Sci & Educ (2012) 21:881–898
DOI 10.1007/s11191-009-9219-1

Developing Content Knowledge in Students Through Explicit Teaching of the Nature of Science: Influences of Goal Setting and Self-Monitoring

Erin E. Peters

Published online: 27 November 2009

Abstract Knowledge about the nature of science has been advocated as an important component of science because it provides a framework on which the students can incorporate content knowledge. However, little empirical evidence has been provided that links nature of science knowledge with content knowledge. The purpose of this mixed method study was to determine if both nature of science knowledge and content knowledge could be increased with an explicit, reflective nature of science intervention utilizing self-regulation over an implicit group. Results showed that the explicit group significantly outperformed the implicit group on both nature of science and content knowledge assessments. Students in the explicit group also demonstrated a greater use of detail in their inquiry work and reported a higher respect for evidence in making conclusions than the implicit group. Implications suggest that science educators could enhance nature of science instruction using goal setting and self-monitoring of student work during inquiry lessons.

1 Introduction

Nature of science knowledge has consistently been identified as a core goal for students of all grades in national curriculum documents, such as those in New Zealand (MoE 1993), the UK (e.g. DfEE/QCA 1999) and the United States (American Association for the Advancement of Science 1993; National Research Council 1996), and has been advocated as an important component of science education because it provides a framework on which the students can incorporate content knowledge (Duschl 1990; Lederman 1992; Matthews 1994; McComas et al. 1998; Parkinson 2004; Peters 2006; Turner 2000). Science students are expected to understand the body of knowledge known as scientific facts, as well as possessing the skills to conduct scientifically designed investigations in order to be scientifically literate.

One path toward scientific literacy for all students is development of nature of science knowledge. The nature of science is a domain that draws from various disciplines such as

E. E. Peters (✉)
George Mason University, 4400 University Drive, MSN 4B3, Fairfax, VA 22030, USA
e-mail: Epeters1@gmu.edu

the philosophy, history, sociology, and psychology of science. The term "science" used here refers to all of the various disciplines of science, biology, chemistry, physics, and earth and space sciences, referencing a general approach. These sets of models viewed collectively describe what science is and how it is performed. A scientifically literate student would be able to be adept in knowing both content knowledge and nature of science knowledge. However, there is little to be gained in knowing the nature of science as a list of facts. The purpose of teaching nature of science knowledge is to provide students with knowledge about the endeavor of science and how science content knowledge has been generated and validated.

Historically, there have been many different orientations about what science is and how it is performed. An incomplete list of examples might include positivism, logical empiricism, critical rationalism, new philosophy of science, structuralism, semantic views, and postmodernism. New models of how science is done continue to emerge. One example of emerging nature of science models is the use of distributed knowledge to solve large-scale problems such as tsunami prediction using the cyberinfrastructure. This model requires that large groups of scientists from different disciplines work together in web-based settings and contribute their expertise to the aggregate knowledge of the community because one research setting would not be sufficient to provide enough information to work to a solution. Debates about the nature of science often lie in the source of perspective about the scientific enterprise and whether it come from scientists, philosophers of science, or science educators (Stenhouse 1985; Duschl 1988; Hodson 1993), the scope of the view taken (Ryan and Aikenhead 1992), and the use of qualitative or quantitative measurement (Gallagher 1991; Lederman et al. 2002). Choosing a nature of science orientation for this study had not only philosophical implications but also educational implications. Within the science education community, a relatively discrete list of such nature of science aspects is beginning to crystallize (McComas 2005; Lederman 2006; Osborne et al. 2003) and is seen as having educational value. All 50 states in the United States have adopted nature of science knowledge standards, to varying degrees, based on this list into their curriculum framework (McComas 2009). The convergent aspects of the nature of science were adopted as the orientation for this study because of the educational value in the elements and for the potential for assisting school systems in making research-based decisions about curriculum.

The convergent aspects of the nature of science that have been explicated include: (a) scientific knowledge is durable yet tentative, (b) empirical evidence is used to support ideas in science, (c) social and historical factors play a role in the construction of scientific knowledge, (d) laws and theories play a central role in developing scientific knowledge, yet they have different functions, (e) accurate record keeping, peer review, and replication of experiments help to validate scientific ideas, (f) science is a creative endeavor, and (g) science and technology are not the same, but they impact each other (Lederman 1992; McComas 2008). Students who attain a well developed understanding the nature of science may gain more insight into the guidelines that the scientific discipline uses to generate and verify content knowledge.

Scientific inquiry can be thought of as a variety of processes and ways of thinking that support development of new knowledge (Flick and Lederman 2004). Teaching about the processes that scientists use to perform inquiry can help develop student understanding of the models that guide the generation of new scientific knowledge. In conducting scientifically designed investigations, students need to be creative, often they conduct their inquiry in small groups, need to select measurements and measuring tools that are appropriate to their inquiry, need to have analysis tools to draw upon, and need to make the logical decisions about the question they are pursing and generating conclusions from trends in data. In other words, science students need to be able to apply the models that represent the nature of science through inquiry in order to gain content knowledge.

Student knowledge of the nature of science has been promoted as a vehicle to help students better fit content knowledge into their own personal conceptual frameworks of how the world works. However, little evidence has been reported on the correlations between nature of science knowledge and content knowledge. The study discussed in this paper builds on prior successful work on teaching the nature of science through explicit, reflective methods, and explores possible mechanisms for learning nature of science knowledge and content knowledge simultaneously. The intervention took the approach that students can learn the nature of science through comparing their own inquiry to the guidelines inherent in the scientific discipline, and that students can learn the nature of science through reflection on their own work, rather than interpreting work of scientists as an outside observer. The study explores the effect of student goal setting and self-monitoring for alignment to guidelines from the scientific enterprise during a guided inquiry lesson on gains in content knowledge and nature of science knowledge.

2 Considerations in Teaching Nature of Science Knowledge

Research has shown learning nature of science knowledge to be difficult, and there have been emergent effective methods offered for teaching nature of science (Akerson and Abd-El-Khalick 2003; Southerland et al. 2003). One technique that has shown promise in increasing nature of science knowledge is an explicit, reflective method (Rudge and Howe 2009; Akerson et al. 2008; Khishfe and Abd-El-Khalick 2002). An explicit, reflective method requires the teacher to openly pinpoint when students are emulating the scientific enterprise, and to provide opportunities for students to monitor their understanding of this the way science generates and verifies knowledge. For example, Khishfe and Abd-El-Khalick (2002) found success in teaching the nature of science by having students participate in a guided inquiry followed by reflective discussions of the nature of science experienced during the inquiry. The present study builds on this knowledge and utilizes concepts from the study of self-regulation of learning (Zimmerman 2000) to provide an alternative explicit, reflective method of teaching the nature of science.

2.1 Self-Regulatory Theory as Foundation for an Explicit, Reflective Method

It has been shown that explicit, reflective methods are useful in teaching the nature of science, and this study extends that idea by adopting clinically effective methods of teaching and learning from the field of educational psychology. The particular learning theory chosen for this study was self-regulation. Self-regulation refers to the degree to which students are metacognitively, motivationally, and behaviorally active participants of their own learning, and has three components that compose an iterative cycle: forethought, performance, and self-reflection (Zimmerman 1998). When students are involved in the forethought phase, they consider the relevant knowledge to the problem they are trying to solve. Given a problem to investigate that has ill-structured boundaries, students will begin by organizing their prior knowledge pertinent to the problem during the forethought phase. In the performance phase, students attempt the given task, and access their prior knowledge to develop the new skills and knowledge used in the task. In the self-reflection phase, students compare the outcome of their task with a standard to see how successful they were. After the students completed this cycle, they attained more knowledge and skills, beginning the cycle with more extensive forethought.

The iterative cycle of forethought, performance, and self-reflection can be more specifically and tangibly implemented in the classroom with goal setting (forethought), attention focusing (performance), and self-monitoring and evaluation (self-reflection). Goal setting is the process of setting specific tasks and strategies to learn to master the task. Attention focusing is referring to the methods used to screen out processes that have a negative effect on learning and to concentrate on the methods that aid learning. Self-evaluating is the process of comparing learning outcomes to the goals set in the forethought phase (Zimmerman 2008). Efforts to incorporate goal setting and self-evaluation have been shown to be effective in developing independent learners in other academic settings (Schunk 1996; Schunk and Ertmer 1999; Zimmerman and Kitsantas 1999), but have yet to be used in an empirical study in a science classroom. In this case a tangible method of self-regulation was adopted to focus on student goal setting and self-monitoring of their success in reaching those goals (Kitsantas and Zimmerman 2006). Attention focuses was built into the intervention through the self-monitoring prompts which focused students on the scientific behaviors that would progress their learning of the nature of science. Because students are not familiar with the ways scientists conduct their work (Hogan and Maglienti 2001), it was necessary for the intervention to provide an example of scientific behavior that set goals for the students during the forethought phase of the guided inquiry. During the performance phase, student conducted the inquiry. In the self-reflection phase, students monitored their own work in the inquiry units for alignment to a particular aspect of the nature of science by utilizing checklists. The use of examples and supporting checklists demonstrate the iterative cycle of self-regulation while also making the method of teaching the nature of science explicit and reflective, and may create a learning environment where students can make more meaning from the content knowledge they gain during the process of conducting inquiry.

Student performance during scientific inquiry may be optimized by reflecting on and being self-regulatory about the guidelines of the scientific enterprise. Setting goals based on an aspect of the nature of science that is prominent in the particular inquiry could help students form specific ideas about what they need to accomplish in order to think scientifically. Goals that are set to help students conduct investigations in a scientific way are advantageous for the following three reasons: (1) they provide tangible, specific standards from which to conduct student work, (2) they can be placed strategically to proximally emphasize a particular aspect of the nature of science, and (3) they make students aware of the quality of their work and give particular ways to improve (Zimmerman 2008). Goals set to achieve growth of nature of science knowledge help students by providing tangible, specific standards for a very ambiguous subject. Goals to improve nature of science knowledge can be placed strategically in a lesson, thus providing a timely, explicit prompt to illustrate the rationale behind developing and verifying the content knowledge. The nature of science can be difficult to teach because it cannot be taught without context, and often the science content that is necessary to illustrate the aspect of the nature of science is often complex (McComas 2008). Placing goals in proximity to the context can maximize learning of the connection between the scientific guidelines that direct the decisions made to conduct inquiry inquiry and the scientific content that is constructed from the experience. Additionally, goals made consciously are more reliably and directly tied to task performance than unconscious goals (Howard and Bray 1988; Locke and Latham 2002). Explicit examples of the scientific enterprise gives students conscious goals for their own work and increase their ability to perform the inquiry. Goal setting includes features necessary for effective learning of nature of science knowledge so in turn, student inquiry can result in improved content knowledge.

Self-monitoring, one of the key sub processes of self-regulation, consists of focusing on paying close attention to a singular feature of one's behavior (Schunk 1996). Researchers have found that self-monitoring can improve students' academic performance (Malone and Mastropieri 1992; McCurdy and Shapiro 1992), academic achievement (Sagotsky et al. 1978; Schunk 1983), and problem solving ability (Delclos and Harrington 1991). Self-monitoring enables the learner to gauge their success in their performance so they can decide to continue with their current performance for the task or to change strategies. This reflective practice, using a self-oriented feedback loop during learning, helps students be more efficient in their learning.

3 Method

Self-regulated learning has been shown to be effective in other academic domains such as strategy use (Weinstein and Underwood 1985), intrinsic motivation (Ryan et al. 1984), and metacognitive engagement (Corno and Mandinach 1983), but has not yet been used in empirical studies of science education. The purpose of this mixed methods embedded study (Creswell and Plano Clark 2007) was to determine if both nature of science knowledge and content knowledge could be increased with an explicit, reflective nature of science intervention utilizing self-regulation over an implicit group. The following research questions guided the study: (1) Will a group given a self-regulatory intervention that develops nature of science knowledge explicitly outperform an implicit group on content knowledge tests and nature of science knowledge tests? (2) What processes in the construction of scientific knowledge are utilized by the implicit group and the explicit group?

3.1 Research Design

Two-hundred and forty-six ($N = 246$) eighth grade students from a middle school located in an urban area of the mid-Atlantic region of the United States participated in the study. One hundred and twenty-six boys and 120 girls were chosen from 12 intact classes over a period of 3 years. All classes were taught by the same teacher who was trained in the delivery of the intervention and who was mindful of the possibility of contamination between the different strategies employed by the explicit and implicit group. The fidelity of the teacher to the delivery of the intervention was checked daily through classroom observations and by daily after school discussions.

The curriculum which was the foundation of the lessons for both groups, explicit and implicit, in this study was based on scientific inquiry (National Research Council 1996). Both the implicit group ($N = 114$) and the explicit group ($N = 132$) were given four sequential guided inquiry lessons on electricity and magnetism. The lessons were taught for 45 min each day over a 6-week period. Each lesson had three main pedagogical elements: (1) explication of student prior knowledge, (2) hands-on activities promoting the construction of knowledge about scientific content and processes, and (3) student-generated summary of the overarching understandings (National Research Council 1996). Student prior knowledge was generated in each of the four lessons through a think-pair-share paradigm (Johnson and Johnson 1994). At the beginning of the lesson, students were given a question that engaged their knowledge about the relevant electricity or magnetism phenomena and asked to write their thoughts individually for 3 min, discuss their ideas with a partner for 5 min, and then the teacher conducted a whole class discussion of their collective ideas. The next portion of the lesson, hands-on activities, were designed to help students learn more detail about the phenomena by making observations, writing descriptions of the physical interactions they witnessed, and making attempts to explain the physical interactions in the activity. Lastly, students were expected to synthesize their new knowledge from the hands-on activities by describing three or four big ideas they found in the lesson. In their summary of the overarching understanding, students were also expected to refer to empirical evidence gathered in the hands-on activities to back up their description of the big ideas. During the hands-on and synthesis portions of the lesson, students were expected to work in assigned groups of three or four students.

Although both groups were given identical content knowledge tasks, each group was given a different way to develop nature of science knowledge. The explicit group was given a self-regulatory training model that set goals for the students regarding their performance of a selected aspect of the nature of science and gave students checklists and questions to self-monitor their progress in aligning their inquiry work to ideas about the nature of science (Metacognitive Prompting Intervention—Science or MPI-S). The implicit group learned about the nature of science implicitly through the inquiry activities and was given additional content questions to account for equal time-on-task. The self-regulatory training model, based on the work of Zimmerman (2000), was used in MPI-S to model scientific thinking for a specific aspect of the nature of science (goal setting) and to teach students to align their decisions about processes and knowledge in the inquiry activities with the guidelines of the nature of science on their own (self-monitoring). MPI-S focuses only on the aspects of the nature of science, and is free of content instruction. For example, the MPI-S prompts for the empirical aspect of the nature of science have the following four phases in the intervention: (1) example of an empirical observation made by a scientist that includes detailed descriptions and standard units for implicit purposes and the instruction by the teacher on the use the checklists to attain an empirical observation that would be accepted in the scientific community (goal setting), (2) checklist that was used in the example for students to compare their decisions in the inquiry to the empirical nature of science (self-monitoring), (3) short checklist for students to align their work with the nature of science and a short list of questions asking about the validity of their empirical evidence (self-monitoring and evaluation), and (4) a longer list of questions probing students' rationales in their decisions about inquiry processes and construction of knowledge based on empirical evidence (self-monitoring and evaluation). MPI-S was given to the students iteratively, so that they had further practice in the training. It was anticipated that students would set goals to learn the strategy of making quality empirical observations based on the modeling and the strategies given in the checklists. Additionally, the training model encouraged students to make observations on their own and helped them to self-monitor the alignment of their observations with observations that would be considered scientific.

3.2 Implicit Group

The implicit group was given four guided inquiry modules that covered the same science content as the explicit group: characteristics of permanent magnets, characteristics of static electricity, characteristics of current electricity, and characteristics of electromagnets. Students in the implicit group were exposed to the nature of science through the design of the guided inquiry modules. The modules were designed with concept maps that required each student claim to be supported with evidence. Students were allowed to change a conclusion in their work after they discussed their results with another group, implicitly demonstrating the tentativeness of the nature of science. The modules were written so that students were interdependent within groups and students needed to be social in order to conduct scientific inquiry. Students were implicitly exposed to the relationship between science and technology as they were free to choose the tools they needed to construct scientific knowledge. Students needed to design their own data tables and forms of collecting data, implicitly demonstrating the need for accurate record keeping in science. Students were encouraged to work in small groups, to share their groups' findings with other groups and the whole class, implying that scientists used peer review in validating data. Time on task was equal because the implicit group received additional content questions to account for the time taken by the explicit group to set goals and self-monitor. Students in the explicit group were expected to conduct the implicit processes above, but they were also supported with the explicit training module based on aspects of the nature of science.

3.3 Explicit Group

The explicit group was given the same modules as the implicit group, but with the self-regulatory nature of science prompts (MPI-S) embedded throughout the activity. Students in the explicit group were asked to set goals and self-reflect on their work during the science inquiry modules with the help of checklists and questions. A sample list of prompts from the third module, separated by phase, can be found in Table 1. This training

Table 1 MPI-S for nature of science concept: Accurate record keeping, peer review and replication of experiments help to validate scientific ideas

Self-regulation training	Prompts
Goal setting	Other people can agree that your observations, inferences and ideas are accurate if they can redo your investigation and find similar observations, inferences and ideas. Scientific knowledge grows when a new idea can be confirmed by the scientific community. Example: I made a magnet out of an iron nail by rubbing the magnet in one direction 50 times. When I did this, the nail, which was not attached to the magnet, picked up 3 paperclips for 1 min. When I rubbed the same nail 100 times in one direction, the nail, which was not attached to the magnet, picked up 5 paper clips. I need to perform more trials to confirm the idea that rubbing a metal object more times makes it more magnetic
Self-monitoring	I would be able to understand my data table weeks or months from now I paid attention to all possible observations I did not intentionally ignore any observations because they did not support my hypothesis My data are organized to show my point of my conclusion I thought about different ways to organize my data and decided on the one that best emphasizes my conclusion
Self-monitoring and evaluation	Could you understand what you did to get your data weeks or months from now? Did you ignore any data/observations that happened? Could you understand what you did to obtain your data weeks or months from now? Are your data organized to clearly illustrate your point? I would be able to understand my data table weeks or months from now I paid attention to all possible observations I thought about different ways to organize my data and decided on the one that best emphasizes my conclusion.
Self-monitoring and evaluation	Are your data organized to clearly illustrate your point? Have you ignored any factors in taking the data? Are all factors accounted for? Explain

technique focused on goal setting and self-monitoring of the nature of science. For example in the first module, the first task the students were expected to complete was to observe the behavior of 2 bar magnets to determine the points where the attraction was the strongest. Students in the explicit group were given an example of how a scientist might write their observations, focusing on a large amount of detail and using standard measurements, which set the targeted performance which students should work toward. Then, students were given a different situation to observe and asked to write observations, but were supported with an extensive checklist to self-monitor their level of detail and clarity for outside readers. In the new situation, students were given disc-shaped magnets and again asked to determine the position of the strongest attraction. Next, students were given irregularly shaped magnets and expected to conduct the same scientific process, given a short checklist with a few open-ended questions to evaluate their self-monitoring. The open ended questions helped to explicate student reasoning so the student could examine the student's decisions in the inquiry unit for alignment with the nature of science. The purpose of asking students to observe the behavior of different shaped magnets was to demonstrate the general idea that all permanent magnets have two poles regardless of shape. Finally, students were given higher level questions that elicited their reasons for making decisions in the inquiry module, for example "Can other people who did not perform this activity understand your observation? How do you know that?" The purpose of the higher level questions was to help students see that the decisions they were making during the inquiry should be based on the nature of science, so that their results would be valid. It was expected that once the students saw that they were operating according to the nature of science, they would understand the "rules" that govern scientific discovery and continue to be guided by the nature of science in their decisions during scientific inquiry. The length of time spent on the nature of science prompts was determined in a prior study and the implicit group was given content questions to account for equal time spent in the tasks.

The first module, which addressed magnetism, focused on the empirical aspect of the nature of science because this module focused on finding patterns in qualitative observations. The second module, which was on static electricity, focused on the differences between laws and theories because students were expected to differentiate between what happened and why the phenomena happened. The third module, which was on current electricity, focused on the need for peer review and data collection, because conclusions about current electricity were to be made based on small differences in quantitative data. Because the differences in the patterns were small, it was useful to have groups combine their results to have a larger data set to verify trends. The fourth module dealt with electromagnets, and focused on aspects of creativity in scientific thinking because students needed to synthesize new knowledge from prior modules to make conclusions. The remaining three aspects of the nature of science, science and technology, social and historical impacts, and the tentative nature of science were not explicitly included in the intervention because of time constraints in the classroom. However, because students were involved in peer discussions that often caused them to change their conclusions, the tentative nature of science was implicit in the modules.

3.4 Quantitative Measures and Data Sources

Mixed methodology was chosen for this study to explain the student outcomes of the intervention through quantitative results, as well as explaining the processes the students used to achieve the outcomes with qualitative results. Quantitative data were gathered from pre-and post-tests of nature of science knowledge and content knowledge. Qualitative data were gathered from student work products, teacher memos, think aloud protocols, and focus group interviews.

3.4.1 Test of Electricity-Magnetism Knowledge (TEMK)

This test assesses each student's individual attainment of content goals for magnetism, static electricity, current electricity, and electromagnetism using 19 short response items. Each question on the TEMK was open-ended and used visual, logical, and analytical forms of communication to assess the content goals. The assessment was designed by the researcher and was evaluated for content and construct validity by a team of national award winning teachers from the United States who worked in the same content area and with the same age group of students. A sample item from the TEMK is "Why are some materials magnetic while others are not?" In order to determine content validity, two questions designed for the National Assessment of Educational Progress or NAEP (National Center for Educational Statistics 2007) were included in the 19 items on the content instrument and were aligned to the grade level and content objectives of the study. The NAEP, otherwise known as "The Nation's Report Card" in the United States, is given to a random sample of students nationally and represents the level of content knowledge for students across that country (National Center for Educational Statistics 2007). The rating criteria for the NAEP were identical to the rating criteria for the TEMK content test for this study. An omitted answer received a 0, a partially correct answer received a 1, an answer that was essentially correct but had a flaw received a 2, and a completely correct answer received a 3. Raters of this assessment were given a code book that indicated the level of answers for each score. Interrater reliability was calculated for consensus with a Cohen's kappa statistic. Forty percent of the responses randomly chosen were found have a Cohen's kappa of .92, which indicates substantial agreement. The Cronbach alpha reliability on the TEMK scoring was measured at .82, indicating high reliability within the test.

3.4.2 The Views of the Nature of Science- Form B (VNOS –B)

The VNOS-B (Lederman et al. 2002) assessed student understanding of inherent guidelines used to conduct science and consists of seven open-ended questions corresponding to the seven identified aspects of the nature of science: (a) scientific knowledge is durable, yet tentative, (b) empirical evidence is used to support ideas in science, (c) social and historical factors play a role in the construction of scientific knowledge, (d) laws and theories play a central role in developing scientific knowledge, yet they have different functions, (e) accurate record keeping, peer review and replication of experiments help to validate scientific ideas, (f) science is a creative endeavor, and (g) science and technology are not the same, but they impact each other (McComas 2005; Lederman 1992). Lederman et al. (2002) argue that nature of science knowledge is best gathered using qualitative methods, and because of the divergent nature of the content, should be free-response and should include an interview component in data collection. Each question on the VNOS-B was ranked using a 0–3 scale: 0 representing no answer, 1 representing novice knowledge, 2 representing emerging knowledge, and 3 representing proficient knowledge using a rubric designed from the research literature recommendations. Interrater reliability was calculated for consensus on 100% of the responses resulting in a Cohen's kappa of .94, which indicates a substantial agreement. In addition to the scoring rubric, questions from the *VNOS-B* were included in the focus group interviews, as suggested in the literature (Lederman et al. 2002).

3.5 Qualitative Data Collection Methods

3.5.1 Student Products from Inquiry Units

Student learning outcomes for the inquiry units, given to both the explicit and the implicit groups, were focused on observable phenomena in electricity and magnetism. For example, the first module guided students to investigate interactions between permanent magnets that were oddly shaped. Students were challenged to use empirical evidence to determine the location of the poles of the magnets, and then to determine the role of domains in magnetic orientation. The completed student products resulted in written responses to student prior knowledge, open-ended content questions, explanation of processes to obtain results, and summarization of findings into enduring understandings and how the evidence from the activities support their ideas. Two other trained science educators who were not directly involved with the project coded 80% of the student products using the code-book developed by the researcher which resulted in a Cohen's kappa of .92 agreement in coding.

3.5.2 Teacher Memos

Memos are a reflective tool used to in many ways such as helping researchers document events that are occurring during the research study or recording confusing events for later analysis (Maxwell 2005). The teacher in this study was given a daily form to record any critical incidents when students had an "ah-ha" moment or when students talked about the nature of science. Teacher memos and student products were used to situate the context for the transcripts of the focus groups and the think aloud groups.

3.5.3 Think Aloud Protocol

Think aloud protocols are used to elicit cognition from students that may not be apparent without probing. Since eighth grade students have little experience in expressing their "inner voices", an established protocol to encourage three levels of verbal reports were used, verbalization of covert encodings, explication of thought content, and explanations of thought processes (Ericsson and Simon 1993). Students were instructed to talk aloud about what they were thinking throughout the course of one of the lessons, instead of focusing on the answer to the problem. Randomly selected students from each group, six students per group for each year of the study, were videotaped while they performed an investigation from the intervention. The total number of students involved in the think aloud protocols over 3 years was 36, 20 girls and 16 boys.

3.5.4 Focus Group Interviews

A focus group was chosen as a method of data collection rather than individual interviews because richer data could be obtained from students building on other student statements about the lessons. After each of the 3 years the intervention, six members were randomly chosen from the explicit group and six members were randomly chosen from the implicit group to participate in focus group interviews, totaling 18 members of the explicit group (9 girls and 9 boys) and 18 members of the implicit group (8 girls and 10 boys). The members of the focus groups were different from the members of the think aloud groups. A semi-structured protocol was chosen because the researcher needed the flexibility to explore phenomena that emerged. Sample questions from the semi-structured protocol were (a) How did you act like a scientist in that lesson? (b) How do you think science class is different from English, history or math class? (c) How can you think about your thinking? (d) What does it mean to you to think like a scientist? (e) Are there other ways of thinking? (f) Do scientists behave differently than other people? Focus group conversations were audio-taped and transcribed using the software, Transana. Two additional researchers open-coded transcripts of the think alouds and the focus group interviews for categories, which were grouped into themes and there was a Cohen's kappa of .73 agreement among the themes. The researchers met to discuss the coding and adjust the themes until there was a Cohen's kappa of .90 for consensus agreement.

4 Results

Correlations were conducted to determine the reliability of the pre-tests and post-tests. Additionally, correlations were performed to determine any interactions between the two measures, content and nature of science knowledge, in the post-test. Significant correlations between the two measures could provide evidence for a connection between nature of science knowledge and content knowledge measures. Correlations between the pre-test and the post-test by group were shown to all have strong positive correlations: pre-post VNOS-B (explicit), $r(132) = .61$, $p < .001$, pre-post VNOS-B (implicit), $r\ (114) = .58$, $p < .001$, pre-post TEMK (explicit), $r(132) = .62$, $p < .001$, and pre-post TEMK (implicit), $r(114) = .66$, $p < .001$. In testing the strength of the relationship between the content measure and the nature of science measure, a strong positive correlation was found, $r(246) = .71$, $p < .001$.

There were no pre-test differences between the implicit and the explicit groups, nature of science knowledge $t(1{,}246) = .16$, $p = .87$, and content knowledge $t(1{,}246) = .51$, $p = .62$ as expected, because the school where the study took place employs policies to ensure the heterogeneity of the science classes. The science classes are populated so that there are approximately equal numbers of high, average, and low performing students, as determined by their science teacher at the end of their seventh grade year. Table 2 presents the means and standard deviations for pre- and post- tests in content knowledge and in nature of science knowledge.

When an analysis of variance was performed, significant differences emerged between the explicit group and the implicit group in both content knowledge $F(1, 246) = 6.63$, $p < .01$ and nature of science knowledge $F(1, 246) = 36.5$, $p < .01$. The explicit group demonstrated a greater gain in content knowledge ($M = 2.15$) and nature of science knowledge ($M = 1.60$) than the implicit group ($M = 1.91$) and ($M = 1.12$) respectively.

Table 2 Implicit and explicit means for content knowledge and nature of science knowledge

Variables	Group							
	Implicit				Explicit			
	Pre		Post		Pre		Post	
	M	SD	*M*	SD	*M*	SD	*M*	SD
Test of electricity and magnetism knowledge	.56	.36	1.91	.47	.60	.41	2.15	.42
Views of the nature of science version B	1.01	.48	1.12	.55	1.04	.32	1.60	.36

The effect size, calculated by Cohen's *d,* for the content measure was $d = .5$ and for the nature of science measure was $d = .8$, demonstrating a large effect size.

An analysis of the VNOS-B items was conducted to determine if there were between group differences for the four aspects of nature of science taught in this study over the three aspects not taught in the study. A omnibus test using multiple analysis of variance (MANOVA) revealed significant differences between the groups on the 4 aspects of the nature of science that were taught versus the 3 aspects of the nature of science that were not taught, F (4, 246) = 7.21, $p < .001$, $\eta^2 = .53$. Specifically, univariate analyses showed that the explicit group outperformed the group in all four aspects taught in the study: empirical evidence, $F(1, 246) = 40.72$, $p < .001$; laws and theories, $F(1, 246) = 2.85$, $p = .007$; habits of mind of scientists, $F(1, 246) = 28.13$, $p < .001$; and creative nature of science, $F(1, 246) = 10.9$, $p < .001$. There were no significant differences between groups on the aspects not explicitly addressed in the study: social/historical, $F(1, 246) = 2.32$, $p = .07$; or science/technology, $F(1, 246) = 1.79$, $p = .07$; The tentative aspects of the nature of science approached the threshold significance $F(1,246) = 3.37$, $p = .05$, which could have been due to the tentativeness of the construction of knowledge found in inquiry learning, which was a pedagogy used for the overall lesson given to both groups.

In examining the construction of scientific knowledge in the groups, two themes emerged regarding the connection of content and nature of science knowledge from the qualitative data: the development of an extensive knowledge base through reflection of the scientific enterprise, and respect for evidence in making conclusions. Both groups reported that they recognized that scientists have extensive knowledge base. However, the explicit group reported using checklists to help develop more detail in their own observations, while the implicit group did not report any reflection of their written observations. Evidence, in the form of observations and data, helped the explicit group make decisions on conclusions, even when there was a conflict in the group. The control group reported that they relied mainly on the teacher to provide the evidence for valid conclusions.

All of the eighth grade students reported that a characteristic of scientists was their extensive knowledge base. Members of both explicit and implicit groups made parallel comments in terms of the large amount of background knowledge scientists must have to conduct their work. A representative sample of comments from the explicit group follows: "science is the study of pretty much everything, you have to know a lot of material to be a scientist," "You have to be able to know lots of information if you are a rocket scientist—there is more stuff to know," "You have to know enough so if your data is wrong—can recognize when the data is wrong," and "Scientists are a lot more thorough, more than everyday life." Statements that characterize the control group are comparable with the explicit group: "A scientist thinks about 'Why does this happen?' more than a regular person who doesn't really care. A scientist would think about conclusions. Scientists are more serious about the world. Regular people don't wonder about the world," "Ask a scientist if the universe is expanding, and they can talk a lot about it. A non-scientist wouldn't be able to talk about it much," and "Scientists would be able to answer a question about atomic theory in a split second. If they don't then they aren't a scientist." Both groups agreed that an important factor in thinking scientifically is to have a broad and deep framework of background knowledge.

Although both groups reported the need for a scientist to have an extensive base of content knowledge, only members of the explicit group acted on this idea in the inquiry units. All of the students in the explicit focus group reported that the explicit method of the checklists helped them to add more detail to their observations: "A lot of times [before this series of lessons] we did not look at each other's results but in this lab you got to write the results and check them with other students," "It helped you learn a lot because it helped you analyze what you were doing with all of the questions you had to answer," "At first I wrote my answer and then I would go back to the checklist to see if my answers were complete. I would not think to be so descriptive about some things, but the checklists said to describe what you got," and "I never thought about writing in science with all of those things. I think if I did not have the checklists that I would have been more vague." Even when the checklists focused on other aspects of the nature of science, such as creativity, members of the explicit group reported that they retained the ability to include detail in their observations, "I retained some of it, most of it, I would be as descriptive as I was in the first module." The explicit group recognized that scientists have a great deal of background knowledge and emulated this by reflecting on their observations, self-monitoring for an appropriate amount of detail, and adding detail when necessary.

Although the implicit group did not have the checklists to help them reflect they were given additional content questions, which did not influence their ability to add detail to their observations. Characteristic comments from the implicit group are "I wrote about the same amount [of information] for my answers with these labs as I did for the step by step labs we used to do," "The labs seemed scientific, but I did not write anymore than I usually do," and "I wrote the observations, made the conclusions, but did not go back to change anything." Although the students in the control group reported that it was important that scientists had a great deal of background knowledge, they did not adopt that habit of mind in their own scientific work.

The students in the explicit group reported placing a higher value on empirical evidence in making conclusions, while the implicit group reported valuing a more didactic approach when making conclusions. The explicit group reported many cases of checking their evidence for alignment with their conclusions, "Also made me realize what I was doing, before I did not realize it… with checking for conclusions and then connect with the data. I usually don't think about that stuff, but the checklists made me do it. Then I realized what I was doing," "The first time we did the checklists, I was surprised that I did not know about this stuff," "I was doing that but I never thought about why I was doing that," "I remember everything that was on the checklist—I did not compare myself with a scientist before—I did not think about what a scientist would care about," "I would write it first and then look at the checklist. If I forgot something then I would like go back and rewrite it," and "I looked at what my own data said and see if it [the conclusion] made sense to me." The checklists guided the students in examining their observations for correspondence to their conclusions.

In the inquiry modules given to both groups, the last task was to generate three or four big ideas learned in the hands-on portion and back them up with empirical evidence. Although both the implicit and explicit groups completed this task, only the explicit group reported the association of their observations with their conclusions or answers. Additionally, the explicit group reported using evidence to resolve any conflicting conclusions among the group members, "Sometimes our results did not come out the same. Then we went to other groups to see what they had. We made them do it again to see how they got it," "If someone in our group did not agree, we would explain it to them until they understood it better," and "We went back and changed our answer when we redid it." Whereas the control group depended on the teacher to resolve conflicting answers in their group, "We would wait until the end of the period, then [the teacher]would tell us which answer was right," "If we thought something different in the lab, we would let them answer their way and we would answer our way," "We would change the answer if we had something different that what [the teacher] told us," and "I did not know what the right answer was in these labs, so I waited until [the teacher] explained it at the end to write down my answer." The control group did not reference their observations to develop consensus in the group, but relied on the authoritative answer from the teacher.

5 Limitations and Discussion

A criticism of this study may be the short period of time of this intervention, 6-weeks, as the literature calls for long-term student engagement with nature of science knowledge (Akerson and Abd-El-Khalick 2003; Southerland et al. 2003). However, some strong effects have been demonstrated over this relatively short period of time, perhaps because of the direct application of learning theory that has been shown effective in other areas. Additionally this study has been limited by a small minority population.

It is well documented that the nature of science is effectively taught using a reflective, explicit approach (Akerson et al. 2008; Khishfe and Abd-El-Khalick 2002). Learning theory is one way to make the nature of science explicit while leveraging on the success of strategies developed in the field of educational psychology. In this study, nature of science is made explicit through goal setting ad self-monitoring. Goal setting has shown to be useful in that it makes the tasks specific, prominent, and meaningful to the students (Zimmerman 2008). Goal setting and self-monitoring has been shown to be key processes in self-regulated learning, and can develop a more pronounced student reflection of the nature of science. Goal setting and self monitoring can also be effective in scaffolding students who do not have any experience with the scientific enterprise to compare their own work in inquiry with the "standards" of the nature of science.

The results of this study provide some evidence that nature of science knowledge is positively correlated with content knowledge. The following explanations for the phenomena of increased content knowledge when exposed to explicit, reflective nature of science prompts are considered in detail below: attention to detail in conducting inquiry, ability to recognize and act on the guidelines used by scientists to do work, and the development of conceptual framework about the nature of science used to organize concepts in a meaningful way.

Students in both the explicit and implicit groups reported their perception that scientists are unique in their ability to retain a great deal of detailed knowledge and their ability to use that detailed knowledge to make new conclusions. However, only the students in the explicit group reported that they went back to their observations and added details after they completed the hands-on portion of the lessons. This may be a function of the self-monitoring aspect of the checklists, rather than directly attributed to nature of science knowledge. The self monitoring aspect of the intervention caused students to reflect on their work and evaluate the level of detail. The strategy of comparing the level of detail of their work to a standard level of detail for scientific work could have helped in generating more content knowledge. The strategy of returning to your work in inquiry, re-reading it, and checking it for appropriate detail may have helped students develop more elaborate networks of concepts and, in turn, learn more content knowledge because of sheer volume of information.

Another possible reason for increased content knowledge due to exposure to the intervention could be the development of respect for the guidelines used by scientists to do work. The nature of science prompts were designed to cause students to reflect on empirical evidence they provided to support their conclusions (empirical), examine the differences between how a phenomena works and why a phenomena works (theory and law), utilize peer review to improve the quality of their methods of valid data collection (habits of mind), and consider multiple perspectives in making conclusions (creative). Both the implicit and explicit groups needed to use reason to extend their prior knowledge through the use of hands-on activities, summarizing their ideas for the lesson, and justifying their reasons for summary statements to the whole class in order to complete the lesson. However, the explicit group reported they resolved differences in their results by redoing the procedure to verify their knowledge. The implicit group always sought the answer from the teacher as described in the qualitative results. The explicit group could have scored higher on the content knowledge post-tests than the implicit group because they developed a more elaborate knowledge network than the implicit group who depended on a succinct “final answer” provided by the teacher. Although both groups were required to perform the same inquiry tasks (making descriptions and explaining the phemonena), the explicit group reported using evidence to resolve contradictions in their work, thus gathering more information to confirm a perspective in the inquiry. This would result in more content knowledge than if the teacher provided a final answer for the group without making them think through why they made their choices for conducting the inquiry. An example from this study can be illustrated in student development of the concept of poles in magnets. In the implicit setting the group obtained the information by seeking help from the teacher, which resulted in the endpoint of the knowledge, that the flat sides of the magnets were the poles. In receiving information in this succinct manner, the extent of student knowledge is the location of the poles. If students were to redo the activity to find more empirical evidence to confirm or deny an idea about the location of the poles, they need to observe similarities and differences in behavior of the two magnets given different positions of the magnets, and they need to deduce from common behaviors of magnets (attraction and repulsion) that there are locations on the magnets where the behavior is stronger and locations where the behavior is weaker. The amount of detail in the information is greater when students use the self-monitoring strategies to reflect on their inquiry work.

The nature of science prompts can explicitly describe to students who have little exposure to the scientific discipline how scientific knowledge is generated and verified. There are definite aspects of the way information is validated in science, and the prompts explicitly help students monitor the way they are completing a task with they way a scientist might complete the same task. Therefore, the prompts offer a concrete method of organizing information. Students in the explicit group reported that they did not realize that they were supposed to write all of the detail until they used the prompts. Once students used the prompts, they were able to understand how to communicate their observations and explanations and reported continued use of the strategies listed in previous checklists on their current task. The nature of science knowledge communicated through the self-monitoring prompts show the rationale behind the construction and verification of scientific knowledge. This leads to more meaningful organization of information, which is a well-documented method to enhance student learning (Flavell et al. 2002; Miller 2002). It has been shown that expert learners possess two qualities that novice learners do not have: ability to attend to relevant information, and ability to call forward an intricate network of connections to the concept at hand (Alexander 2003). The explicit and reflective method of delivery that the nature of science prompts provide show students what is important to attend to. The prompts explicitly tell students correct strategies for developing observations and explanations, and help students pay attention to the important information used to create detailed and connected observations and explanations. Once students can be adept in identifying relevant important knowledge, then they can proceed to develop more intricate networks of expert information.

6 Implications and Conclusion

All students in this study reported recognizing that scientists must acquire a great deal background knowledge to be successful in advancing the scientific body of knowledge. Students in the explicit group of this study were able to acquire more content knowledge because the intervention scaffolded their ability to recognize and act on the guidelines of the scientific enterprise. Once students attained the understanding of why the processes of science occurred, they were more adept at comprehending and utilizing content knowledge. Science educators should consider this implication when dealing with the implementation of the breadth of curriculum called for in national standards. Increased student knowledge about the nature of science can facilitate the acquisition of science content knowledge. Science educators should carefully examine the role of the nature of science in curriculum design in order to optimize knowledge about the scientific enterprise concurrently with content knowledge. Nature of science knowledge may be better understood by students if it were intricately connected with their own investigations as well as teaching it by using examples from the scientific discipline.

Students in secondary educational settings are rarely exposed to the guidelines of the scientific enterprise. Explicit, reflective methods of teaching the nature of science are one way to introduce students to the ways scientists gather information and validate knowledge. Results of this study has provided some evidence that self-regulation can be used to make the nature of science explicit, resulting in increasing nature of science knowledge as well as science content knowledge in students using this strategy. Science educators may be informed by the results of this study to incorporate other effective learning theories that make nature of science knowledge explicit and utilize reflection or student self-monitoring of knowledge. Science educators should take advantage of the work done in educational psychology to identify effective learning strategies, and apply the strategies in the classroom setting to optimize student learning of nature of science knowledge as well as content knowledge.

References

Akerson, V. L., & Abd-El-Khalick, F. (2003). Teaching elements of nature of science: A yearlong case study of a fourth-grade teacher. *Journal of Research in Science Teaching, 40*, 1025–1049.

Akerson, V. L., Buzzelli, C. A., & Donnelly, L. A. (2008). Early childhood teachers' views of nature of science: The influence of intellectual levels, cultural values, and explicit reflective teaching. *Journal of Research in Science Teaching, 45*, 748–770.

Alexander, P. A. (2003). Expertise: Can we get to there from here? *Educational Researcher, 32*, 3–29.

American Association for the Advancement of Science. (1993). *Benchmarks for scientific literacy*. New York: Oxford University Press.

Corno, L., & Mandinach, E. (1983). The role of cognitive engagement in classroom learning and motivation. *Educational Psychologist, 19*, 88–108.

Creswell, J. W., & Plano Clark, V. L. (2007). *Designing and conducting mixed methods research*. Thousand Oaks, CA: Sage Publications.

Delclos, V. R., & Harrington, C. (1991). Effects of strategy monitoring and proactive instruction on children's problem-solving performance. *Journal of Educational Psychology, 3*, 35–42.

DfEE/QCA. (1999). *Science: The national curriculum for England, key stages 1–4*. London: Department for Education and Employment/Qualifications and Curriculum Authority.

Duschl, R. A. (1988). Abandoning the scientistic legacy of science education. *Science Education, 72*, 51–62.

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

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data*. Cambridge, MA: The MIT Press.

Flavell, J. H., Miller, P. H., & Miller, S. A. (2002). *Cognitive development*. Upper Saddle River, NJ: Prentice-Hall.

Flick, L. B., & Lederman, N. G. (2004). Introduction. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications teaching, learning, and teacher education* (pp. ix–xviii). The Netherlands: Kluwer.

Gallagher, J. J. (1991). Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. *Science Education, 75*, 121–133.

Hodson, D. (1993). Philosophical stance of secondary school science teachers, curriculum experiences, and children's understanding of science. *Interchange, 24*, 41–52.

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

Howard, A., & Bray, D. (1988). *Managerial lives in transition*. New York: Guilford Press.

Johnson, D. W., & Johnson, R. T. (1994). *Learning together and alone: Cooperative, competitive and individualistic learning*. Boston: Allyn and Bacon.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching, 39*, 551–578.

Kitsantas, A., & Zimmerman, B. J. (2006). Enhancing self-regulation of practice: The influence of graphing and self-evaluative standards. *Metacognition and Learning, 3*, 201–212.

Lederman, N. G. (1992). 'Students' and teachers' conceptions about the nature of science: A review of the research. *Journal of Research in Science Teaching, 29*, 331–359.

Lederman, N. (2006). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831–880). Mahwah: Lawrence Erlbaum Associates.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). 'Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching, 39*, 497–521.

Locke, E. A., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American Psychologist, 57*, 705–717.

Malone, L. D., & Mastropieri, M. A. (1992). Reading comprehension instruction: Summarization and self monitoring training for students with learning disabilities. *Exceptional Children, 58*, 270–279.

Matthews, M. (1994). *Science teaching: The role of history and philosophy of science*. New York, NY: Routledge.

Maxwell, J. A. (2005). *Qualitative research design: An interactive approach*. Thousand Oaks, CA: Sage Publications.

McComas, W. F. (2005). *Seeking NOS standards: What content consensus exists in popular books on the nature of science?* Paper presented at the Annual Conference of the National Association of Research in Science Teaching, Dallas, TX.

McComas, W. F. (2008). Seeking historical examples to illustrate key aspects of the nature of science. *Science & Education, 17*, 249–263.

McComas, W. F. (2009). *A critical review of current U.S. state science standards with respect to the inclusion of elements of the nature of science*. Presentation given at the National Association of Research in Science Teaching, Garden Grove, CA.

McComas, W. F., Clough, M. P., & Almazroa, H. (1998). A review of the role and character of the nature of science in science education. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 3–39). Dordrecht: Kluwer.

McCurdy, B. L., & Shapiro, E. S. (1992). A comparison of teacher monitoring, peer monitoring, and self-monitoring with curriculum-based measurement in reading among students with learning disabilities. *Journal of Special Education, 26*, 162–180.

Miller, P. H. (2002). *Theories of developmental psychology* (4th ed.). New York: Wirth.

MoE, Ministry of Education. (1993). *Science in the New Zealand Curriculum*. Wellington: Learning Media.

National Center for Educational Statistics. (2007). *The nation's report card*. Retrieved [On-Line] March from http://nces.ed.gov/nationsreportcard.

National Research Council. (1996). *National science education standards*. Washington DC: National Academy Press.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes toward science: A review of the literature and its implications. *International Journal of Science Education, 25*, 1049–1079.

Parkinson, J. (2004). *Improving secondary science teaching*. London: Routledge Falmer.

Peters, E. E. (2006). Why is teaching the nature of science important? *Journal of Science Education in Virginia, 1*, 55–58.

Rudge, D. W., & Howe, E. M. (2009). An explicit and reflective approach to the use of history to promote understanding of the nature of science. *Science & Education, 18*, 561–580.
Ryan, A. G., & Aikenhead, G. S. (1992). Students' preconceptions about the epistemology of science. *Science Education, 76*, 559–580.
Ryan, R. M., Connell, J. P., & Deci, E. L. (1984). A motivational analysis of self-determination and self-regulation in education. In C. Ames & R. Ames (Eds.), *Research on motivation in education* (pp. 13–52). New York: Academic Press.
Sagotsky, G., Patterson, C. K., & Lepper, M. R. (1978). Training children's self-control: A field experiment in self-monitoring and goal-setting in the classroom. *Journal of Exceptional Child Psychology, 25*, 242–253.
Schunk, D. H. (1983). Goal difficulty and attainment information: Effects on children's achievement. *Human Learning, 2*, 107–177.
Schunk, D. H. (1996). Goal and self-evaluative influences during children's cognitive skill learning. *American Educational Research Journal, 33*, 359–382.
Schunk, D. H., & Ertmer, P. A. (1999). Self-regulatory processes during computer skill acquisition: Goal and self-evaluative influences. *Journal of Educational Psychology, 91*, 251–260.
Southerland, S. A., Gess-Newsome, J., & Johnston, A. (2003). Portraying science in the classroom: The manifestation of scientists' beliefs in classroom practice. *Journal of Research in Science Teaching, 40*, 669–691.
Stenhouse, D. (1985). *Active philosophy in education and science*. London: George Allen & Unwin.
Turner, T. (2000). The science curriculum: What is it for? In J. Sears & P. Sorenson (Eds.), *Issues in science teaching* (pp. 4–15). London: Routledge Falmer.
Weinstein, C. E., & Underwood, V. L. (1985). Learning strategies: The how of learning. In J. W. Segal, S. F. Chipman, & R. Glaser (Eds.), *New directions in Piagetian theory and practice* (pp. 39–49). Hillsdale, NJ: Erlbaum.
Zimmerman, B. J. (1998). Developing self-fulfilling cycles of academic regulation: An analysis of exemplary instructional models. In D. H. Schunk & B. J. Zimmerman (Eds.), *Self-regulated learning: From teaching to self-reflective practice* (pp. 1–19). New York: The Guildford Press.
Zimmerman, B. J. (2000). *Attaining self-regulation: A social cognitive perspective: Handbook of self-regulation*. New York: Academic Press.
Zimmerman, B. J. (2008). Goal setting: A key proactive source of academic self-regulation. In D. H. Schunk & B. J. Zimmerman (Eds.), *Motivation and self-regulated learning: Theory, research and applications* (pp. 267–295). New York: Lawrence Erlbaum Associates.
Zimmerman, B. J., & Kitsantas, A. (1999). Self-regulated learning of a motoric skill: The role of goal setting and self-monitoring. *Journal of Applied Sports Psychology, 8*, 69–84.