the light of available evidence and criticism (Osborne et al., 2013).

Scientific argumentation involves prior knowledge and understanding related to an issue (Osborne et al., 2004; Sadler, 2004; Lawson, 2003). This helps the students in constructing arguments which shows that understanding existed even before constructing an argument and without prior knowledge, construction of argument is difficult (De Lima et al., 2010). It appears that if prior knowledge and understanding existed before the construction of an argument, then it is difficult to ascertain that understanding was caused by involvement through argumentation.

Meanwhile, it might be the improvement in conceptual understanding of other students who observe this argumentation process between students possessing relevant knowledge. Another explanation for improvement in conceptual understanding may be the restructuring of pre-instructional conceptual structures that helps in the acquisition of science concept through involvement in argumentation process (Duit & Treagust, 2017).

CONCLUSION AND RECOMMENDATIONS

The use of scientific argumentation in science classrooms though useful and interesting is still not without challenges. Conducting argumentation with students lacking prior knowledge or holding contradictory beliefs may pose issues of either accepting others argument or creating confrontational situations during class. Moreover, the benefit linked with improving conceptual understanding, discovery of new knowledge and developing critical skills needs further research in exploring the processes where by these benefits might be achieved. However, argumentation may be useful as a dialogic and interactive process in science education.

In order to engage students in scientific argumentation, there is a need for developing and encouraging the use of new instructional models that can provide ample opportunities for developing abilities require for scientific argumentation (Sampson et al., 2011). Moreover, the students shall be guided to understand the nature of scientific argumentation to prepare them to meet the new standard of science and scientific inquiry (Sampson et al., 2013).

Another strategy for developing argumentation skills in students might be offering them opportunities to talk to one another related to science. This would enable them to articulate reasons for their claim/decision to justify their stand. While, others will challenge their views and offer alternative answers thus improving conceptual understanding (Newton, Driver, & Osborne, 1999). Argumentation can also be introduced in science classrooms by facilitating students' discourse through encouraging questions, making decisions and justifying it through reasoned argument (Polman & Pea, 2001). The use of evidence is very important for giving explanation and supporting one's claim.

The problem of existence of prior knowledge for constructing argument can be tackled by suggesting some reading material to the class as home assignment. This would help the students in forming a minimum knowledge base for argumentation activity in the next class. It is also advisable that argumentation activity may be performed by forming small groups of students. This will further augment argumentation process through mutual interaction among the students. Even, the mutual discussion during argumentation and presentation of counter-arguments may be helpful to students in understanding and learning the relevant information. This can be justified by assuming that human learn in an environment of social interaction which may help in improving the overall performance of the sample under investigation (Vygotsky, 1978). If the science classrooms are to be made student-centered, it is imperative that argumentation may be given a central role in training of science educators (Duschl & Osborne, 2002).

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