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Students Opportunities to Develop Scientific Argumentation in the Context of Scientific Inquiry: A Review of Literature

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Abstract: The purpose of this literature review is to investigate what kinds of research have been done about scientific inquiry in terms of scientific argumentation in the classroom context from the upper elementary to the high school levels. First, science educators argued that there had not been differentiation between authentic scientific inquiry by scientists and school scientific inquiry by students in the classroom. This uncertainty of goals or definition of scientific inquiry has led to the problem or limitation of implementing scientific inquiry in the classroom. It was also pointed out that students' learning science as inquiry has been done without opportunities of argumentation to understand how scientific knowledge is constructed. Second, what is scientific argumentation, then? Researchers stated that scientific inquiry in the classroom cannot be guaranteed only through hands-on experimentation. Students can understand how scientific knowledge is constructed through their reasoning skills using opportunities of argumentation based on their procedural skills using opportunities of experimentation. Third, many researchers emphasized the social practices of small or whole group work for enhancing students' scientific reasoning skills through argumentations. Different role of leadership in groups and existence of teachers' roles are found to have potential in enhancing students' scientific reasoning skills to understand science as inquiry. Fourth, what is scientific reasoning? Scientific reasoning is defined as an ability to differentiate evidence or data from theory and coordinate them to construct their scientific knowledge based on their collection of data (Kuhn, 1989, 1992; Dunbar & Klahr, 1988, 1989; Reif & Larkin, 1991). Those researchers found that students skills in scientific reasoning are different from scientists. Fifth, for the purpose of enhancing students' scientific reasoning skills to understand how scientific knowledge is constructed, other researchers suggested that teachers' roles in scaffolding could help students develop those skills. Based on this literature review, it is important to find what kinds of generalizable teaching strategies teachers use for students scientific reasoning skills through scientific argumentation and investigate teachers' knowledge of scientific argumentation in the context of scientific inquiry. The relationship between teachers' knowledge and their teaching strategies and between teachers teaching strategies and students scientific reasoning skills can be found out if there is any.

Keywords: scientific inquiry, scientific argumentation, scientific thinking, procedural skills, reasoning skills, scaffolding.

Introduction

Science reform reports argue that scientific literacy has become a necessity for everyone. The view is that everyone needs to use scientific information to make choices that arise every day. For this purpose, the *National Science Education Standards* (National Research Council [NRC], 1996) present a vision of a scientifically literate populace by outlining what students need to know, understand, and be able to do by understanding what scientists do to construct new knowledge through their physical observations and experimentation.

Scientific Inquiry

Scientific inquiry is one way that scientists build new scientific knowledge. Reform recommendations are that students need to have opportunities to experience scientific inquiry to understand how scientists construct their new knowledge. Instruction in this process involves students making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence;

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using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results as scientists do to investigate natural phenomenon (NRC, 1996; p23). During this inquiry process, students develop an understanding of how they know what they know and what evidence supports what they know. The *Standards* also expect students to understand the nature of scientific inquiry, indicating how and why scientific knowledge changes in response to new evidence, logical analysis, and modified explanations debated within a community of scientists (NRC, 1996).

Teaching Scientific Inquiry in the Classroom

However, many studies in science education have found that many scientific inquiry practices implemented in the classroom require low cognitive thinking processes or they are just cookbook type activities without opportunities for students' to understand the nature and limitations of scientific knowledge building (Gallagher & Tobin, 1987; Krajcik et al., 1998). Gallagher & Tobin (1987) reported that inquiry process was presented as a recipe to follow steps without opportunities to apply reasoning skills. Tasks required low cognitive demand for reasoning during laboratory time with the emphasis on students completing their tasks rather than students learning science as inquiry. Krajcik et al. (1998) also reported that students did not use opportunities to draw conclusions by reflecting on their data and questions. Some students in groups drew conclusions based on their experience rather than their data. Others developed research questions which were not connected to their content. This evidence suggests that teaching scientific inquiry focuses more on hands-on activities than on reasoning about the process and results.

The *Standards* are clear when they advise educators that scientific inquiry is not simply hands-on activity. Getting students to understand science as inquiry requires their minds-on activities through argumentation, explanation, and communicating results as well as hands-on activities through experimentation and exploration. What is minds-on activity during scientific inquiry? Crawford (2000) described how one biology teacher implemented scientific inquiry with opportunities for student communication, which emphasized the students reasoning skills as well as their hands-on activities. This biology teacher in Crawford (2000) provided opportunities for argumentation by encouraging students to interpret the data with their own comments. Students in groups also tried to represent the data using three different graphs to see how they were alike or different in displaying data to see how those data were supportive of their hypotheses. Additionally, when students encountered anomalous data during their investigation, the teacher suggested that they should replicate the reliable data. Crawford, Kelly, & Brown (2000) also described how one elementary teacher created opportunities for students to engage in scientific discussions with each other to foster their own interest and to initiate questions so that the whole class could participate in scientific inquiry beyond a teacher-led curriculum. Students were offered opportunities to use their knowledge of inquiry processes, such as posing questions, observing, and offering alternative interpretations. Students also used their social practices, such as group norms for speaking and listening and particular ways of formulating an explanation.

This evidence above suggests that minds-on activities during scientific inquiry classroom instruction means to provide students with opportunities for understanding that scientific knowledge is both socially and individually constructed. Students were encouraged to determine what would constitute evidence to support each explanation, to explore each explanation, and to gather evidence that either supports or rejects each in turn critically and logically through argumentation. In addition, students were critical of their tools and methods by reflecting on what they learned, such as evaluating and communicating the advantages and disadvantages of the specific models used to explain natural phenomenon. With these points, teachers in Crawford (2000) and Crawford, Kelly, & Brown (2000) were considered to be successful in implementing scientific inquiry with students' opportunities of argumentation, through which they can understand the nature of scientific inquiry as well as science concepts.

Scientific Argumentation

What does student argumentation in the classroom mean? Driver, Newton, & Osborne (2000) state that argumentation is important within the social practice of science since students can develop knowledge and understand the evaluative criteria used to establish scientific theories which enhance the public understanding of science and improve scientific literacy. There are four goals for argumentation in the classroom: (1) to develop students' conceptual understanding, (2) to develop investigational capability, (3) to develop an understanding of scientific epistemology, and (4) to understand the value of a social practice of argumentation with peers and teachers (Driver, Newton, & Osborne, 2000).

Kuhn stated that we should experience science as argumentation as well as science as exploration to understand scientific thinking activity of scientists since students' scientific thinking can be developed best when they practice exercises of describing and justifying theories, presenting alternative theories, presenting counterarguments, and providing rebuttals through argumentations with peers and teachers (Kuhn, 1986; 1993). It has been illustrated that students need to distance themselves from their own beliefs to a sufficient degree to be able to evaluate those beliefs as objects of cognition. That is, Kuhn mentioned that students should have the capacity to think about their own thoughts. Her concern is not that students acquire correct experimentation strategies of traditional scientific hypothesis-testing strategies, but that students develop the ability to coordinate their existing theories with new evidence they generate in an explicit way to think about their own thoughts.

Vellom & Anderson (1999) investigated 6^{th} graders' argumentation through small and whole class group work with the content of density. The instructional sequence started from teacher's demonstrating some phenomena using three different color solutions with different densities. The students were then challenged to make as many different stacks as possible using three different solutions and to make stacks with color solutions in small groups. Finally, the teacher and students worked together to find out possible and impossible stacks of three different densities through argumentation when presenting the results in groups. All students took pre- and post-tests for conceptual understanding and two target students participated in interviews for further analysis. Its findings described that: (1) through argumentation with peers and the teachers, students reached one agreed theory or knowledge by sharing their ideas with supportive or refuting evidence from their investigation, and (2) students had opportunities to discuss experimental techniques and replication and to assess whether a particular scientific claim or fact fits into a larger pattern of data and theory. By developing argumentations with peers and teachers, every student knew which stacks were possible and which were impossible from their understanding that the stacking order depended on a property of the solutions themselves. This study showed how students learn science concepts in the context of scientific inquiry through argumentation based on their observations and experimentation.

Vellom & Anderson (1999), however, reported that inappropriate instruction by the teacher as authority made a few students unsuccessful in generating adequate standards through their discussion. For example, when the teacher introduced one stack of solutions, he attempted to control opportunities for some target students to speak more during the class discussion and imposed the rules so that issues could be resolved only by class consensus.

Groups Work as Social Practice for Scientific Argumentation

Then, what kind of teaching strategies can enhance students' argumentation to understand how scientific knowledge is constructed through scientific inquiry activities? A pivotal teaching strategy for teachers to provide students with opportunity of argumentation is through small groups activities with peers or teachers. Studies (e.g., Richmond & Striley, 1996) about students' argumentation of scientific inquiry in the classroom have found that the different type of small groups influenced students' achievement of science concept and skills of scientific inquiry.

Richmond & Striley (1996) investigated 24-10th grade students' argumentation through video and audiotapes during four laboratory investigations of integrated science content over 3 months to see how students constructed and used their developing scientific knowledge to solve problems with in the context of cooperative learning, that is, small group work, to encourage communication. The results released that the specific social roles and leadership styles developed within groups greatly influenced the ease within which students developed scientific understanding. In the beginning of laboratory experiments, students experienced difficulties in differentiating a problem from hypothesis, understanding the value of controls in designing experiments, and distinguishing between what they observed and what the observations mean. As experiments went on, the levels of engagement rose as a result of the group work and students' arguments became more sophisticated and better situated in an intellectual context; that is, students could formulate appropriate scientific arguments by identifying the relevant problem, collecting useful information, stating a testable hypothesis, collecting and summarizing data, and discussing the meaning of the data. In addition, three different styles of group leaders influenced students understanding of different content into a larger intellectual picture: (1) the *inclusive leader* who constructed knowledge through argumentation together with other students, (2) the *persuasive leader* who led argumentation in constructing knowledge mainly, and (3) the *alienating leader* who constructed knowledge which was too fragile. Overall, this study put the emphasis on what kind of leader(which leader was most effective in small groups was most effective for students to think scientifically in understanding how scientific knowledge is constructed. Its finding was that the inclusive leader was the most effective for this purpose.

Herrenkohl et al. (1999) selected 27- 3rd/4th grade gifted and 24-5th grade regular students with two teachers to see how students develop and refine their explanations for floating and sinking through the process of negotiation to reveal the importance of using group discourse. For this purpose, Herrenkohl et al. implemented some interventions: (1) the *tools* of predicting and theorizing, summarizing results, and relating predictions, theories, and results, (2) *specific roles* assigned to students as experimenters in small groups and as audiences in whole class presentations, (3) *question charts* to make critiques when presenting results, and (4) *theory charts* to document developing theories over time. Pre- and post-test showed that all students improved their conceptual understanding significantly. Transcripts of students' argumentations in groups showed the importance of using small groups with assigning specific roles to students; (1) *Procedural roles,* such as who collected the data, who kept time, and who collected the materials; (2) *Audience roles*, such as who predicted and theorized, who summarized results, and who related predictions and theories. This study released the importance of students' specified roles during inquiry experimentation and argumentation in guiding them to think scientifically in understanding how scientific knowledge is constructed.

Both studies of Richmond & Striley (1996) and Herrenkohl et al. (1999) showed how effective students' specified roles in small groups were in developing their abilities to think "scientifically" for the construction of scientific knowledge through argumentation with peers or teachers. Then, it is relevant at this point to define what is "scientific thinking".

Scientific Thinking

Kuhn (1989) defined the heart of *scientific thinking* is the ability to differentiate the evidence and theory respectively and to coordinate these two appropriately to construct new knowledge. She describes the scientist as someone who: (1) is able to consciously articulate a theory that the scientist accepts, (2) knows what evidence does and could support it and what evidence could contradict it, and (3) is able to justify why the coordination of theories and evidence has led the scientist to accept a theory or reject others regarding for the same phenomenon (p. 674). On the basis of this definition of scientific thinking skills, Kuhn and other researchers (Klahr & Kotovsky, 1989) investigated the process of scientific thinking and obtained the results to suggest that there are significantly different thinking processes among the child, the lay adult, and scientist.

Kuhn, Amsel, & O'Loughlin (1988) selected 3rd, 6th, 9th graders, average adults, and graduate students as experts, to see how those subjects used a variety of devices to bring evidence and theory into alignment when their theory and evidence were inconsistent. It was found that younger subjects were less likely than older ones to distinguish firmly between theory and evidence and less likely to be able to resolve the conflict between the two. For example, one of the studies had to do with the effects of features of a set of sports balls on the quality of a players serve. Evidence was portrayed by the actual balls placed in baskets labeled *GOOD SERVE* and *BAD SERVE* and the subjects were asked to relate the evidence to these two different theories. One of 3rd graders' evaluations was minimal and insufficient evidence. His response included that Mr. Size (differentiating *GOOD or BAD SERVE* theories) would win because the ball is big and Mr. Color would lose because the color doesn't matter, even though he theorized that size was causal (with large balls for *GOOD SERVE* small balls for *BAD SERVE*) and color was noncausal.

Klahr & Dunbar (1988) selected 3rd to 6th graders and undergraduate students who have computer background to find out the function of one key from a keypad based on their trial-error practices with BigTrak robot through their abilities to coordinate the two problem spaces of *hypothesis and experiment. Hypothesis space* is guided both by prior knowledge and by experimental results. *Experiment space* is guided by the current hypothesis, and it may be used to generate information to formulate new hypotheses. Klahr and Dunbar reported that there was little difference between children and the adults at the level of subjects' global behavior on the task. That is, both groups clearly understood the nature of the task and realized that they could only discover how the device worked by making it behave, observing that behavior, and generating a summary statement that captured the behavior in a universal and general fashion.

Klahr & Dunbar (1988), however, found that there were profound differences in the consequences of how this general orientation toward discovery was implemented. Adults had a 95% success rate, whereas 90% of the children failed. This difference was not from their procedural ability of generating informative experiment but from their reasoning and inducting ability from the results of those experiments. Children were observed to generate some data to patch a faulty hypothesis or to produce an expected effect, whereas adults generated a data pattern over which they could induce a new hypothesis. Children were observed to induce new hypotheses from experiments, but none of them were able to use an experimental result to induce a new theory. Adults were largely successful in completing their job assigned, whereas children showed limited ability to coordinate two problem spaces of hypotheses and experiments and to design informative experiments that led to successful problem solutions (Klahr & Kotovsky, 1989).

All these studies (Kuhn, Amsel, & O'Loughlin, 1988; Klahr & Dunbar, 1988; Klahr & Kotovsky, 1989) reveal that scientific thinking skills essential to construct scientific knowledge during inquiry process are related to the skills of differentiating evidence from theory and coordinating them together. It is also concluded that these scientific thinking skills that scientists use in their investigation of natural phenomenon cannot be the same that students use in their daily life. Kuhn (1989) stated that children are like scientists in the sense of *understanding of scientific phenomenon,* which means that child and scientist gain understanding of the world through construction and revision of a succession of models, or paradigms, that replace one another. However, Kuhn argued that the *process of scientific thinking* to revise those models or theories is different between child and scientist. Reif & Larkin (1991) also examined students' understanding about scientific inquiry at schools. Reif & Larkin (1991) stated that students had erroneous conceptions of scientific goals, that is, they used goals and ways of thinking that were effective in everyday life but inappropriate to science, and they devised ways of thinking that were not suitable to science.

Students need to develop scientific thinking skills during their scientific inquiry lessons at schools organized by teachers such as the ability to differentiate evidence from data. Scientific thinking skills are achieved through practices of argumentation with a certain scientific concept in the context of scientific inquiry (Duschl & Osborne, 2002). For this purpose, teachers need to provide students with opportunities in which students can develop conceptual understanding, develop their investigative competence, and understand the epistemology of science.

Teachers' Roles in Scaffolding for Scientific Argumentation

Hogan, Nastasi, & Pressley (2000) investigated 8th grade student groups' argumentations with and without a teacher's help to develop the model to explain phenomenon. Students' accomplishments differed somewhat depending on the presence or absence of a teacher in the discussion. The teacher tended to act as a catalyst in discussions, motivating students to expand and clarify their thinking without direct instruction or other exposure to conceptual information. Teacher-guided discussions were a more efficient means of attaining higher levels of reasoning and higher quality explanations but peer discussion tended to be more generative and exploratory. When students worked by themselves, they tended to initiate new avenues of discussion by making a conceptual contribution, such as sharing ideas, rather than by asking one another questions. On the other hand, when students interacted with a teacher during discussion, new conceptual territory was opened mainly by the teachers direct requests for information. Most students' contributions to a discussion with the teacher's help were conceptual since teachers' role was predominantly as a questioner and students' role as respondents in teacher-guided groups. Teachers were clearly in control of students' discussion but they did not dominate interactions between/among students. This evidence showed that teachers created conditions that caused students to expand and clarify their own thinking by teachers' prompting and clarifying ideas.

Yerrick (2000) examined the effects of open inquiry instruction with low achieving high school students as researcher and teacher with the content of physics. Yerrick examined students' argumentation, which was observed to shift toward understanding the nature of the scientific argumentation. Students offered more tentative and sophisticated answers and they constructed their explanations linking evidence to warrant after Yerrick's instruction. Furthermore, students all referred to the body of evidence that tests would produce when they were asked how they would know if they were right. For students' argumentations, Yerrick required students (1) to pose a hypothesis with supporting evidence to propose models or explanations, (2) to design and carry out experiments in groups of three to test their claims, (3) to discuss their models or initial claims with the whole class, which ended in one of two ways; either students agreed to accept the model or they returned to the lab for more evidence. To develop a discourse community without teachers authority to determine correct answers, Yerrick promoted the notion that students questions and experiences were to be valued first, and critique of those ideas was promoted as a subsequent necessity for communal understanding of any problem.

These two studies, Hogan, Nastasi, & Pressley (2000) and Yerrick (2000), showed how teachers roles in scaffolding could promote students argumentations to develop their scientific thinking skills during their scientific inquiry activities. In the scaffolding process, teachers pose questions not to evaluate but to discover what students now know and what ideas students are struggling with. Teachers prompts and hints are to make students progress in understanding rather than simply evaluating what they are learning (Pressley et al., 1996).

Concluding Remarks

Recent studies about scientific inquiry emphasize the use of scientific argumentation to understand the nature of scientific knowledge based on their observations and experimentation. Students need to learn how to think scientifically through their argumentation, which requires students abilities to differentiate evidence from theory and coordinate them to understand how scientific knowledge is constructed. Then how can we provide students with those opportunities for scientific argumentation then? Studies about students' argumentation imply that educators and teachers can and need to develop a pedagogy which provides students with argumentation opportunities and which enhances those skills. Herrenkohl et al. (1999) showed how students enhanced their abilities of reasoning skills as well as procedural skills in the context of small groups with some charts designed by the teachers. Those charts facilitated students' reasoning skills of differentiating data from theory and coordinating them in developing explanations of phenomenon. Surely, teachers' prompts and questions encouraged students to extend their thinking process to the broader science content. The role of the teacher in scaffolding to promote students' argumentation ability is not simply for triadic dialogue consisting of teacher's question, students' responses, and teacher's evaluation (Lemke, 1990). With a great deal of knowledge about curriculum and individual students, teachers can understand the problems that their students are experiencing so well so that they can generate a variety of prompts and questions stimulating students' thinking in appropriate directions and away from misconceptions (Pressley et al., 1996).

The most important finding from reviewed studies about students' argumentation abilities is the lack of opportunities for them to use argumentation in the classroom to learn science and about science. That is, there is a general lack of pedagogical expertise among science teachers in organizing activities in which students are given a voice. Therefore, it is important to improve teachers' knowledge, awareness, and competence in managing student participation in discussion and argumentation as well as to enhance the argument skills of young people. For this purpose, it is important to know what kinds of teaching strategies enhance students' argumentations or not in the classroom.

In addition, it is necessary to study how teachers provide more opportunities for argumentation and scaffold students to extend their reasoning skills as well as procedural skills for investigation compared to others who do not.

Further research concerns can start from the problem of scientific inquiry in the classroom first. The problem of scientific inquiry includes no opportunities of argumentations to understand how scientific knowledge is constructed. Students can develop their scientific reasoning while developing scientific argumentation. Furthermore, students scientific reasoning is more facilitated by small groups with specified roles. Additionally, teachers explicit roles of scaffolding are to facilitate students' scientific reasoning.

Based on these theoretical frameworks, some research questions can be developed about what kinds of instructional strategies can be emerging for opportunities of students' scientific reasoning during their argumentation. First of all, it is important to look for the patterns or explicit generalizable instructional strategies of scientific argumentation implemented by teachers. What is teachers' knowledge of scientific argumentation during scientific inquiry? Is there any relationship between teachers' knowledge and their practices of students' argumentation in the classroom? Do students display different abilities of reasoning skills depending on their teachers' different instructional strategies? For these research questions, secondary schools are appropriate to see how teachers provide opportunities for students to make argumentation to understand nature of scientific inquiry and argumentation, since the students before the ages of 10 or 11 are known to hold incomplete scientific knowledge to do scientific inquiry (Carey et al, 1989). The research questions can be posed as follows.

- What kinds of explicit instructional strategies are emerging when teachers scaffold students to develop their argumentation?
- What kind of knowledge or definition about scientific argumentation do teacher hold during scientific inquiry?
- What is the relationship, if any, between teachers' instructional strategies and their knowledge of scientific argumentation in the context of scientific inquiry?
- What is the relationship, if any, between different students' abilities of reasoning skills, differentiating theory and evidence or coordinating them, and their teachers instructional strategies?

This investigation is significant for practical reasons. Many teachers are not sure of how to use scaffolding to help students understand how scientific knowledge is constructed. If generalizable and exemplary instructional strategies can be found that have enhanced students' argumentation, those strategies can be documented and used as guide lines for other inservice teachers to employ to develop students' argumentation. This study will be a reminder that teachers serve an important role in classroom by guiding and scaffolding ways in which knowledge gets shaped, refuted, and promoted.

Identifying exemplary instructional strategies for students' argumentation can also have significance in teacher education for preservice teachers. Preservice teachers are trained to design scientific inquiry lessons with the emphasis on hands-on activities through experimentation rather than minds-on activities through argumentation. Therefore, by identifying good models or functions of students' argumentation during scientific inquiry this investigation can lend support for science educators to provide preservice teachers with more practical knowledge of how to create scientific inquiry environments full of argumentation.

References

Bybee, R.W., 2000, Teaching science as inquiry. In Minstrell, J. and van Zee, E.H., Inquiring into inquiry learning and teaching in science (pp. 21-46). American Association for the Advancement of Science: Washing-

ton, DC.
Carey, S., Evans, R., Honda, M., Jay, E., and Unger, C., 1989, An experimental is when you try and see if it works: Middle school conception of science. International Journal of Science Education, 11 (special issue), 514-529.
Crawford, B.A., 2000, Embracing the essence of inquiry: New roles for science teachers. Journal of Research in Science Teaching, 37(9), 916-937.
Crawford, T., Kelly, G.J., and Brown, C., 2000, Ways of knowing beyond facts and laws of science: An ethnographic investigation of student engagement in scientific practices. Journal of Research in Science Teaching, 37(3), 237-258.
Driver, R., Newton, P, and Osborne, J., 2000, Establishing the norms of scientific argumentation in classrooms. Science Education, 84, 287-312.
Duschl, R.A. and Osborne, J., 2002, Supporting and promoting argumentation discourse in science education. Studies in science education, 38, 39-72.
Gallagher, J.J. and Tobin, K., 1987, Teacher management and student engagement in high school science. Science Education, 71(4), 535-555.
Herren Kohl, L.R., Palincsar, A.S., DeWater, S.L., and Kawasaki, K., 2000, Developing scientific communities in classrooms: A sociocognitive approach. The Journal of the Learning Sciences, 8(3 & 4), 451-493.
Hogan, K., Nastasi, B.K., and Pressely, M., 2000, Discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. Cognition and Instruction, 17(4), 379-432.
Klahr, D. and Kotovsky, L., 1989, Complex information processing: The impact of Herbert A. Simon. New Jersey: Lawrence Erlbaum Associates.
Klahr, D. and Dunbar, K., 1988, Dual space search during scientific reasoning, Cognitive Science, 12, 1-48.
Krajcik, K., Blumenfeld, P.C., Marx, R.W., Bass, K.M., Fredricks, J., and Soloway, E., 1998, Inquiry in project-based science classrooms: Initial Attempts by middles students. The Journal of the Learning Science, 7 (3 & 4), 313-350.
Kuhn, D., 1993, Science as argument: Implication for teaching and learning scientific thinking. Science Education, 77(3), 319-337.
Kuhn, D., 1992, Thinking as argument. Harvard Educational Review, 62(2), 155-178.
Kuhn, D., 1989, Children and adults as intuitive scientists. Psychological Review, 96(4), 674-689.
Kuhn, D., 1989, Making cognitive development research relevant to education. In W. Damon (Ed.), Child development today and tomorrow (261-287). San Francisco: Jossey- Bass Publishers.
Kuhn, D., Amsel, E., and O'Loughlin, M., 1988, The development of scientific thinking skills. San Diego: Academic Press, INC.
Kuhn, D., 1986, Education for thinking. Teachers College Record, 87(4), 495-511.
Lemke, A.L., 1990, Talking science: Language, Learning, and Values. New Jersey: Ablex Publishing Corporation.
National Research Council, 1996, National Science Education Standards. Washington, D.C.: National Academy Press.
Pressley, M., Hogan, K., Wharton-McDonald, R., Mistretta, J., and Ettenberger, S., 1996, The challenges of instructional scaffolding: The challenges of instruction that supports student thinking. Learning Disabilities Research & Practices, 11(3), 138-146.
Reif, F. and Larkin, J.H., 1991, Cognition in scientific and everyday domains: Comparison and learning implications. Journal of Research in Science Teaching 28(9), 733-760.
Richmond, G. and Striley, J., 1996, Making meaning in classrooms: Social processes in Small-group discourse and scientific knowledge building. Journal of Research in science Teaching, 33(8), 839-858.
Yerrick, R.K., 2000, Lower track science students argumentation and open inquiry instruction. Journal of Research in Science Teaching, 37(8), 807-838.
Vellom, R.P. and Anderson, C.W., 1999, Reasoning about data in middle school science. Journal of Research in Science Teaching, 36(2), 179-199.

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Appendix

Terms definition

Scientific inquiry

Clarification of what is meant by scientific inquiry will help to understand the topic being discussed. The *Standards* (NRC, 1996) defines scientific inquiry as the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work (p. 23). The *Standards* use the term "Inquiry" in three ways: One is content that students should understand about scientific inquiry. The other is the ability that they should develop from their experiences with scientific inquiry. Inquiry is also referred to as teaching strategies and the processes of learning with activities of inquiry (Bybee, 2000). Scientific inquiry can be divided into two types: *Authentic scientific inquiry* that scientists do at research sites and *School scientific inquiry* at classroom sites. Based on our understanding about scientific inquiry, the big difference between these two types of scientific inquiry results in the opportunities for argumentation by students in the classroom. Scientific inquiry is not guaranteed only in hands-on activities. Scientific inquiry envisioned by the *Standards* can take place through minds-on activities as argumentation and explanation as well as hands-on activities as experimentation and exploration.

Scientific Argumentation

Students understand how scientific knowledge is constructed through scientific argumentation, which shifts our view away from seeing science as an empirical process, where truth is grounded in observations and conclusions are deduced from such observations, toward science as a social process of knowledge construction, which involves conjecture, rhetoric, and argument. That is, scientific knowledge or claims seem to be grounded through the process of scientific argument-relating hypothesis to evidence available. It is on the basis of the strength of the arguments and their supporting data that scientists judge competing scientific knowledge and work out whether to accept or reject it.

Social practices as small group works

In the classroom, small groups work with peers and teachers become social practices in which students explore their own arguments with different positions and develop the confidence and skills necessary in making life decisions. In small groups, there are three different students' roles: leaders, helpers, and noncontributors. All students are found to develop abilities of scientific reasoning depending on the types of leaders, which include inclusive, persuasive, and alienating leaders (Richmond & Striley, 1996). It is expected that social and intellectual achievement would be the greatest for those students in inclusive leadership through the greatest social skills with roles of advocates and altruistic by leaders.

Scientific thinking

Students are supposed to develop their scientific thinking skills by interacting with peers and teacher through argumentation during their scientific inquiry activities. Scientific thinking is defined as the skill to differentiate evidence from theory and coordinate them to develop model or explanation. A central premise underlying science is that scientific theories stand in relation to actual or potential bodies of evidence against which they can be evaluated (Kuhn, 1989, p. 674). Through the scientific thinking process, the scientist (a) is able to articulate a theory that the scientist accepts, (b) knows what evidence could support or contradict it, and (c) is able to justify why the coordination of available theories and evidence had led to accept that theory and reject others purporting to account for the same phenomenon.

Scaffolding for students scientific thinking

Another way to approach bridging the gap between what students can and cannot do is through scaffolding. Scaffolding is a process enabling child or a novice to solve a problem or carry out a task that would be beyond the learners unassisted efforts. Scaffolding by more able adults or peers through interactions involves construction of knowledge within the social context. In science, teachers release direct responsibility of the task gradually and they instruct and assist students to learn science. Pressley et al. (1996) noted that there are important inadequacies of scaffolding for its effectiveness in promoting cognitive growth and the authors implied that scaffolding is part of effective instruction but that instruction fully supporting the development of student thinking includes much more.