DELINEATING THE ROLES OF SCIENTIFIC INQUIRY AND ARGUMENTATION IN CONCEPTUAL CHANGE PROCESS

Ozgur K. Dogan
Marmara University, Turkey

Mustafa Cakir
Marmara University, Turkey

Robert E. Yager
University of Iowa, U.S.A.

ABSTRACT: The purpose of this paper is to address the relevance and discuss the importance of scientific inquiry and argumentation processes, which are indispensable elements of constructivist science education paradigm, in teaching for conceptual change. Inquiry based learning, argumentation and conceptual change theory are separately emphasized by educational researchers as useful tools to reach the ultimate purpose of science education, scientific literacy. These three concepts are strongly related, however the nature of their relationship is not explicitly discussed in the literature and therefore relationship is not apparently clear. This review offers a viewpoint on the links of these three major ideas and provides guidelines for those who plan or design learning environments especially teachers. This paper is divided into four subsections. The first part focuses on what conceptual theory means and second part provides a brief literature review on inquiry based learning environments. While third section concentrates on the relationships between inquiry-based learning and conceptual change theory, the last section explains the position of argumentation among these educational concepts.

Keywords: conceptual change theory, inquiry based learning, argumentation

INTRODUCTION

With each passing day, the effort of humankind to understand and learn about the natural world continues to grow. We are regularly bombarded with scientific and technological developments in printed and electronic media. Advances in science and technological applications provided us with powerful and immediate benefits and improved our health, materials, and life in a short period of time. However, the same technologies and scientific advances are also blamed for, with their unexpected deleterious consequences, enormous global problems such as pollution, extinction of species, overpopulation, global warming, deforestation, and desertification. Consequently, it can be argued that although the benefits of the new scientific and technological developments are immediate; their cost is high when we consider the long-term environmental and social consequences which are usually hidden and unpredictable. Maybe we are not aware of the importance of understanding these developments and problems which so powerfully affect our lives. These are not only the concerns of the community of scientists but also all individuals, who are the “active” part of the society, directly or indirectly make decisions about these issues and affect our shared world. However, science seems to be outside the average individual’s ability to comprehend and evaluate because it is often associated with technical jargon which is not comprehensible to the lay public. In order to address these concerns, the National Research Council (NRC,1996), uses the term “scientific literacy” as the ability of individuals who use scientific principles and processes to make decisions and to get involved in discussions about issues which affect the public. Science, technology, and values/morals of society are three different but interrelated constructs. As a result of their dynamic and operational nature both science and technology constantly influence the society not only by creating new values (Cowan, 1998; Martin, 1998) but also influencing how we construct our identities (Mesthene, 1997; Winner, 1997). The interplay of science, technology, and society can be conceptualized as multiple ways of interaction (Brickhouse, 1998).

Scientific literacy is defined as “knowledge and skills in science, technology, and mathematics, along with scientific habits of mind and an understanding of the nature of science and its impact on individuals and its role in society” (AAAS, 2001, p. vi). When the dynamic and operational nature of science and technology are considered, the need for individuals’ critical thinking skills is apparently clear. Since there is no one (single) understanding of the nature of science (Alters, 1997a, 1997b; Matthews, 1996), it is important to promote and encourage students to develop multiple understanding of nature of science. Successful critical thinking about the interrelationships among science, technology, society, and environment is only possible when individuals achieve to develop multiple understandings of the nature of science.

Recently, generating scientifically literate citizens has become an exceptional goal for countries; this goal turns out to be a main ambition for most educational policies. The launch of Sputnik by Soviet Union in 1957 is the most effective event which pushed countries to take the decision to change their educational policies and their curriculum (Aikenhead, 2003; Puvirajah, 2007). The reform movements in science education specifically aim to generate students who possess higher order thinking skills and needed cognitive strategies such as selecting, organizing, and utilizing scientific knowledge for a productive life (Hurd, 1998). Individuals who have higher order thinking skills and use cognitive strategies not only be able to monitor developments in science and technology but also play essential roles in making decisions on social and political issues.

Educational reform must aim to prepare scientifically literate citizens in this century and researchers must make an effort to integrate inquiry based teaching and scientific argumentation to their curricula to accomplish conceptual change if it is necessary. Consistent with this line of thinking, the next section describes fundamentals of inquiry based learning, scientific argumentation, and relationship of these two concepts to acquire desired conceptual change.

What are the relationships among, conceptual change theory, inquiry-based learning, and argumentation?

Assessing alternative explanations, weighing evidence, interpreting texts, and evaluating the potential viability of scientific claims are all seen as essential components in constructing scientific arguments (Latour & Woolgar, 1986). Furthermore, argument is central in the process of conceptual change as described by Posner, Strike, Hewson and Gertzog (1982). Argumentation provides opportunities for learners to negotiate their understandings, and consider and evaluate each other’s arguments. Conceptual change depends on socially constructing and reconstructing one’s own personal knowledge through a process of dialogic argument (Driver, Newton & Osborne, 2000).

In this section, a theoretical approach is provided for delineating relationships among, conceptual change theory, inquiry-based learning, and argumentation. These three concepts are strongly related, however the nature of their relationship is not explicitly discussed in the literature and therefore relationship is not apparently clear. In this chapter, we first present the process of scientific knowledge generation by the community of scientists and how this process is integrated in school science classrooms over time. Subsequently, we explain how this process fits to conceptual change theory. Before presenting “how do scientists produce scientific knowledge” and “how do educational scientists integrate the idea of –students as scientists- to school science classrooms”, we need to explain briefly what conceptual change theory is. Thus, we would be able to show links between aspects of inquiry-based learning what will be discussed later and conceptual change theory.

Conceptual Change Theory

Basically, conceptual change theory is focused on how individuals reconstruct their cognitive schemes and models for change of conceptions ‘under the impact of new ideas and new evidence’ (Posner et al., 1982, p. 212). Posner and his colleagues state that individuals’ cognitive frameworks (they used the term conceptual ecology) can be modified (assimilation) or can be entirely changed (accommodation) according to new concepts’ conformity to their existing conceptual ecology. Apparently, generation of this theory took its roots from the work of Thomas Kuhn (1970). According to Kuhn all individuals have general obedience to the scientific community which they belong. He called these general acceptances “paradigms”. Thus, all scientists generate research questions, design research, construct new explanations and test their explanations under the light of the paradigm to which they belong. These commitments to the paradigm continue till there are contradictions which occur between new explanation and the theoretical basis of the paradigm. Hereby, there are two situations in behalf of scientific progress (Kuhn, 1970). The first one is, if new explanation works compatible with the core ideas of existing paradigm then there is no need to make any paradigmatic changes which Kuhn called this condition normal science. As an analogy, this situation is matching up with the assimilation concept in conceptual change theory suggested by Posner and his colleagues. They argued that sometimes students use their existing conceptual frames to deal with new phenomena. If students’ existing beliefs, knowledge, and experiences are well-suited with new concepts, then new concepts are easily linked to the frames that became ready to new learning situations. The second situation for scientific advancement in Kuhnian thought is scientific revolution which is new phenomenon that dealt by scientists does not match with the core ideas of the paradigm. Under this situation scientists might make radical changes about their beliefs, knowledge and experiences as a result the paradigm they belong changes. Kuhn argued that these kinds of changes are extremely difficult. Accomplishing such changes means reorganizing all conceptual and cognitive frames changing whole worldview similar to converting to a new religion. This Kuhnian thought matches with the term accommodation in conceptual change theory. Posner et al. (1982) defined accommodation as extreme changes in the case of discrepancies in the new phenomenon and the conceptual ecology of the individuals. Similar to paradigm shift, the kind of deep changes required for accommodation are extremely hard and they need some conditions to succeed. Posner et al. (1982) has indicated that there are four important conditions for accommodation to occur:

- Dissatisfaction with an existing conception; if students' existing ideas do not work for solving a problem or generating an explanation about a natural phenomenon anymore, students feel the need to change their current ideas.
- Intelligibility of a new conception; if a new conception is not intelligible, students cannot adapt to a new concept in their cognitive scheme.
- Initial plausibility of a new conception; a new conception must look initially consistent to a learner.
- Possibility of a fruitful research program; a new conception has to have the power to solve new problems which satisfy a learner more than the previous conception for future research.

Scientific Inquiry and Inquiry-based Classrooms

The analogical approach about scientific inquiry and inquiry-based classrooms allow us to understand how similar the scientists and students are in case of generating "knowledge" (Pera, 1994; Magnusson, Palincsar & Templin, 2006). Two kinds of scientific inquiry model, introduced by Pera (1994) and Magnusson et, al. (2006), are 'The Methodological Model and The Dialectical Model.'

Scientific inquiry, in a traditional perspective which Pera (1994) called The Methodological Model, "is a game with two players: the inquiring scientist who asks questions and nature who provides answers" (Magnusson et al., 2006, p.132). Implementation of this approach to the educational programs was known as the discovery learning approach in 1960s' (Magnusson et al., 2006). In a discovery learning approach, students are exposed to particular questions and experiences in such a way that they "discover" the planned concepts for themselves (Hammer, 1997). In later years, question marks began to increase for discovery learning as a result of the studies related to the nature of science (Magnusson et al., 2006). In accordance with these changes about perspectives on nature of knowledge, traditional inquiry has given its place to contemporary scientific inquiry which Pera (1994) called The Dialectical Model. Instead of traditional inquiry, contemporary inquiry includes three components such as; a scientist or a group of scientists that we call benchmark, nature itself, and another group of scientists that debate with the first group according to the features of scientific dialectics (Magnusson et al., 2006). When we compare these two aspects of inquiry, we can see that the most distinguishing thing is that the contemporary inquiry aspect contains another group of scientists who examine the reliability of findings of the benchmark group. This difference makes contemporary inquiry more consistent than traditional inquiry because there is a community's agreement upon nature's correct answer. As opposed to a traditional aspect of inquiry, contemporary aspect of inquiry focuses on scientists' use of their reasoning and thinking skills more. With this focus scientific inquiry reflects a distinct shift from science as exploration and experiment to science as argument and explanation (NRC, 2000; Zembal-Saul, 2009).

DeBoer (2006) argued that as scientists seek to understand the natural world through their investigations, students in inquiry classrooms try to move forward with their understanding of the principles and methods of science through investigations of their own. Therefore, educational scientists started to think that integrating the idea of "students as scientists" to teaching programs would be more useful for generating scientifically literate societies in the future (DeBoer, 2006; Puvirajah, 2007). Based on this idea, inquiry-based teaching is seen to mean a classroom environment where students think and do research like scientists and also present their findings to their peers and get agreements on them (NRC, 2000, Harlen, 2004). Although it has started to scrutinized more recently, the message of this idea was offered by John Dewey approximately a century ago in 1909. Dewey stated that, doing science is more than gaining "knowledge"; there is also a process which has to be learned by students (NRC, 2000; Simon, Erduran & Osborne, 2006).

Basically, the inquiry-based teaching is defined as a teaching strategy where students describe objects and events, generate their own questions, gather data, analyze and interpret those data, construct explanations, criticize those explanations against current scientific "knowledge", and discuss their explanations with the other members of the classroom (NRC, 1996; Byers & Fitzgerald, 2002). It is clear that in order to achieve this process, students need some cognitive abilities and skills. NRC (1996) indicated that these abilities and skills are needed to be able to; (1) ask epistemologically and ontologically proper questions, (2) design and implement accurate research, (3) decide convenient research instruments, (4) think critically and logically about data and explanations, (5) generate alternative explanations and generate arguments to criticize them.

Features of inquiry-based classrooms

According to Goh (2002), student cohesiveness, self-esteem and confidence, a sense of belonging and motivation to learn are psychosocial dimensions which influence the learning environment positively. Thus, the promotion of the positive effects of these psychosocial dimensions depends on well-organized classrooms where supportive relationships with teachers and classmates are formed and an emphasis on participation occurs (Moss, 1991). According to Furtak (2006), inquiry-based classrooms have four dimensions which are; methodological, conceptual, epistemological, and social (Figure 1). *Methodological dimension* of the classroom has to do with the imitating the scientific inquiry process by involving students in a process where they generate questions and hypothesis, and analyze data and then interpret them (Cakir, 2004). It is unquestionable that providing a proper environment to students to develop such methodological skills is an essential part of inquiry-based classrooms (Furtak, 2006). However, without these skills students might be able to generate some ideas about an authentic question but they cannot plan a process which they want to criticize their own hypotheses and theories.

The *conceptual dimension* is about the content knowledge of students. Basically, when students try to produce an explanation on behalf of a natural event, they need to have sufficient content or theoretical knowledge about that event (Posner et al., 1982).

The *Epistemological dimension* of inquiry is especially significant as it relates to general purposes of science education (Hogan & Maglienti, 2001). The epistemic beliefs of scientists and students play a central role in the whole inquiry process (Lederman & Stefanich, 2006). Beliefs in regard to "What is science?", "How does science work?", "What is the nature of scientific knowledge?", "What is the impact of the social and historical milieu on scientific ideas?", "Who are these people we called scientists?" and "What is the role of empirical evidence in science?" are some of the aspects which have been frequently focused on by educational scientists. Puvirajah (2007) has argued that, engaging students in an inquiry process provide them to construct and/or to reflect on their beliefs about science. As very few students consider science as a process which examines the models and theories instead of science as a heap of certain and constant "knowledge" (Sandoval, 2003).

The *Social dimension* of inquiry process provides students with an effective learning environment. Constructing knowledge in a social environment is the main idea in contemporary inquiry-based classrooms. In such environment, students interact with each other and with their teachers to criticize their own ideas as they find opportunities to see alternative explanations to reconstruct their ideas. In this respect, Duschl (2007) has stated that during the inquiry process, discussions concerning the phenomenon which are investigated in the classroom require students to revise their concepts and beliefs about those phenomena. On the other hand, an effective science education program must develop students' abilities of discursive practices that enable them to apply their understandings of science to personal decision-making and engage them in public discourse about issues related to science and society (Driver et al., 2000).

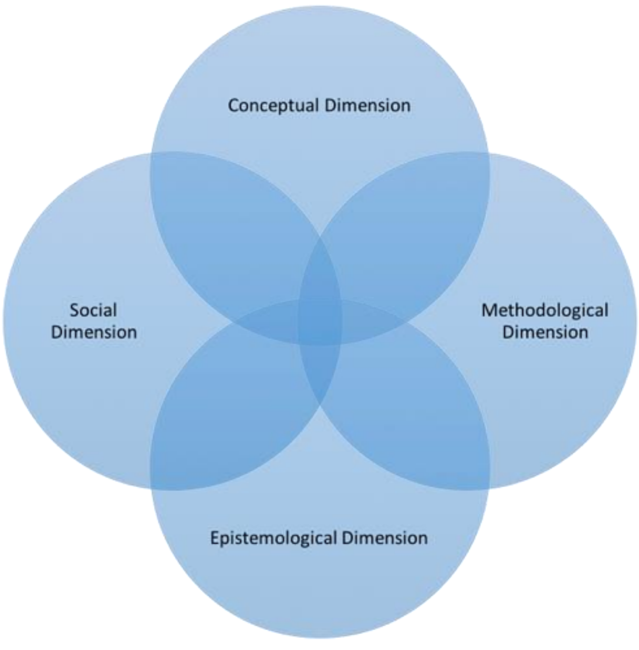

Figure 1. Dimensions of Inquiry-based classrooms.

These four dimensions about inquiry-based learning are working together to maximize students' meaningful learning. "Meaningful learning" is the integration of new concepts into our cognitive structures according to quality and quantity of our existing cognitive structures to new concepts (Novak, 2002). Clearly, if previous incorrect concepts have been memorized, changing such concepts is not big deal for students. Since memorized concepts have no links to cognitive structures and they are easily replaced. Unless, the previous learning occurs with the link of misconception then conceptual change is too hard for the learner. Inquiry-based teaching strategies help students to reflect on the reliability of their cognitive structures and the fitness of the new concepts.

Connecting inquiry-based teaching with conceptual change theory

All emphasized aspects of inquiry relate to the theory of conceptual change. Methodological and conceptual dimensions of inquiry are basically "back stage" of the process of conceptual change. These dimensions are concerned with all the preparation and also with the direction of the process. Conceptual and methodological aspects of inquiry aim to introduce individuals to new concepts and/or to skills for learning new concepts. We can see these two dimensions as "accessory aspects" for the theory of conceptual change. But the other two dimensions of inquiry have unique places for supporting the theory.

Epistemological dimension plays an essential role in conceptual change process. During the inquiry process, students construct new knowledge against their prior knowledge and beliefs (Posner et al., 1982). Therefore, if student beliefs about the nature of knowledge are shaped by contemporary views of nature of knowledge, then they can be open-minded about the uncertainty of existing concepts. Students with such beliefs can change their existing conceptions easier than biased ones. This does not mean that conceptual change process is too easy for that individuals; but we mean that whenever the student encounters a new phenomenon, students with such an attitude can ask the proper questions about new phenomenon and can decide what count as an appropriate answer for the new phenomenon.

On the other hand, we believe that the most important dimension of inquiry for changing inappropriate conceptions is the social aspect. We are aware that all aspects of inquiry must work harmonically for changing process. However, without a social dimension, this process might be a black box in which vicious cycles of individuals' judgments exist. As we recall, the first step of conceptual change theory is the need for dissatisfaction of individuals with an existing conception. Without the social aspect of inquiry, students (and also scientists) can generate alternative explanations but these explanations also take their roots from students' own experiences and beliefs. Therefore, students need an environment which allows them to see and weigh the alternative explanations that come from other individuals with plenty of different prior experiences. Hereby, the proper environment can provide great chance for dissatisfaction for students who have misconceptions and the need to change their conceptions. Precisely, classroom discussions of ideas are most powerful tools for criticizing and comparing alternative explanations. Meanwhile, students can find chances to cognitively challenge different ideas. However, unconstructed, improperly constructed, or question and answer "discussions" in the classroom can affect students negatively which might cause confusion. Thus recently, the social dimension of inquiry has received more attention and interest from the researchers (e.g. Driver et al., 2000; Duschl, 2000; Simon et al., 2006; Sampson & Clark, 2008). Instead of classroom discussion, these purposefully constructed and logical processes of inquiry are labeled as "argumentation". According to McNeill and Pimentel (2010), most of the teachers use traditional types of discussion structure, which is characterized with the initiation, response, and evaluation (IRE), in their classrooms. When a discussion is structured traditionally, teacher initiates process with a question (initiate-I), students respond to that question (respond-R) and finally teacher evaluates the student responds (evaluate-E). Such a triple construct results minimal student-student and student-teacher interactions. Traditional discussions have inappropriate structures for classrooms where contemporary inquiry-based strategies are used (McNeill & Pimentel, 2010).

What is this popular concept called "Argumentation"?

As the National Research Council (1996, p. 36) has stated, "an important stage of inquiry and of student science learning is the oral and written discourse that focuses the attention of students on how they know what they know and how their knowledge connects to larger ideas, other domains, and the world beyond the classroom". Therefore, the importance of argumentation shows itself by students' logical and critical reflections concerning their explanations and conceptions. In other words, argumentation is a knowledge construction process in which concrete representation of the ideas occur for peer review and revision (e.g. Driver et al., 2000; Duschl, 2000; Sampson & Clark, 2008). As a result, the definition of argumentation is "the process of argument construction that is used for support or denying explanations which are generated from the inquiry process" (Sampson & Clark, 2008).

Informal reasoning performed in non-deductive situations that are essentially the everyday situations of life and work (Voss, Perkins & Segal, 1991) and involves the use of various forms of argument. Informal reasoning is situated within a variety of social and cultural meanings; therefore, it is carried on within different social contexts and applied in different situations. Exploring the use of argument in everyday life as well as in classroom settings is important because an argument implies critique (Mathison, 1995) which allows students to question and make decisions about which specific claims they value in an argument and how they position themselves in relation to them. An important element of critical thinking, according to Dewey's (1909/1991) idea of 'reflective thought', is the use of evidence to support a certain belief or claim.

There are plenty of models about the argumentation process in the literature. But almost all of them take their origins from the work of Toulmin (1958). Evidence is one of the main elements of the model of thinking as argument developed by Toulmin (1958). Toulmin's argumentation model involves six components (Figure 2). According to him; data, warrants and claims are basic and indispensible components of argumentation.

Furthermore, backings, qualifiers, and rebuttals are the components which are the needed components for solidifying the arguments. Briefly; (1) claims are assertions about what exists or values that people hold; (2) data are statements that are used as evidence to support the claim; (3) warrants are statements that explain the relationship of the data to the claim; (4) qualifiers are special conditions under which the claim holds true; (5) backings are underlying assumptions that are often not made explicit; (6) rebuttals are statements that contradict either with the data, warrant, backing or qualifier of an argument (Newton, Driver & Osborne, 1999; Osborne, Erduran & Simon, 2004; Simon et al., 2006; Yackel, 2002).

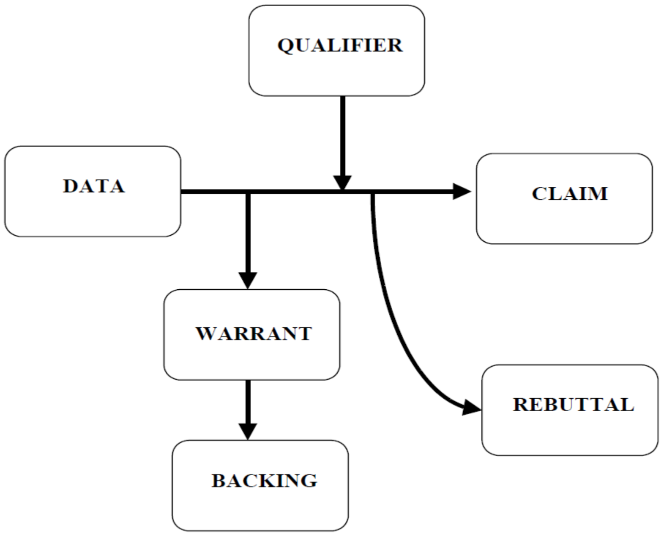

Figure 2. Toulmin's argument pattern (Simon et al., 2006, p.240).

Driver, Newton and Osborne (2000) raised a concern by claiming that Toulmin's scheme presents argumentation in a decontextualized way and "No recognition is given to the interactional aspects of argument as a speech event, of that it is a discourse phenomenon that is influenced by the linguistic and situational contexts in which the specific argument is embedded" (p. 294).

Alternatively, argumentation should be examined and situated within specific contexts while taking into consideration the social framework within it is developed. Argumentation is emphasized in the education literature in two distinctive ways labeled as "rhetorical" (Kuhn, 1992) or "didactic" (Boulter & Gilbert, 1996) and "dialogical" or "multi-voiced". Rhetorical argument is used to persuade others of the strength of the case being put forward while dialogical argument is used when different perspectives are being examined and the purpose is to reach agreement on acceptable claims or courses of action (Driver et al., 2000, p. 291). In other words, dialogic argument is a social activity happening through negotiation. This view is also consistent with Schwab's (1962) idea of presenting science as a product of fluid enquiry and emphasizing science as a process of constructing knowledge situated within specific socio-cultural contexts.

Integrating argumentation into inquiry process

In the literature, the most obscure point maybe the position of argumentation within the inquiry process. Nevertheless, some researchers clearly state that, argumentation brings inquiry to a conclusion based on social agreement (Sampson & Clark, 2008; Langsdorf, 1997). Based on this idea, argumentation can be placed at the end of the inquiry process (Figure 3). As figure 2 shows, inquiry process can be split into two parts. The first part of the inquiry is the "research" and the second part is the "argumentation". In the first part individuals design research, based on a question about a natural phenomenon; then they gather the data, analyze and interpret the data for generating an explanation. In the second part, argumentation, generated explanations are presented to the community and individuals develop arguments to defend their explanations. In this scientific reasoning process, rival ideas are compared. This comparison is made with regard to the strength of the argument to counter arguments. And also warrants and backings of the arguments, reliability of evidence, and association between the evidence and the claim are important discriminators of the arguments.

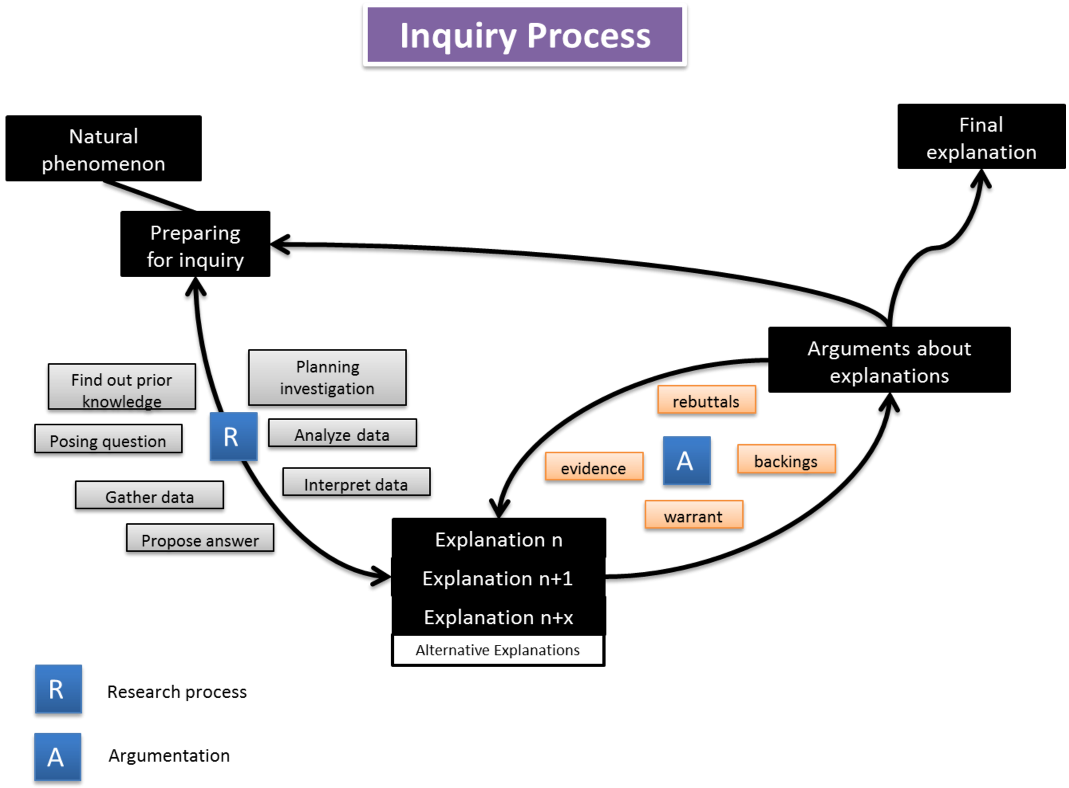

Figure 3. The process of inquiry in school science classrooms.

Our position is that argumentation can be divided into two parts for school science classrooms as well. The first one, internal argumentation, is getting students involved in the scientific inquiry process. That is students undertake investigations and generate explanations about the natural phenomenon and get involved in argumentation. As an example, Cakir (2004) designed an instructional module for prospective teachers to engage them in an inquiry activity in which one of the aims was providing them an insight about inquiry process as future teachers. He used software named Catlab to provide students a teaching and learning environment where they could be able to; gather, analyze, interpret data, and generate and discuss their explanations. During the process, students worked on mono and dihybrid crosses to generate explanations about given scenarios about the coat colors of cats. This genetics-based inquiry process finalized with a classroom discussion that focused on assumptions, predictions, collecting data, evidence, experimental design, and testing alternative explanations. Such inquiry experiences involve both research and argumentation processes together.

The second type of argumentation is Complementary Argumentation where students generate arguments about alternative explanations that have been generated previously. Some studies emphasized the importance of this reasoning process in the case of less accessible information, and more open-ended and debatable socio-scientific issues (e.g. Means & Voss, 1996; Sadler, 2004) such as Global Warming, Nuclear Testing, Animal Testing. The difficulty of experimentation of these ideas in school science classrooms causes the implementation of this "informal reasoning" process. In this instance, students try to defend explanations which are most suitable with their prior knowledge, experiences and their conceptual ecologies.

REFERENCES

American Association for the Advancement of Science (AAAS). (2001). *In Pursuit of a Diverse Science, Technology, Engineering, and Mathematics Workforce: Recommended Research Priorities to Enhance Participation by Underrepresented Minorities*, Washington, DC: AAAS.

Aikenhead, G. S. (2003). *Research report: Concepts of evidence used in science-based occupations: Acute-care nursing.* Available at URL: http://www.usask.ca/education/people/aikenhead/acnursing.htm.

Alters, J. B. (1997a). Whose nature of science? Journal of Research in Science Teaching, 34(1), 39-55.

Alters, J. B. (1997b). Nature of science: A diversity or uniformity of ideas? Journal of Research in Science Teaching, 34(10), 1105-1108.

Boulter, C. & Gilbert, J. (1996). Texts and contexts: Framing modelling in the primary science classroom. In G. Welford, J. Osborne and P. Scott (eds), Research in Science Education in Europe, Current Issues and Themes (London: Falmer Press), 177–188.

Brickhouse, N. W. (1998). Feminism(s) and science education. In Fraser, B. J. & Tobin, K. G. (Eds.), International handbook of science education (pp. 1067-1081). Great Britain: Kluwer Academic Publishers.

Byers, A., & Fitzgerald, M.A. (2002). *Networking for leadership, inquiry, and systemicthinking: a new approach to inquiry based learning.* Journal of Science Education andTechnology, 11 (1), 81-91.

Çakır, M. (2004). *Exploring Prospective Secondary Science Teachers' Understandings of Scientific Inquiry and Mendelian Genetics Concepts Using Computer Simulation.* (Doctoral dissertation). Pennsylvania State University, Pennsylvania.

Cowan, R. S. (1998). The industrial revolution in the home: Household technology and social change in the twentieth century. In Hopkins, P. D. (Ed.), Sex/Machine (pp. 33-49). Bloomington: Indiana University Press.

DeBoer, G. E., (2006). Historical Perspectives on Inquiry Teaching in Schools. Scientific Inquiry and Nature of Science. L. B. Flick and N. G. Lederman: 131-157.

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

Duschl, R. A. (2000). Making the nature of science explicit. In R. Millar, J. Leach, & J. Osborne (Eds.), *Improving science education: The contribution of research* Philadelphia: Open University Press.

Duschl, R. A. (2007). Quality Argumentation and Epistemic Criteria. In S. Erduran & M. P. Jiménez-Aleixandre (Eds.), *Argumentation in Science Education*., Springer.

Furtak, E. M. (2006). *The Dilemma of Guidance in Scientific Inquiry Teaching.* (Doctoral dissertation). Stanford University, Stanford, CA.

Goh, S. C., (2002). Studies on Learning Environments in Singapore Classrooms. In S. C. Goh & M. S Khine (Eds), *Studies in educational learning environments: An international perspective* (pp. 1-26). Singapore: World Scientific.

Hammer, D. (1997) 'Discovery Learning and Discovery Teaching', Cognition and Instruction, 15: 4, 485 — 529.

Harlen, W. (2004) 'A systematic review of the reliability and validity of assessment by teachers used for summative purposes', in *Research Evidence in Education Library*, Issue 1, London: EPPI-Centre, Social Sciences Research Unit, Institute of Education.

Hogan, K. & Maglienti, M. (2001) Comparing the epistemological underpinnings of students' and scientists' reasoning about conclusions, *Journal of Research in Science Teaching*, 38(6), pp. 663–687.

Hurd, P. D. (1998). *Scientific literacy: New minds for a changing world*. Science Education, 82, 407–416.

Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago: University of Chicago Press.

Kuhn, D. (1992). Thinking as argument. *Harvard Educational Review*, *62*(2), 155-179.

Langsdorf, L. (1997) *Argument as inquiry in a postmodern context*. Argumentation 11: 315-27

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

Lederman, J. S., Stefanich, G. P. (2006). Addressing Disabilities in the Context of Inquiry and Nature of Science Instruction. Scientific Inquiry and Nature of Science. L. B. Flick and N. G. Lederman: 55-74.

Magnusson, S. J., A. S. Palinscar, Templin. (2006). Community, Culture, and Conversation in Inquiry-Based Science Instruction. Scientific Inquiry and Nature of Science. L. B. Flick and N. G. Lederman: 131-157.

Matthews, M. R. (1996). The nature of science and science teaching. In Fraser, B. J. & Tobin, K. G. (Eds.), International handbook of science education (pp. 981-999). Great Britain: Kluwer Academic Publishers.

Martin, M. (1998). The culture of the telephone. In Hopkins, P. D. (Ed.) Sex/Machine (pp. 50-74). Bloomington: Indiana University Press.

McNeill, K. L. & Pimentel, D. S. (2010). *Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation.* Science Education, 94(2), 203-229.

Mesthene, E. G. (1997). The role of technology in society. In Shrader-Frechette, K. & Westra, L. (Eds.), Technology and values (pp. 71-85). New York: Rowman & Littlefield Publishers, Inc.

Means, M. L., & Voss, J. F. (1996). Who reasons well? Two studies of informal reasoning among children of different grade, ability, and knowledge levels. Cognition and Instruction, 14(2), 139–178.

Moos, R. (1991). Connection between school, work and family settings. In B. Fraser & W Walberg (Eds.), *Educational environments: Evaluation, antecedents and consequences* (pp. 29-53). London: Pergamon.

National Research Council (1996). *National Science Education Standards* (Washington, DC: National Academy Press).

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

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education,* 21(5), 553-576.

Novak, J. D. (2002). Meaningful Learning: The Essential Factor for Conceptual Change in Limited or Inappropriate Propositional Hierarchies Leading to Empowerment of Learners. Sci. Educ. Vol. 86, pp. 548 – 571

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

Pera, M. (1994). The Discourses of Science. Chicago, The University of Chicago Press.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66(2), 211-27

Puvirajah, A. (2007). Exploring the quality and credibility of students' argumentation: Teacher facilitated technology embedded scientific inquiry, Wayne State University.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*,**41**, 513–536.

Sampson, V., & Clark, D. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education*, *92*(3), 447-472.

Sandoval, W. A. (2003). *Conceptual and epistemic aspects of students' scientific explanations.* Journal of the Learning Sciences, 12(1), 5–51.

Schwab, J. J. (1962). The teaching of science as enquiry. Cambridge, MA: Harvard University Press.

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

Toulmin (1958). *The Uses of Argument*, Cambridge: Cambridge University Press 1958.

Voss, J.F., Perkins, D.N. & Segal, J.W. (1991). *Informal Reasoning and Education*. Hillsdale, NJ, Erlbaum.

Winner, L. (1997a). Technologies as forms of life. In Shrader-Frechette, K. & Westra, L. (Eds.), Technology and values (pp. 55-70). New York: Rowman & Littlefield Publishers, Inc.

Yackel, E. (2002). What we can learn from analyzing the teacher's role in collective argumentation. *Journal of Mathematical Behavior*, *21*, 423-440.

Zembal-Saul, C. (2009). Learning to teach elementary school science as argument. Science Education, 93 (4) 687 - 71