THE USE OF MIND MAPPING SOFTWARE TO IMPROVE PRIMARY SCHOOL STUDENTS' ABILITY TO CONSTRUCT SCIENTIFIC ARGUMENTS

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ABSTRACT

The purpose of this study was to examine elementary school students' ability to construct scientific arguments. We set out to analyze students' arguments in aspects of structure and validity of claims, before and after instruction. Our hypothesis was that students' knowledge of the subject domain would affect their ability to construct scientific arguments; in addition, we hypothesized that a teaching intervention that aimed to promote collaborative exchange of ideas among students, provided available and contradictory evidence about a subject and enabled graphical representation of arguments, would help students improve the structure of their scientific reasoning. The samples of the study comprised 24 5th graders of a rural public elementary school in Cyprus. Students were asked to construct arguments about a controversial issue in ecology. Should the fox vulpes vulpes be protected or hunted? The arguments constructed by students were analyzed before and after the teaching intervention. The tool used for the graphical representation of arguments was "Reason!Able", a software package that helps the creation of simple diagrams of complex reasoning, in a way that makes discernible the building blocks of an argument. (http://www.goreason.com/). The results indicate that students used more claims to support an argument after gaining more information about the subject. The results also indicate that our teaching intervention was generally successful and that Reason!Able is an appropriate tool for argument mapping. The number of claims used in each argument was increased and the structure of arguments became more complicated. The results demonstrate conclusively that there was a general improvement in argumentation practice and give us hope that, within scaffolded environments, students can construct and improve their scientific argumentation skills.

KEYWORDS

Argumentation, mind mapping, graphical representation, critical thinking, scientific reasoning, learning environments

INTRODUCTION

The development of critical thinking is an important objective of contemporary education. Students, as members of the public, should improve their higher order thinking skills and be able to think critically about the important issues that affect their lives at local and global level; these are complex issues and their understanding and solutions require both scientific and critical thinking ability.

Argumentation practices in science classrooms help students become critical thinkers. Students should be given the opportunity to construct and evaluate arguments by considering the range of information sources available on particular issues (Driver et al., 2000). They should also be able to ask critically about the origin and reliability of evidence and learn how to use evidence to reach a conclusion.

The phrase "nature of science" typically refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 2002). Teachers' views about the nature of science affect both the content and the methods of their teaching.
If science is seen as an empirical process then claims to truth are grounded in observation and conclusions are seen as unproblematic deductions from those observations (Newton et al., 1999 p.555). Science is therefore presented as a linear succession of meaningful discoveries (Driver et al., 2000) and science teaching has the role of letting students learn about these discoveries through confirmatory experiments that present scientific claims as unproblematic. This authoritarian view of science facts within school science does not leave space for socioscientific issues to be raised as science is seen as a subject in which there are clear "right answers" and where data lead uncontroversially to agreed conclusions (Sandoval 2001; Driver et al., 2000). As a result, students do not have the ability to critically evaluate the scientific claims generated by the plethora of socioscientific issues that confront them in their everyday lives (Norris & Phillips, 1994; Solomon, 1991 as cited in Driver et al 2000, p.288).

On the other hand, if science is seen as a social process, empirical claims are not seen as unproblematic because observations are proved to be theory laden (Hanson 1958, Kuhn 1962 as cited in Newton et al., 1999). As a result claims have to be grounded through processes of argumentation, so that the available evidence can be connected to the theories of scientists. The social nature of science gives argumentation a central role in science education. Students need opportunities not only to hear explanations given by experts but also to engage in the process of evaluating alternatives ideas themselves in order to become familiar with scientific practice and ways of thinking. Students, according to Sandoval (2000), must be able to explicitly reflect upon what they know, how they know it, and why they believe it, in the same way that scientists do.

Argumentation, apart from an epistemic practice is a useful procedure for revealing students' own ideas. Intuitive ideas, prior experience and alternative ideas require discussion and argumentation to bring about belief revision and refinement of knowledge leading to conceptual change and development (Ravenscroft, 2000). It is important to give students the opportunity to construct their own knowledge socially, as scientists do. Talking and arguing in science lessons enables students to achieve conceptual change as they socially construct, and reconstruct, their own personal knowledge (Driver et al., 2000).

In addition, epistemological criteria that students formulate, can function as standards for evaluating not only others' but also their own scientific claims. This procedure, according to Hogan and Maglienti (2000) influences the way that people respond to anomalous data and undergo conceptual change. Students who see science as a dynamic enterprise of theory development are found to better integrate formal scientific conceptions with their everyday experience (Sandoval et al.,2000).

Argumentation, therefore, helps students learn about their own ideas and change them in the light of new evidence. However, students are not the only members of the classroom that should know about their ideas. The way a student argues and connects evidence to theory gives the teacher valuable messages about students' understanding of a topic (Touger et al, 1995 as cited in Krasidou et al., 2000) and therefore can be used as an alternative method of evaluation of students knowledge, either in the beginning or at the end of a lesson.

Argumentation practice affects students' epistemological beliefs, especially with respect to the social nature of science. Students' epistemological beliefs affect not only their conceptual understanding but the strategies they use to test any available evidence as well. Research has shown a correlation between elementary school students' use of controlled experimentation strategies and their epistemological beliefs about the nature of scientific knowledge construction (Sodian & Schrempp, 1997). Students who saw scientific claims as unproblematic were less likely to use controls in their own experiments than were students who understood science as a method that uses experiments to rule out alternative interpretations of results (Hogan and Maglienti 2001,pp.665). A crucial point in the investigation procedure that students should practice is the presentation of possible interpretations that come out of a set of data and their examination of the arguments for each in the light of evidence (Driver et al., 2000). Students should be given the opportunity for argumentation because it is the ultimate step in an investigation before accepting or not a knowledge claim.

In summary, we can say that argumentation practice affects students' epistemological understanding, enforces conceptual change and affects students' epistemic practices (Sodian & Schrempp, 1997; Hogan and Maglienti 2001; Driver et al., 2000). We could suggest, therefore, that learning environments should be designed in a way that support students to investigate, represent, communicate, assess, and evaluate knowledge claims.

THE STRUCTURE OF SCIENTIFIC ARGUMENTS

The construction of a scientific argument requires the expression of a conclusion, a final claim, that should be a logical consequence of data which must be supported by general laws that can by tested by experiment and observation. (Zuzovksy & Tamir, 1999) Toulmin describes argumentation as a rational procedure; many components contribute to this reasoning process that people follow - or should follow - to reach a conclusion or knowledge claim from specific data (Pilar, 1998). These components are described as follows:

a) **Data** – are the facts that support the claim
b) **Warrants** – the reasons (rules, principles etc) that justify the connections between the data and the claim
c) **Backings** – are the basic assumptions that provide the justification for the warrants
d) **Qualifiers**- they specify the conditions under which the claim can be taken as true; they represent the limitations of the claim.
e) **Rebuttals**- they specify the conditions when the claim will not be true
f) **Claim-** it is the conclusion (Driver et al, 2000 p.293)

The following figure presents the components of the argument model as described by Toulmin:

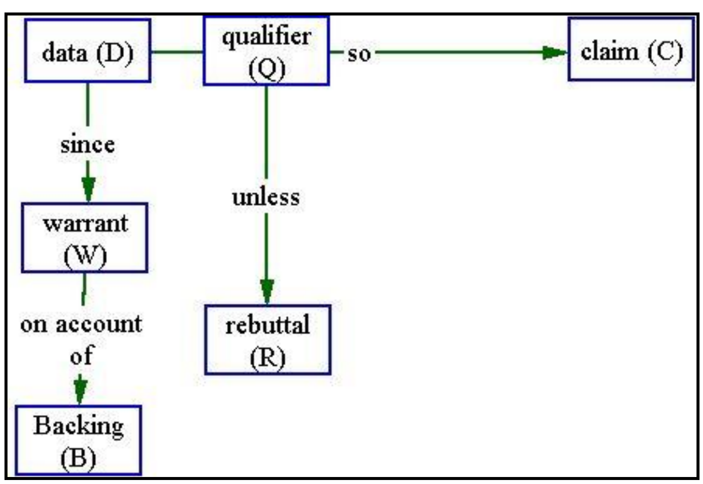


Figure 1. Toulmin's model components (modified from Kelly et al. 1996, as cited in Pilar 1998, pp.319)

Toulmin's model is very helpful in describing the relationship between evidence and knowledge claims. This relationship could be also be described by the D-N model (Deductive-Nomological model described by Hembel 1965, as cited in Zuzovksy and Tamir 1999, pp.1102) which has to satisfy certain logical and empirical conditions: A claim should be a logical consequence of data which must be supported by general laws – whether empirical generalizations or theoretical laws that can by tested by experiment and observation.

However, Toulmin's model is inadequate in describing the argumentation process, as it needs to be supplemented by social and psychological accounts when real life arguments are being analysed (Newton et al, 1999 pp.554) as well as by rhetorical and linguistic factors contributing to the construction of a scientific argument.

Argumentation, as defined above, is a complex procedure. Therefore, students´ ability to construct scientific arguments cannot be defined as a simple ability that students either have or do not. Argumentation ability is analyzed in several other abilities and can be better be described by the term "argumentation skills". One group of skills that students should have when constructing an argument concerns data handling, including, among others, the ability to cite sufficient and relevant data, critically evaluate data and distinguish data from explanations. Several studies reveal a number of difficulties related to data handling.

Students seem to understand that they need to cite some data to support their claims. However, they think that data "speak" for themselves and there is no need to interpret them. They usually just cite data, and in some cases describe it. They do not actually use data rhetorically to support their claims (Sandoval, 2001). The nature of argument, however, requires a scientific and rational conjecture between data and the claim, the conclusion. However students and nonscientist adults interpret the term "conclusion" in a broader everyday sense: They judge their conclusions according to whether they seem like reasonable things to say based not only on the evidence, but also on what they personally know and believe (Hogan and Maglienti, 2001).

Prior beliefs significantly influence the way that students respond to data as pre-existing concepts become the tools of thought and function as perceptual categories for observing phenomena (Bell, 1995). When presented with contradictory evidence students usually distort the evidence to adjust to their prior beliefs without necessarily being aware that they are doing so (Sodian et al., 1991; Shepardson, 1999; Bell, 1995). Apart from distorting the evidence, students are found to ignore data that they ought to consider when evaluating claims or assimilate such data in ways that do not damage their current theories (Chinn and Brewer, 1998; Kuhn et al., 1998). This may be a reason that students usually use only positive positions in order to support a claim and very rarely use counterarguments or present different points of view on the same issue (Driver et al., 2000).

The abilities concerning data handling, including evidence – theory and evidence – explanation distinction, are affected by several characteristics of the evidence such as the type of information provided as well as the amount and size of available evidence (Sanbonmatsu et al., 1997; Brem & Rips 2000). For example, students' ability to provide appropriate evidence is affected by the presence or lack of relevant data: if they do not have sufficient information their choice may not reflect their beliefs about what makes good evidence and as a result their choices become more extreme. Alternatively, participants' evaluation could be moderated by evidence availability (Brem and Rips, 2000). When evidence is present, they use it; but when evidence is scarce they turn to a consideration of plausible causal mechanisms.

In addition to characteristics of evidence, students' understandings of the concepts involved in the domain affect their interpretive frameworks and in turn their ability to evaluate data. Gaps in knowledge lead to other methods, not necessarily scientific, of evaluating data in order to fill them (Shepardson, 1999; Brem & Rips, 2000). Moreover, students' epistemological beliefs about the "source of knowledge" affect their evaluation of data, as they determine the way that students respond in the light of new evidence, especially when this evidence conflicts with their initial theory (Chin and Brewer, 1993 as cited in Mason, 1997; Samarapugavan, 1997 as cited in Hogan and Maglienti, 2001). As a result, students with a more dynamic view of the scientific process create arguments that include more multiple warrants in their scientific explanations (Bell, 1997). On the other hand, students whose beliefs about boundaries of knowledge were very restricted were prevented from noticing, receiving and considering new information that could helped to change their ideas about the topic of argumentation (Hogan and Maglienti, 2001). Finally, social factors may determine students' response to evidence, as young students- especially high school students- seek to belong to a social group and value conformity and harmony much more than criticism, negotiation and revising explanations. As a result the types of explanations provided by students in school settings are rather poor (Zuzovksy and Tamir, 1999).

Argumentation in science classrooms seems to be a difficult task. However, several studies give encouraging results about students who were engaged in argumentation activities in a well organized and scaffoled environment (Driver et al., 2000; Duschl et al., 1999;Bell, 1997; Sandoval, 2001). The study reported here used an argument-mapping tool available from *The Reason Group*, called Reason!Able to improve elementary school students' ability to construct scientific arguments. The main goal of this work was to analyze students' arguments in the aspects of structure and validity of claims, before and after instruction. Our hypotheses were that:

- Students' knowledge about a topic would affect their ability to construct scientific arguments
- A teaching intervention which would
    - promote collaborative exchange and discrimination of ideas among students
    - give available and contradictory evidence about a subject , and
    - "make things 'visible' by allowing graphical representation of arguments (Bell, 1997)

      would help students improve the structure of their scientific arguments.

METHODOLOGY

Overview of research design

The study was performed in April – May 2002. The participants in the study were 24 5th graders of a rural public primary school in Cyprus.

In the beginning place students were presented with a problematic situation in which the Ministry of Agriculture of Greece was sponsoring hunters for killing red fox as a species that was harmful, whereas a group of people were disagreeing saying that the red fox should be protected. No more information was given at this stage and students were asked to work in groups and write down what they believed about the issue (First response).

Afterwards, students explored the topic in a WebQuest environment. They learned about the topic by reading articles, interviews, and stories about the red fox from both points of view and, finally, decided what their position would be. Again they wrote down their arguments (Second Response).

Teaching Intervention

In this phase we stopped dealing with the red fox problem and the classroom became engaged in another controversial issue: *Genetically modified food*. The teaching intervention was conducted in the following stages:

- Students were informed about the topic in a WebQuest environment. They were assigned the role of a member of parliament who was responsible for voting on a law either for preventing genetically modified food, allow it or, finally, demanding for appropriate labeling such kind of food. As members of parliament, students were exposed to four different views from their counselors. (The lesson was adapted and modified from a unit on "Decisions – Decisions on line": GE Foods – http://www.tomsnyder.com/)

- Students engaged in an open discussion in the classroom, trying to defend the arguments presented by the counselors, which they represented (graphically or in paper and pencil). It was very helpful for children to see different points of view and try to engage in argumentation construction in order to convince a "neutral" group of students who were assigned the role of the parliament member.
- We then presented to the students "Reason!Able" software. Reason!Able is a software package that helps you build simple diagrams of complex reasoning, so that you can see the building blocks of an argument much more easily (http://www.goreason.com/). The tool was selected as appropriate for our teaching intervention because it enables students both to build and evaluate arguments. Its visual representation of claims and reasons (data and warrants), helps visualizing the relationships between the components of an argument. *Reason!Able* environment, in addition, prompts for arguments and counterarguments (rebuttals) in order to reach a final claim, thus helping students present a thesis other than their own as well. The software also provides opportunity for creating multireasoned as well as multileveled arguments.
- Students used Reason!Able to construct their arguments about genetically modified food.
- We helped students fill missing components from their arguments (i.e. objections), or organize better the structure of their final claims.

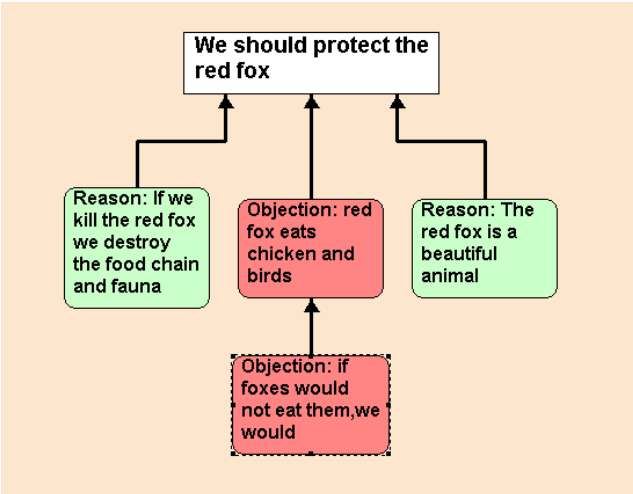
Post responses

After the topic on "Genetically modified food" we returned to the initial "red fox problem". Students used "Reason!Able" to construct arguments about the red fox on their own (Response 3). After that they had to compose their letter again, based on their argument structure, and send it to the Greek Ministry of Agriculture (Response 4).

Process of data homogenization

Our data consisted of both text and graphical representations in ReasonAble! In order to homogenize this data we converted text to diagrams, as in the following example:

Table 1. Convention of texts to diagrams for scoring purposes

Text *(Group 5, Response 1)*:	**Diagrammatic Representation in ReasonAble!**
"We believe that the red fox should be protected because it is a beautiful animal. Besides, if the red fox wouldn't eat chicken and birds, we (humans) would. In addition, we shouldn't kill the red fox because we are going to destroy the food chain and fauna."	

This conversion helped us group the responses and set common criteria for evaluating them.

Criteria for evaluating scientific arguments

Toulmin's model defines a framework for evaluating the logical structure of an argument. On one hand we can evaluate whether an argument contains the components mentioned by Toulmin and, on the other, evaluate the relationships among those components and their contribution to the final claim. Components alone are not enough to set a good argument as the *relations* between the various components of the argument determine its quality. Students should set specific *cause and effect* relations, which should be connected *logically* (Sandoval and Reiser 1997, p.7).

However, Toulmin's structure was not adequate for our purposes as it has several disadvantages:
Firstly, Toulmin's structure analyzes single arguments. However, arguments in real life are usually *complex*. Many interrelated reasons and objections can be found contributing to the reasoning process of reaching a final claim. Arguments can be both *multileveled* – where many reasons or rebuttals bear on a single conclusion- and *multilayered*- reasons or objections are further supported by premises. We could evaluate, then, not only the components of an argument but the complexity of its structure as well. Secondly, Toulmin's structure is "positively" situated and does not leave much space for counterarguments. Arguments and counterarguments should be treated equally in the process of reaching a final claim.

Finally, Toulmin's structure is very complicated for most primary school students.
As a result, we used a rather simplified framework for analyzing the structure of student's arguments. This framework was based on the D-N model, which serves as an assessment criterion according to which a statement (claim, explanandum) should be a logical consequence of the explanans (reasons, or objections). In addition we checked for the complexity of the arguments. The criteria for evaluating students' arguments were the following:

1. The number of claims used to support their final claim (both reasons and objections)
2. The percentage of *relevant* claims used to support their final claims
3. The existence of counterarguments (objections)
4. The number of levels in the argument.

RESULTS AND DISCUSSION

The criteria were used for analyzing the students' responses as shown in Table 2.

Table 2: Application of criteria for evaluating students' scientific arguments; average correspondence for all groups

	Average for all groups, n = 6 groups, N= 28 students			
Criterion	**Response 1**	**Response 2**	**Response 3**	**Response 4**
Number of claims	2,67	4,83	6,33	5,00
Percentage of relevant claims	97,17	100,00	91,83	96,67
Existence of counterarguments (Percentage of groups)	50,00	83,30	100,00	100,00
Number of levels in the argument	1,50	2,17	2,50	2,00

Table 3: Change with respect to the previous response

Average of all groups scientific Arguments, n = 6 groups, N= 28 students	**Response 1**	**Response 2**	**Response 3**	**Response 4**
Number of claims		81,25%	31,03%	- 21.05%
Percentage of relevant claims		2,92%	- 8.17%	5,26%
Existence of Counterarguments		66,60%	20,05%	0,00%
Number of levels		44,44%	15,38%	-20,00%

First Hypothesis:

Students' knowledge about a topic would affect their ability to construct scientific arguments

The first hypothesis was tested by comparing Responses 1 and 2. (The first Response about the red fox and the second response after reading the subject). The results indicate number of claims made by students increased by 81% , almost double the initial number of claims. This looks very reasonable, as children cannot present sufficient claims about a subject, unless they have an appropriate knowledge background. Gaining knowledge about a subject also affects the nature of their claims (Hogan and Maglienti, 2201 pp.665), as more groups provide now counterarguments, and the complexity of their arguments is improved (average before 50%, after 83,3%). The results implicate that if we want our students to engage in a good scientific discourse and construct good scientific arguments we should provide them with sufficient knowledge. Both data type and availability and conceptual understanding appear to affect students' ability for argumentation (Sanbonmatsu et al., 1997; Brem & Rips, 2000).

Second Hypothesis

A teaching intervention which would promote collaborative exchange and discrimination of ideas among students, give available and contradictory evidence about a topic, and "make things 'visible' by allowing graphical representation of arguments (Bell, 1997, p.4) would help students improve both the structure and the quality of their scientific arguments.

The second hypothesis was tested by comparing the results from Responses 2 and 3 (Diagrams in Reasonable! after teaching intervention).

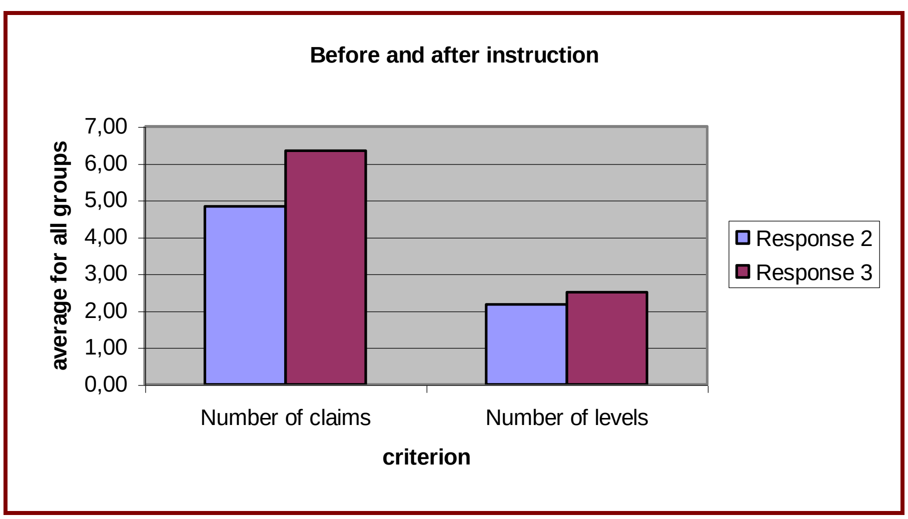


Figure2. Structure of arguments before and after using Reason!Able

As shown in figure 1 above, the results indicate that our teaching intervention was successful and that Reason!Able is an appropriate tool for argument mapping. The number of claims used in each argument was increased and the structure of arguments became more complicated, as most groups constructed multileveled arguments of 3 levels each, compared to the 2 levels, which was the dominant value before intervention. However, the ability that students show to provide more claims does not guarantee that these claims are relevant to the final claim; on the contrary, the fact that the procedure of adding reasons or objections to the argument structure in Reason!Able environment was very easy and let students add irrelevant claims more often than they did before instruction. This implicates that students need more practice in considering what is relevant or not.

Conclusively, we can say that the results show a general improvement in student performance and give us hope that within scaffolded environments students can construct and improve their scientific arguments (Bell, 1997 ; Duschl et al., 1999).

OTHER FINDINGS

Rhetorical Use of Data

Table 2 gives us precious information about students' ability to "write down" an argument in text format. A comparison between Response 3 – argument map constructed in ReasonAble! – and Response 4 – the text that was written based on the argument map- reveals several difficulties that students had in transforming the map to text.

Firstly, the number of claims decreases; this is might be due to children's inability to "rhetorically refer to data" (Sandoval 2000), even though they may cite it. They think that data "speak for themselves" and there is not need to provide any extra information to rhetorically support it. In our example, students omit some data and as a result "text" arguments have 76% of the claims that have been used in the argument map. A reason that let to these results, apart from students inability to rhetorically refer to data, might be the fact that they were tired and bored. Response 4 was the fourth time when children had to construct the same argument about the red fox. We have observed that they were not as enthusiastic as in the beginning of the study. In addition, we have to mention these students' dislike for any task that reminds them of "essay composition".

A second difficulty that we've noticed is that whereas argument maps have a high level of organization and complexity, written arguments present claims in a linear form one after the other with no sign of organization, combination or comparison with the use or proper conjunctions.

These results implicate that argument mapping is not the same ability as argument writing. If we are going to use argument mapping as a tool to improve argument structure, we also need to provide practice for transferring maps to text.

Implications For Teaching

Traditional science teaching does not empower students with the ability to argue scientifically through the kinds of socio-scientific issues that they have to face in their lives. However, pupils have to be equipped with the ability to think scientifically through everyday issues and argumentative practices will need to be a prominent feature of their education in science (Newton et al., 1999, pp.556). The results of this study demonstrate that children can construct scientific arguments; however there are many difficulties that they have to overcome.

There is a need of organizing science classrooms as knowledge building communities (Scardamalia & Bereiter, 1993 as cited in Sandoval et al., 2000 p.6) in which discussion and debates about claims and evidence are central activities. Rich problem contexts allow debate over alternative explanations (Sandoval and Reiser, 1997). Scaffolded learning environments have to be designed very carefully for promoting students' argumentation in science classrooms.

In addition, teachers have to become familiar with argumentation practice in their classrooms as well as managing a classroom discussion effectively, which is a difficult pedagogical task (Sandoval and Reiser, 1997 pp.3).

Critical thinking should not only be a central purpose of our curriculum for young students, but also should characterize teachers and curriculum developers. As they gain these skills, they will surely have very different approaches about science teaching and argumentation practice in science classrooms.

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