LEARNING TO TEACH ARGUMENTATION: CASE STUDIES OF PRE-SERVICE SECONDARY SCIENCE TEACHERS

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ABSTRACT. The article presents a case for the promotion of argumentation in science in preservice teacher education. In recent years, argumentation has emerged as a significant goal for teaching and learning of science. As an important aspect of scientific inquiry, argumentation plays a role in the generation and justification of knowledge claims. The theoretical background on the role of argumentation is reviewed and an empirical study is reported on the ways in which teacher training can be supported in the use of argumentation in science classrooms. Case studies of two Turkish teachers are used to illustrate how teachers structure lessons and support argumentation in secondary science classrooms after a series of training sessions. Results indicate that the teachers incorporated those features of pedagogical strategies (e.g. group discussions and presentations) targeted by the training.

KEYWORDS. Argumentation, Teacher Education, Case Studies.

INTRODUCTION

Argumentation is nothing new under the sun. Some of the great thinkers in the history of humanity, such as Plato and Aristotle, have been engaged in argumentation. Many domains, including many world religions, politics and law have relied on the use of argumentation. When we turn to science, we witness that the very establishment that we call 'science' is based on argument. Scientists use arguments to establish theories, models and explanations about the natural world. Consider a recent piece of news about a previously undiscovered feature of the Solar System observed by astronomers using California's Palomar Observatory. A new planet has been given the name 'Sedna' after the Inuit goddess of the ocean. Astronomers now say they have evidence that Sedna has its own moon, although this needs to be confirmed. There is likely to be some debate about whether Sedna really qualifies as a true planet but some scientists are already saying it re-defines our Solar System. The emergence of new evidence prompts scientists to reconsider our models, theories and explanations and to argue for the revision or the abandonment of existing knowledge.

When we turn to science education, we are faced with the fact that we don't do enough

justice to the teaching and learning of argumentation and as such, even graduates of science programmes are typically unable to provide evidence and justification to some of their claims about the natural world. Try asking any group of people the reasons for believing in the following fundamental tenets of contemporary science: that day and night are caused by a spinning Earth; that matter is made of atoms; that diseases are caused by tiny living microbes. Few, if any, are able to provide the seminal piece of evidence for the first about day and night (Durant, Evans & Thomas, 1989) let alone the evidence for the other axiomatic beliefs of science.

Such failings expose the weakness of a science education, a science education that has placed its emphasis on what should be believed in rather than why something should be believed in. Without question, arguments from authority are a justified and legitimate form of argument. However, the predominance of such forms of argument in the science classroom undermines the rationale for a discipline that is distinguished by its central commitment to evidence as the basis of justified belief and the rational means of resolving difference and controversy (Siegel, 1989). Failure to emphasise and foreground the distinctive hallmark of science is ultimately self-defeating leaving students with beliefs that they are unable to justify to others.

In the science classroom, argument often becomes a monologue, a one-way conversation where the pupil cannot engage in genuine questioning of their teacher because they lack the resources to challenge or question the assertions of the teacher. The result is that the world is portrayed as a set of absolutes, characterised by 'right' and 'wrong' answers with the origins of scientific ideas, their metaphorical roots, and any element of uncertainty simply excised. Restoring the consideration of evidence, reasoning and argument requires instead the recognition of a contemporary model of science.

Giere's model is an attempt to capture the fact that scientists are involved in studying the material world (Giere, 1991). In that process they gather data from instruments and measurements and they develop models of how they think the world behaves. These models allow them to make predictions that they then test. What Giere's model demonstrates is that observation and experiment are the handmaidens to generating arguments about the fit, or lack of it, between theory and data. For data lead to models and theories, models lead to arguments about which evidence is significant, and data, in turn lead to arguments about the success or failure of theories. In short, there is a complex cyclical and reflexive interaction between models and evidence to which evaluative argument makes a central contribution.

Are our efforts for changing the curriculum consistent with such views on science? Science education curriculum innovations in science like those sponsored by the Nuffield Foundation in the UK and the National Science Foundation in the USA in the 60s and 70s, have had little impact on the practices of science teachers (Welch, 1979). Four decades after Joseph Schwab's argument that science should be taught as an 'enquiry into enquiry', and almost a

century since John Dewey advocated classroom learning be a student-centred process of enquiry, we still find ourselves struggling to achieve such practices in the science classroom. Witness the publication of Inquiry and the National Science Education Standards (National Research Council, 2000), and the inclusion of 'scientific enquiry' as a separate strand in the English and Welsh science national curriculum (DfEE, 1999).

Such recent policy level arguments serve as signposts to an ideological commitment that teaching science needs to accomplish much more than simply detailing what we know. In addition to teaching the content of science, of growing importance is the need to educate our students and citizens about how we know, and why we believe in the scientific world view e.g., science as a way of knowing (Duschl, 1990; Driver et al., 1996). Such a shift requires a new focus on (1) how evidence is used in science for the construction of explanations – that is on the arguments that form the links between data and the theories that science has constructed; and (2) the development of an understanding of the criteria used in science to evaluate evidence and construct explanations.

In this paper, we present a case that argumentation should be a central aspect of science teaching and learning. Like any unfamiliar or relatively underemphasized strategy, the execution of argumentation in real science classroom will demand more than rhetoric. It will necessitate long-term and supportive professional development of science teachers. We begin our discussion by first establishing the status of research in science education in recent years. Here we visit the theoretical and empirical aspects of the work on argumentation. The emphasis will be on teaching and in particular on professional development of science teachers to facilitate the teaching and learning of argumentation in science classrooms. We then turn our attention to some research outcomes from a project that involved the training of preservice science teachers to implement argumentation in their classrooms. We conclude with some implications for future studies in argumentation in science.

ROLE OF ARGUMENTATION IN SCIENCE EDUCATION

Over the past few decades numerous studies have focused on the analysis of argumentation discourse in educational contexts (e.g, Driver, Newton, & Osborne, 2000; Duschl, Ellenbogen & Erduran, 1999; Erduran, & Jiménez-Aleixandre, in press; Erduran, 2006;Kelly & Takao, 2002; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000). These studies have highlighted the importance of discourse in the acquisition of scientific knowledge (Boulter & Gilbert, 1995; Pontecorvo, 1987; Schwarz, Neuman, Gil, & Ilya, 2003) and the development of habits of mind in science (e.g. Kuhn, 1970). The implication is that argumentation is a form of discourse that needs to be appropriated by children and explicitly taught through suitable instruction, task structuring and modelling (e.g. Mason, 1996).

Recent approaches have thus framed science learning in terms of the appropriation of community practices that provide the structure, motivation and modes of communication required to sustain scientific discourse (Kelly & Chen, 1999; Lemke,1990). These approaches stand in sharp contrast to the traditional views of science learning that focus on outcomes such as problem solving (Gable & Bunce, 1984), concept learning (Cros, Chastrette & Fayol, 1987) and science-process skills (Heeren, 1990). Science learning is thus considered to involve the construction and use of tools which are instrumental in the generation of knowledge about the natural world. In this framework, argumentation is a significant tool instrumental in the growth of scientific knowledge (Kitcher, 1988) as well as a vital component of scientific discourse (Pera, 1994). Argumentation plays a central role in the building of explanations, models and theories (Siegel, 1991) as scientists use arguments to relate the evidence they select to the claims they reach through use of warrants and backings (Toulmin, 1958).

The philosophical and cognitive foundations of argumentation have played a central role in the justification of research in argumentation in science education (e.g. Duschl & Osborne, 2002; Erduran & Osborne, 2005). Contemporary perspectives in philosophy of science (e.g. Giere, 1991; Kitcher, 1988) emphasize that science is not simply the accumulation of facts about how the world is. Science involves the construction of theories that provide explanations for how the world may be. In proposing provisional explanations for the underlying causes of events, theories are open to challenge and refutation (e.g., Popper, 1959). Science often progresses through dispute, conflict and argumentation rather than through general agreement (e.g, Kuhn, 1970, Latour & Woolgar, 1986). Thus, arguments concerning the appropriateness of experimental design, the interpretation of evidence and the validity of knowledge claims are at the heart of science, and are central to the everyday discourse of scientists. Scientists engage in argumentation and it is through this process of argumentation within the scientific community that quality control in science is maintained (Kuhn, 1992).

Beyond coherence with current philosophies of science, there are cognitive values of argumentation in science education. From the cognitive perspective, to the extent that argument involves the public exercise of reasoning (Kuhn, 1992; Billig, 1996), lessons involving argument will require children to externalise their thinking. Such externalisation requires a move from the intra-psychological plane, and rhetorical argument, to the inter-psychological and dialogic argument (Vygotsky, 1978). When children engage in such a process, and support each other in high quality argument, the interaction between the personal and the social dimensions promotes reflexivity, appropriation and the development of knowledge, beliefs and values. Furthermore, to grasp the connection between evidence and claim is to understand the relationship between claims and warrants and to sharpen children's ability to think critically in a scientific context, preventing them from becoming blinded by unwarranted commitments (Quinn, 1997).

From the sociocultural perspectives on cognition, argumentation is a critical tool for science learning since it enables within learners the appropriation of community practices including scientific discourse (Kelly & Chen, 1999). If enculturation into scientific discourse is significant to science learning, then it becomes imperative to study such discourse to understand how the teaching and learning of argumentation can be traced, assessed and supported. In this sense, the improvement and development of tools for capturing implementation of significant features of argumentation becomes a major concern for science education research.

SCHOOL-BASED RESEARCH IN ARGUMENTATION

In our work with secondary teachers and students in the United Kingdom, we investigated strategies and resources for promoting and sustaining argumentation in the science classroom (Erduran, Simon & Osborne, 2004; Osborne, Erduran & Simon, 2004a; Simon, Erduran & Osborne, 2006). As a result of a 2-1/2 year school-based research project funded by the Economic and Social Research Council, we have seen that (a) it is possible to train teachers to adapt their teaching to place more emphasis on the construction of argument; (b) children's skills at argument do improve with practice. Furthermore, we were able to develop an analytical framework for studying argumentation in the classroom (Erduran et al., 2004).

The resources produced by teachers during the project work were useful instructional tools. For example in one activity, pupils were presented with a scenario where they were asked to decide about whether a moving, unicellular organism was a plant or an animal cell. The organism called euglena is in fact neither. It has features of both plants (e.g. chlorophyll) and animals (e.g. it moves). Children were then given cards that had factual statements about euglena, and they were asked to use the evidence from the cards to reach a conclusion about whether or not euglena was a plant cell or an animal cell. Some of the pedagogical strategies that would complement these activities included coordination of group discussions, presentations as well as asking questions that would stimulate argumentation such as "What is your evidence? How do you know?"

Our work with the ESRC funded research project led to the development of a training resources on argumentation. We were encouraged by the results given that 8 of the 12 teachers had displayed significantly higher quality arguments in their lessons after one year of training (Osborne et al., 2004). The IDEAS Project, funded by the Nuffield Foundation is a culmination of our efforts for professional development of teachers (Osborne, Erduran & Simon, 2004b). The IDEAS (Ideas, Evidence and Argument in Science Education) pack, first published in 2004 and reprinted in 2005, consists of 28 clips of ordinary teachers dealing with how to structure and approach the teaching of argument in science.

The pack also contains materials to support 6 half day workshops exploring aspects of teaching argument: (1) how to introduce argument; (2) how to manage small group discussions; (3) how to teach argument; (4) what resources can be used to support argumentation by students; (5) how to evaluate arguments; and (6) how to model them for pupils. The materials come on CD ROM as Word and Powerpoint files. In addition, there is a set of resource materials to support the teaching of ideas, evidence and argument in school science education. This consists of 15 sample lessons which teachers can use to try out some or all of the approaches in the IDEAS CPD sessions. Each of the activities comes with an introduction which provides: (a) the aims; (b) the learning goals of the activity; (c) teaching points which highlight aspects of background knowledge or what knowledge the students may need for the activity; (d) a teaching sequence which suggests how the materials might be implemented in the classroom; and (e) background notes for activities that require further elaboration on the science background some of the background science needs further elaboration.

Training of Pre-service Science Teachers in Argumentation

The IDEAS pack was used in the training of chemistry pre-service teachers (Ardac, Erduran & Yakmaci-Guzel, 2005) in an ongoing research project based in Istanbul, Turkey. The participants consisted of 17 trainee teachers (12 females and 5 males) enrolled in a science teacher certification course at an English medium university. The pre-service teachers were trained using the IDEAS pack over a 6 weeks period during the spring term of the 2005-2006 academic year. The sessions took place as an integral part of the "practice teaching in chemistry course" that is offered during the final term of the training program. The course requires pre-service teachers to plan, revise and teach a minimum of three chemistry lessons during their field practice. For the purposes of the present study, the pre-service teachers were expected to plan and implement at least one out of the three lessons as an argument lesson derived from the IDEAs pack. Each training session included a 90-minutes workshop based on the IDEAs workshop agenda where teacher training included some recommendations for encouraging students' use of evidence to support their claims as well as the video exemplars of good practice illustrated in the IDEAs video (Osborne et al., 2004). Pre-service teachers were further familiarized with Toulmin's Argument Pattern (TAP) (1958) which is subsequently used to identify the structure of arguments manifested throughout each lesson. Following the training sessions, the participants were given two weeks to prepare an argumentation lesson around a chemistry topic that would agree with the regular school curriculum. During the planning phase, pre-service teachers were expected to use the feedback and suggestions from their instructor to come up with a lesson plan that used major components of an argumentation lesson. During the three weeks that followed the planning phase, pre-service teachers implemented their lesson plans in actual classrooms.

Informed by literature on educational change (e.g. Fullan, 1991), and the failures of the past, we were conscious of a careful consideration of how teacher development could result in sustained change particularly when the production of the training resources did not involve them. Current thinking has recognised that a centrally important concept for any curriculum innovation is that of 'ownership' (Ogborn, 2002). Innovations succeed when teachers have a sense that new approaches belong to them, at least in part. As Ogborn (2002) argues, there 'has to be something of real novel value for teachers to identify with'. However, the need for ownership requires that teachers are a central feature of the process of development and not marginalized to becoming deliverers of someone else's innovations. They must be free to adapt, transform and develop the ideas to their own context and, if necessary, change their aim, function or implementation. Only in this manner can teachers begin to own new practice and to incorporate it into their regular repertory of strategies and approaches to the teaching of science.

Hence, even though the training resources were adapted from one national context (United Kingdom) to another (Turkey), the work proceeded collaboratively with a small group of teachers, in through drawing on theoretical ideas and putting these into practice in order to develop materials and strategies that can be adopted and owned by them. As such, the pre-service teachers had the freedom to pick and choose whatever strategy they found useful for their purposes in teaching an argument lesson.

Lessons from each teacher implementing lessons in Istanbul secondary schools were audiotaped. Selection of topics (e.g. Periodic Table, Acid Rain, Mercury: metal or non-metal?, Radioactivity) to adapt for argument lessons was done by trainees. The data sources in this project were teacher talk, student group talk, students' written work, teacher lesson plans, teacher interviews after training and teacher written responses to argument questions. This work particularly addressed the following research questions: (1) How are pre-service teachers interpreting argument lessons in their teaching? Are they using the strategies promoted in the training sessions? (2) What are the argument outcomes in students' learning? What is the nature of their arguments and argumentation? Here the focus is on the teaching strategies used by the trainees.

TEACHING STRATEGIES AND STUDENT OUTCOMES

In examining the teachers' strategies, the focus was on how the teachers (a) structured the task, (b) used group discussions, (c) questioned for evidence and justifications, (c) modelled argument, (d) used presentations and peer review, (e) established the norms of argumentation, and (f) provided feedback during group discussions. These features were implicit in the training resources and were investigated with the original teachers in the ESRC project (Simon, Erduran & Osborne, 2005). Here we will present case studies of two Turkish female trainee teachers in

their 20s to illustrate their teaching relative to these criteria. Our investigation into student outcomes have concentrated on the (a) nature of arguments, (b) nature of questions, (c) criteria for evaluating evidence, and (d) use of opposition including how counterarguments are ruled out.

The latter, result on students' argumantation will appear in a subsegment publication in more detail.

Case 1: Hulya

Table 1: Teaching strategies used by Hulya

Teaching Strategy	Example
Task structure	Competing theories
Questioning	"How do you know? What's your evidence?
Modeling	"If you look at this one, it can't be a metal because…"
Use of presentations	"You will swap seats and tell your friends what you have done and how you reached your conclusions."
Establishing norms of argumentation	"I know that you know this by heart but what I want is for you to find out why it's there."

Hulya did a lesson on the Periodic Table where she began the lesson with an introduction to the history of the Periodic Table. She used group activities and writing frames to support students' engagement in argumentation. Another strategy she used was the use of "envoys to groups" where representative students from each group was sent to another group to present results of group discussions. Subsequently all of the groups made presentations and the lesson ended with a summary. The primary teaching strategies used by Hulya are summarized in Table 1.

The main task in this lesson was framed in terms of 'competing theories' where students were asked to place missing element in the Periodic Table and decide whether or not it is a metal or a non-metal. Hulya outlined the task clearly indicating that "You need to judge the evidence to decide whether this can be a metal or not." During this lesson, Hulya asked many open-ended questions that were included as argument prompts in the training pack. For instance, she asked "How did you classify this element? Why?", "How do you know that?" Hulya provided much support to students by modeling what would be a good argument. For example, she used the statement stems as "If you look at this one, it can't be a metal because…" Hulya made use of presentations by using envoys across groups. She established the norms of argumentation by highlighting the significance of why it's important to provide justifications for our knowledge.

In terms of student outcomes, there is evidence from Hulya's lesson that students were able to construct a range of arguments. For instance, students related data to claims (e.g. "It could be aluminium because it dissolves in water.") as well as more complex arguments

involving warrants and backings as well (e.g. "We are sure about this one because it has all the properties. It's soft and it's close to these so this one also is…"). The nature of the questions asked by students tended to be clarification questions (e.g. "Are we considering the rows or the columns?") while the criteria used for evaluating evidence included the idea of classification (e.g. "We could see if it's a metal, non-metal or semi-metal."). Students tended to discount others' ideas by proposing alternative claims (e.g. "I said this but he said something else.").

Case 2: Nil

Nil conducted a lesson where she presented mercury as an instance to be argued about. She introduced the lesson by asking the main question: Is mercury a metal or a non-metal?. She used group work and presentations, and the lesson ended with a summary. The teaching strategies relevant for promoting argumentation employed by Nil are summarized in Table 2.

Table 2: Teaching strategies used by Nil.

Teaching Strategy	Example
Task structure	Competing theories
Questioning	"How do you know that it forms compounds with non-metals?" "What sort of an experiment can you do?"
Modeling	"You are presenting a strong argument. Mercury is a metal because it conducts electricity, because metals conduct electricity."
Use of presentations	"You have to convince us through your presentations."
Establishing norms of argumentation	"You can say it reacts with noble gases but you have to have evidence." "If you cannot provide evidence then you have to be careful about your claims. I heard it's like that is not enough."

Nil's lesson presented the task of arguing for mercury being a metal or not. The main assumption behind this issue is that children often think of metals in terms of solids. Hence the liquid nature of mercury could potentially provide the stimulus for discussion. Nil used questioning, modeling and presentations as strategies to promote and support argumentation as well as explicit statements on the norms of argumentation.

Nil's students generated a range of arguments including claims supported with data (e.g. "It is a metal because all its properties are consistent." and claims supported with data, warrant and backing: (e.g. "We think mercury is a metal because it has a d- orbital and it can conduct electricity. It has a shiny appearance"). Like Hulya's students, Nil's students mainly asked clarification questions (e.g."Is the boiling point of mercury 14^0C?"). They were able to generate criteria for evaluating evidence (e.g. "You think it being a liquid is not a physical property. Its

being a liquid is because its melting point is low and that's a chemical property."). There was also evidence for the use of rebuttals and oppositions (e.g. "The only property that suggests it's a non-metal is its liquid state but this can be changed. We can turn it into a solid but we can't play around with the number of electrons in its orbitals").

RESULTS

The results briefly summarized in the case studies here extend to all the 14 trainee teachers. There is evidence on all aspects of teaching strategies investigated that the trainees are using argumentation techniques in their classrooms. The extent of difference between the trainees relied on their use of meta-talk and the quality of the feedback provided to the students. Consider the following from a trainee's use of meta-talk:

> What did you tell me to oppose this point of view? You showed me evidence. During a discussion, what do you need to do in order to make a claim acceptable? You have to base your claim on real evidence. Definitions can be right or wrong. Whichever definition you are supporting or not supporting, you will have to decide. For that position you think is right, you can provide extra evidence. Let's say one definition is right and another wrong. You will prove to me using evidence or your knowledge how this position is right. This is right because…I want you to make me believe in what's right. Whoever reads this will have to be convinced.

Such instances of meta-talk were infrequent and there were also numerous missed opportunities for giving feedback to students in scenarios such as the following:

> In the gaseous state, the amount of energy required to pull out an electron from the outer orbital is less because in the gaseous state, the atoms are further apart.

In this instance, even though the piece of data appealed to is correct (ie. "in the gaseous state, the atoms are further apart"), the claim or the conclusion reached by using this piece of data is incorrect. In other instances (e.g. "Why should I spend more energy in a solid? When you pull out an electron from an atom, the orbit does not disappear, therefore there is no difference in the circumference") the data used might not support the conclusion reached. Such instances suggest that formative feedback in argumentation might be challenging to beginning teachers although other advanced skills such as modeling and questioning did not seem to present as much difficulty. These are preliminary results only. However we are encouraged by the level of engagement by the pre-service teachers, their commitment to the use of some key strategies such as group discussions and presentations, and the outcomes displayed by their pupils.

CONCLUSIONS & IMPLICATIONS

Our work in school-based research in the teaching and learning of argumentation has provided us with some guidelines for training teachers to promote and support argumentation in science lessons. However, the coordination of current curricular goals with new strategies such as argumentation places extra demands on teachers. If the curriculum emphasizes content outcomes, it will be very difficult for science teachers to open up the discussion space in their classrooms to allow argumentation to take place. Furthermore, without a shift in what gets assessed in terms of teaching and learning performances, it is unlikely that some of the encouraging results observed in our research could be sustainable in the long term. However, even the short-term training of pre-service teachers resulted in attainment of intended pedagogical and learning goals, an encouraging outcome indeed.

Methodological considerations illustrate the need to further develop tools that would be sensitive to identifying not only the structure but the content of arguments. Our work has focused on the process of argumentation not as an ideological preference over content of argument but rather as a pragmatic need to instill both in teachers and students the mechanisms of arguing. Without a sense of the need for providing evidence to justify claims, we wonder how students could see the need for presenting an argument at all, let alone an argument that has internal consistency in terms of its content. Our intention is to extent the line of work on argumentation to develop new tools that would be effective in capturing the quality of content as well as the process.

Implications for future studies in teacher education include the need to trace the developmental stages in the learning to teach argumentation - from novice to expert. What are the learning trajectories for science teachers in getting to know how to teach argumentation? This area of research in argumentation remains relatively uncharted (e.g. Erduran, 2006; Simon, Erduran & Osborne, 2005). The nature of the contribution of argumentation studies to other aspects of science teaching is equally unknown. It will be imperative to situate argumentation in other aspects of science teaching if argumentation is to have systemic validity in professional development. It is when we, as teacher educators, figure out how we can help teachers in their mediation of disagreement with reason that argumentation studies will truly extend the historical precedence of argument embodied for centuries in Plato and Aristotle.

REFERENCES

Ardac, D., Erduran, S., & Yakmaci-Guzel, B. (2005, August). *Ideas, Evidence and Argument in Pre-Service Science Teaching in Turkey*, Paper presented at the European Science Education Research Association, Barcelona

Boulter, C. J.& Gilbert, J. K. (1995). Argument and science education. In P. J. M. Costello, & S. Mitchell (Eds.), *Competing and consensual voices: The theory and practice of argumentation*. Clevedon: Multilingual Matters.

Cros, D., Chastrette, M., & Fayol, M. (1987). Conceptions of second year university students of some fundamental notions of chemistry. *International Journal of Science Education*, 10, 331-336.

Department for Education and Employment (DfEE). (1999). *Science in the National Curriculum*. London: HMSO.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Buckingham, UK: Open University Press.

Driver, R., Newton, P.,& Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, 84(3), 287-312.

Durant, J. R., Evans, G. A., & Thomas, G. P. (1989). The Public Understanding of Science. *Natur*e, 340, 11-14.

Duschl, R., Ellenbogen, K., & Erduran, S. (1999, April). *Understanding dialogic argumentation*. Paper presented at the annual meeting of American Educational Research Association, Montreal.

Erduran, S. & Jimenez-Aleixandre, M. P., (Eds.) (in press). *Argumentation in science education: recent devolopment and future directions*. Dordrech: Springer.

Erduran, S. (2006). *Promting ideas, evidence and argument in initial teacher training*. School Science Review, 87 (321), 45-50.

Erduran, S. & Osborne, J. (2005). Developing arguments. In S. Alsop, L. Bencze, & E. Pedretti (Eds.), *Analysing exemplary science teaching: Theoretical lenses and a spectrum of possibilities for practice*. Philadelphia: Open University Press.

Billig, M. (1996). *Arguing and thinking* (2nd ed.). Cambridge: Cambridge University Press.

Duschl, R. A. (1990). *Restructuring science education: the importance of theories and their development*. New York, NY: Teachers College Press.

Duschl, R., & Osborne, J. (2002). Supporting and promoting argumentation discourse. *Studies in Science Education*, 38, 39-72.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: developments in the application of Toulmin'sargument pattern for studying science discourse. *Science Education*, 88(6), 915-933.

Fullan, M. (1991). *The new meaning of educational change* (2nd ed.). London: Cassell.

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Gable, D., & Bunce, D. (1984). Research on problem solving in chemistry. In D. Gabel (Ed.), *Handbook of research in science teaching and learning* (pp. 301-326). New York: MacMillan.

Giere, R. (1991). *Understanding of scientific reasoning* (3rd ed.). Forth Worth, TX: Holt, Rinehart, and Wilson.

Heeren, J. K. (1990). Teaching chemistry by the Socratic Method. *Journal of Chemical Education*, 67(4), 330-331.

Jimenez-Aleixandre, M. P., Rodrigues, A. B. & Duschl, R. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education*, 84(6), 757-792.

Kelly, G. J. & Chen, C. (1999). The sound of music: Constructing science as a sociocultural practices through oral and written discourse. *Journal of Research in Science Teaching*, 36(8), 883-915.

Kelly, G., & Takao, A. (2002). Epistemic levels in argument: An analysis of university oceanography students' use of evidence in writing. *Science Education*, 84(6), 757-792.

Kitcher, P. (1988). The child as parent of the scientist. *Minds of Language*, 3(3), 215-228.

Kuhn, D. (1992). *Thinking as argument*. Harvard Educational Review, 62, 155-178.

Latour, B., & Woolgar, S. (1986). *Laboratory life: The construction of scientific facts* (2nd ed.). Princeton, NJ.: Princeton University Press.

Lemke, J. L. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Ablex Publishing.

Mason, L. (1996). An analysis of children's construction of new knowledge through their use of reasoning and arguing in classroom discussions. *Qualitative Studies in Education*, 9(4), 411- 433.

National Research Council. (2000). *Inquiry and the national science education standards*. Washington, DC: National Academy Press.

Ogborn, J. (2002). Ownership and transformation: Teachers using curriculum innovation. *Physics Education*, 37(2), 142–146.

Osborne, J. F., Erduran, S., & Simon, S. (2004a). Enhancing the quality of argument in school science. *Journal of Research in Science Teaching*, 41(10), 994-1020.

Osborne, J. F., Erduran, S. & Simon, S. (2004b). *Ideas, evidence and argument in science*. In-service Training Pack, Resource Pack and Video. London: Nuffield Foundation.

Pera, M. (1994). *The discourses of science*. Chicago: University of Chicago Press.

Pontecorvo, C. (1987). Discussing and reasoning: The role of argument in knowledge construction. In E. De Corte, H. Lodewijks, R. Parmentier, P. Span (Eds.), *Learning and Instruction: European research in an international context*, (239-250). Oxford: Pergamon Press.

Popper, K. (1959). *The logic of scientific discovery*. London: Hutchinson.

Quinn, V. (1997). *Critical thinking in young minds*. London: David Fulton.

Schwarz, B. B., Neuman, Y., Gil, J., & Ilya, M. (2003). Construction of collective and individual knowledge in argumentation activity. *Journal of the Learning Sciences*, 12(2). 219-256.

Siegel, H. (1989). The rationality of science, critical thinking and science education. *Synthese* , 80(1), 9-42

Simon, S., Erduran, S. & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom, *International Journal of Science Educatio*n, Vol. 27, No. 14, 18, pp. 137–162

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

Vygotsky, L. (1978). *Mind in society*. London: Harvard University Press.

Welch, W. (Ed.). (1979). *Twenty-five years of science curriculum development*. (Vol. 7). Washington, DC: American Educational Research Association.

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