Physics Education and STSE: Perspectives From the Literature

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(Received: 25.08. 2013, Accepted: 16.10.2013)

Abstract
Science, technology, society, and environment (STSE) education has recently received attention in educational research, policy, and science curricular development. Fewer strides have been made in examining the connections between STSE education and learning/teaching physics. Examples of moving STSE theory into practice within a physics classroom can be found in the educational literature and are alluded to the physics literature. This article examines the literature on connecting STSE to physics and attempting to find relevancy for students learning the science from educationalists' and physicists' perspectives.

Key words: Science education, STSE education, Physics Education Research, Pre-service teachers

Introduction

Physics enrolments at the secondary school level continue to decline (Alsop & Watts, 2000; Brickhouse, 2001; DeBoer, 1991; Hart, 2001; Zohar, 2005). Research into what can be done to address this has been undertaken both by physicists and science educators, since both groups realize the importance of a physics education component for a scientifically literate individual. This article reviews the literature concerning physics education from educators' and physicists' perspectives, and examines connections that have already been suggested about STSE-infused physics education.[1]

Some argue that declining enrolment in physics is related to how the subject is learned and taught. As McDermott (1998) stated:

> *Unless we are willing to apply the same rigorous standards of scholarship to issues related to learning and teaching that we regularly apply in more traditional research, the present situation in physics education is unlikely to change. (p. 8)*

This area of research has come to be known as *physics education research* (PER). PER has been conducted worldwide (McDermott & Redish, 1999) with similar findings, regardless of the language or culture of the students.

PER can be approached via two perspectives (Akarsu, 2010; Beichner, 2009): physicists' and science educators'. Physicists approach educational research as they would methodologies used in the physical sciences. Science educators are familiar with current educational research methodologies and trends, and very likely have less depth of knowledge

[1] STSE stands for *science, technology, society, and environment education*.

in the content of physics (Harrison, 2010). Members of both groups have the same goal at heart: to help students and teachers of physics to better understand the science, comprehend the relevancy of the study of physics, and promote its value. Below, I review the relevant literature from both perspectives. Very few researchers have straddled both groups, but recently, however, physicists and physics educators are beginning to consider what can be learned from one another's findings.

Physicists' Perspective

PER researchers, predominantly trained physicists, have conducted systematic studies of student learning at the university level. According to Beichner (2009):

> *They are physicists who treat education as topic worthy of scientific study. . . . Physics education research is not just curriculum development or instructional design. It is not merely a service enterprise for teachers, although its findings can certainly be put to good use by them. Instead, PER is focused inquiry into what happens as students struggle to grasp and use the concepts of physics. Obviously there are limitations to discerning a person's thoughts, but repeated patterns of responses (either in a single student or across many students at different times and places) can lead us to generate theories that explain other situations and, in some cases, have predictive power.(p. 3)*

PER researchers often employ methodologies similar to those used in their physics laboratories, because "scientific tools and methods can and should be used to improve teaching and learning" (Beichner, 2009, p. 2). Two primary research methods are used: an individual demonstration and interview, and widely administered written tests. Researchers have also engaged students in dialogue, examined homework and written reports, conducted classroom observations, and used pre- and posttesting of students (van Aalst, 2000; Akarsu, 2010; Beichner, 2009; Harrison, 2010; Holubova, 2005; Knight, 2004; Maloney, 1994; McDermott, 1991, 1998, 2001, 2006; McDermott, Heron, Shaffer, & Stetzer, 2006; McDermott & Redish, 1999; Redish, 2003; Waltner, Wiesner, & Rachel, 2007; Wieman & Perkins, 2005).

Noting that most PER studies have involved college students, Beichner (2009) acknowledged that PER could be conducted at different education levels:

> *Researchers looking at learning by precollege students are usually, but not exclusively, found in education departments. An unfortunate truth is that some physics faculty will only listen to other physicists, and not regard the work of science education researchers as valid. This is regrettable because science education researchers have usually had training in the complicated methodologies needed to carry out this type of work. . . . Both PER workers and science education researchers can benefit from each other's knowledge and background. (Beichner, 2009, p. 4)*

Physicists have found that a wide gap between the learning objectives of most physics instructors using traditional forms of instruction, and students' actual level of conceptual understanding (Akarsu, 2010; Beichner, 2009; Leonard, Dufresne, & Mestre, 1996; McDermott, 1991, 1998, 2001; McDermott & Redish, 1999; Redish, 2003; Saul, 1998):"conceptual understanding enters into any consideration of problem solving in physics because the solver's knowledge base is a critical factor in how the solver proceeds"(Maloney, 1994, p. 327). Assessments have been developed and conducted of students' epistemological beliefs and how these beliefs influence students' learning and their expectations of physics (Redish, 2003; see van Aalst, 2000). Other areas of study by PER physicists have included problem solving, attitudes of students, social aspects, technology, and evaluation of specific instructional interventions and instructional materials (Beichner, 2009).

In November 2005, the National Research Council released *Rising Above the Gathering Storm* (cited in McDermott, 2006). The report focused on improving K–12 science and mathematics education and suggested that teachers were the key to improving student performance: "To make science meaningful to young students, teachers need to know how we know as well as what we know"(McDermott, 2006, p. 760).With regard to epistemology and knowledge generation, this view was also reflected in Lederman and Lederman's (2004) discussion of HPS (history and philosophy of science) and NOS (nature of science).

McDermott and other PER researchers (e.g., Akarsu, Redish, Knight, Harrison, and Beichner) have not mentioned using STSE as a possible teaching approach to make science—including physics—more meaningful. They have not contemplated placing the content of science courses within today's social, cultural, or political context; nor have they discussed using an issue-based approach, or addressed the importance of scientific literacy in the context of physics education. If these lacunae were addressed, then perhaps movement towards advancing scientific literacy (including STSE) would be possible.

PER studies conducted by physicists have found that traditional teaching methods at the university level are ineffective (Beichner, 2009; Harrison, 2010; Knight, 2004; Redish, 2003):"students are able to correctly answer traditional test questions without understanding the basic physics concepts or learning the useful concept-based problem-solving approaches of physicists"(Wieman& Perkins, 2005, p. 37); and a "10% level of retention after 15 minutes is typical for a non-obvious or counterintuitive fact that is presented in a lecture"(Wieman& Perkins, 2005, p. 37).

An overview of the state of PER in Canada as of 2005 was published by the Canadian Association of Physicists (Hawkes & O'Meara, 2005). PER can be found in many Canadian universities—including Acadia and Mount Allison, and the Universities of Toronto and British Columbia—and the list continues to grow (Hawkes& O'Meara, 2005; Hillel, 2005; University of British Columbia, 2008). The Ontario Association of Physics Teachers, in partnership with Ryerson University's Department of Physics and the Perimeter Institute, is currently working to establish a grassroots movement of PER in Ontario. Ontario's Ministry of Education mentioned PER in their 1987 report examining teaching and learning physics in Ontario in the senior division. A province-wide survey of teachers, students, curricula, and achievement was conducted, to complete a "test run of Ontario Assessment Instrument Pools (OAIP) Physics"(McLean, 1987, p. 7). The survey information was to have assisted with interpreting the achievement results, but no direct follow-up from this report has been located.

PER has been conducted globally over the past two decades in the hope of shedding light on how to improve the learning experience of physics students. Mainly conducted by physicists, its research has benefited those who use it to improve teaching techniques.

Science Educationalists' Perspective

There is a set of common goals for any scientific inquiry. "All scientists are trying to improve their understandings and explanations about the natural world. . . . We need to provide students with a broader view of scientific inquiry and the nature of science" (Bybee, 2006, p. 3). Science education research is rich in practical examples and studies based on advances in biology and chemistry, but less so in physics. It advocates for all areas of science education, but fails to mention how STSE can be used in teaching physics specifically. When looking at the science classroom in general, Lederman and Stefanich (2006) considered what makes a good science teacher:

> *The role of the effective teacher is to focus on the science processes and their meaning rather than the product (Martin, 1997), to focus on the students' reasoning skills rather than on accurate direct answers. . . .The primary goal of the instructor is to develop higher order thinking skills in the learner, not to disseminate information (Victory & Kellough, 1997; Zorfass, 1991).(p. 72)*

Surely the same could be applied to the physics classroom and physics classroom teacher. When students, regardless of education level, are unsuccessful, teachers need to re-examine their pedagogy: what they are doing and why it is not working(Lederman & Stefanich, 2006). Educators have long known these things. For example, recommendations concerning inquiry as a method for better student engagement were made by Smith and Hall in 1902:

> *Hall, speaking for physics, likewise offered a range of inquiry-based teaching methods and analyzed the advantages and disadvantages of each.. . . [In the] guided discovery approach, what Hall called "inquiry,". . . students did not have to discover everything on their own but they did have to seek solutions to questions for which they did not have the answers. In this way they would still be acting as genuine investigators and not simply confirming something that was already known to them. (DeBoer, 2006, p. 25)*

Smith and Hall "argued against the textbook approach" (DeBoer, 2006, p. 24) and did not recommend lecturing. The theme was to engage students in learning, and not just have them listen to teachers conveying information.

In 1920, the National Education Association's Commission on the Reorganization of Secondary Education (CRSE) issued a report in which the CRSE's physics committee "addressed the importance of the laboratory as a place for genuine inquiry rather than as a place to 'verify laws,' to 'fix principles in mind,' to 'acquire skills in making measurements,' or to 'learn to be accurate observers'" (DeBoer, 2006, p. 26).In 1932, the National Society of the Study of Education (NSSE) indicated "the best use of the laboratory was for the solution of students' own science problems" (DeBoer, 2006, p. 27).

Inquiry takes more classroom time, so questions arise as to whether content would be reduced in an inquiry-based approach, thereby denying students a breadth of understanding and knowledge. However, it may be better for students to have a deep understanding of a few concepts rather than a surface level understanding of many: "students who had high school courses that spent more time on fewer topics, concepts, problems, and labs performed better in college than those who raced through more content in a textbook-centered course" (Sadler and Tai, 2001, p. 111,as quoted in Metz, 2006, p. 118). Eloquently, physicist Philip Morrison stated: "less is more". To understand [Morrison's comment], one needs to understand the nature of scientists' knowledge and how they use it. As physicist William Bragg explained, "The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them." (Metz, 2006, p. 118) Another concern in physics education, related to students seeing the big picture, is the "solving of word problems depicting a physical event" (Magnusson, Palincsar, & Templin, 2006, p. 138):

> *In actual practice of science, one would need to determine what events to observe and what variables to measure and how to measure them before arriving at a point that might resemble solving a word problem, and of course in science, an underlying theoretical frame would be a part of selecting particular events and variables of interest. It is no surprise then that those who have learned problem solving by completing word problems focus on the surface features of the problem rather than underlying principles as is typical of a scientists approach to problem solving. (Champagne, Klopfer, & Gunstone, 1983, as cited in Magnusson, Palincsar, & Templin, 2006, p. 138)*

To assist students in relating the content to the context, the literature suggests the idea of inquiry (Abell, Smith, & Volkmann, 2006).When considering this approach, the concern of what and how much to tell students often arises. But inquiry does not imply any involvement of the teacher—just selective involvement: "Volkmann's case of physics instruction informs us that we should consider how we help students of teaching recognize and address dilemmas of telling in their own science teaching" (Abell et al., 2006, p. 197).

Shipman (2006) simply summarized reasons for moving towards inquiry and away from lecturing as: "lecturing doesn't work" (p. 359; see also Wallace & Louden, 2000). Inquiry learning was significantly better for students:

> *One of the most comprehensive studies was done in physics by Hake (1998), comparing the results of inquiry-based instruction to the results of lecturing in a national sample of 6000 students taking courses at dozens of institutions.(Shipman, 2006, p. 359)*

Inquiry methodology can be understood through an STSE lens. If students were encouraged to use inquiry, they would be encouraged to see the relevancy of the content through context. The scope of problems or issues studied could include technology, society, environment, history, philosophy, NOS, decision making, action, and agency.

Physicists, Educationalists, and the STSE Connection

Many PER-based physicists suggest enhancing learning by using a variety of teaching strategies, such as encouraging students to participate in lectures, talk about methods, and discuss the meaning of problem-solving tasks. This way, students would learn about physics while learning to do physics (reminiscent of Hodson's 1998 "learning about science"; see Bloom, 2006; Redish, 2003; Saul, 1998; Wieman & Perkins, 2005), and to contextualize physics (Kortland, 2005). Researcher Harrison (2010) summarized this PER perspective as follows:

- *Most students learn best by interacting with their peers. . . .*
- *Peer interactions are most effective when they are based on conceptually based activities. These activities are particularly effective when they force students to confront their misconceptions.*
- *The activities are particularly effective when they involve real physical apparatus. The apparatus need not be sophisticated or expensive: often material available at minimal cost from the local hardware store can be effective. (Harrison, 2010, p. 2)*

Similarly, many educationalists have suggested changing pedagogy to include things such as peer instruction; interactive lecture demonstrations; laboratory sessions; and tutorial sessions in which groups of students investigate and report on conceptually based activities, and the instructor uses guided study as an instruction technique (Beichner, 2009; Harrison, 2010; Knight, 2004; Redish, 2003).

Internationally, clear examples can be found of the movement of physics education away from the use of traditional teaching strategies towards a more student-centred, STSE-like physics experience. Viennot (2003) provided six instructional sequences, reworked as a result of PER, for the Grade 9 curriculum in France. In the Netherlands, the physics curriculum is context-based, with the student's life as the starting point. It develops ideas using technological artifacts and natural phenomena, and finishes with socioscientific issues and ideas concerning the nature of science (Kortland, 2005). New curriculum in the Czech Republic stresses the idea of "including more environmental problems in physics teaching and learning" (Holubova, 2005, p. 17). Contextualizing physics is also a theme found in PER literature from Germany. There, physics content is placed in the students' contexts, because "physics instruction that is student orientated will generate a long-term individual interest and therefore a lifelong openness to science" (Waltner et al., 2007, p. 502). Such contexts include:

- *accentuation of the social relevance of physics and its findings;*
- *connection to everyday situations;*
- *clarification of potential fields of practice;*
- *implementation in medicine;*
- *environmental protection; and*
- *physics in relation to the body. (Hoffmann et al., as cited in Waltner, 2007, p. 502)*

Neither Waltner nor Hoffmann used the term *STSE*, but this list does suggest an STSE orientation.

A cornerstone of STSE education is the HPS approach (Alsop & Pedretti, 2001; Pedretti, 1996, 2005). Some PER researchers have recommended incorporating HPS into physics education: "from a pedagogical perspective, historical issues provide a good entry point into a class discussion about difficult conceptual issues" (Knight, 2004, p. 17). Nashon, Nielsen, and Petrina (2008) suggested that "using HPS could 'remove math phobia from physics,' thereby having the potential to engage more students" (p. 397). However, the PER literature makes no explicit mention of STSE.

Moving away from lectures and making the classroom more student-centred has been advocated by educators since early in the 20th century. We can only hope that it will not take another hundred years for the university community to accept the idea of teaching STSE-infused physics.

Integrating STSE Into Physics Education

Physics has been described as a science that allows for "constructing idealized models of the world." But, in an interesting paradox, physics students "who do well on examinations are generally unable to apply the concepts of physics to common everyday situations" (Hart, 2001, p. 525). Perhaps the reason is in the critical details: "[Viennot claimed that] … 'increasingly, we are urged to relate what is taught to daily life, and to experiments that can be conducted in the classroom'" (van Aalst, 2005, p. 27). However, "student experiments are frequently difficult to interpret. . . . The problem here is that, if such details are glossed over, the subject matter loses much of its coherence" (van Aalst, 2005, p. 419), because:

> *Students know that things are more complicated than we lead them to believe and they are often not satisfied with the level of understanding they achieve. As a result, perhaps, they see physics as a loose collection of facts and statements. (van Aalst, 2005, p. 421)*

Physics can thus come to be seen as only for those who continue in physics. Yet the concepts of physics are all around us, every day. As science teachers, we must therefore find ways to connect physics content to the real world, especially for students who may not have the level of mathematics or the depth of understanding to take into account all variables in play at any given time.

Incorporating HPS into physics education does seem to yield positive results for both teachers and students. This approach is not new. Lawrenz and Kipnis (1990) discussed a program which "facilitate[d] an increase in student experimentation by showing physics teachers how to repeat historically important experiments with simple and inexpensive replicas of historical apparatus" (p. 54).The authors' findings were interesting when combining a hands-on, Hodson-style historical approach and physics content:

> *Participants were more likely than other teachers to promote student involvement with laboratory activities and to use historical information, and . . . were even more likely to involve students in laboratories dealing with topics covered in the institute than in other topics. . . . Students of these participants were more likely to enjoy their classes, to be involved in experiments, and to have received a historical perspective. (Lawrenz & Kipnis, 1990, p. 58)*

Language and perspective are also important when considering physics education's connection to STSE. Most physicists are usually quite good at explaining how their research can affect societal development and the impact on the environment, and describing the technology used and possible advancements of technology from their research. However, at no time do they use STSE terminology; the term quite often is only found in education literature. Yet physicists agree upon and advocate for the importance of research being for the good and betterment of society. For example, Natural Sciences and Engineering Research Council (2011) granting requirements for Discovery Grants state that "collaborative programming . . . [can] support a program of quality research that can have a meaningful impact on the field of study" (p. 2).The section on scientific or engineering excellence states:"[The researcher(s) need to comment on the] quality of contributions to, and impact on, the proposed and other areas of research in the natural sciences and engineering.[They also need to state the] importance of contributions to, and use by, other researchers and end-users" (NSERC, 2011, p. 3). In the description of the merit of the proposal, researchers must "[explain the] significance and expected contributions to research; potential for technological impact and the "extent to which the scope of the proposal addresses all relevant issues, including the need for varied expertise within or across disciplines" (NSERC, 2011, p. 4). There is no place on the granting forms which indicates that researchers need to explain the significance of their research using STSE terminology, yet STSE ideas, cornerstones, and currents are implied in the application. The importance of an STSE perspective is acknowledged, but the language and terminology are different.

Preservice Teachers' Perceptions About Physics and STSE

Physics teachers' and preservice teachers' perceptions of an STSE-oriented physics curriculum have not been extensively researched (Nashon et al., 2008; Pedretti, Bencze, Hewitt, Romkey, & Jivraj, 2008). In Ontario, teachers who are currently teaching science and preservice science teachers who are about to enter the secondary school system have probably not experienced an explicit STSE-oriented science curriculum as students, although they may have experienced some issues-based science education. Since the science curriculum now places STSE expectations at the forefront, one wonders what challenges physics teachers and prospective physics teachers will experience.

Science teachers have the potential to bring an STSE-oriented science curriculum to life: "The decisive component in reforming science education is the classroom teacher. . . . Unless classroom teachers move beyond the status quo in science teaching, the reform will falter and eventually fail" (Bybee, 1993, p. 144). For Tobin (1994), "teacher beliefs are a critical ingredient in the factors that determine what happens in the classroom" (p. 64);and for Stigler and Hiebert (1999), "some people believe that beginning teachers might be more effective, entering the profession with fresh ideas" (pp. 143–144). Stigler and Hiebert (1999) also noted, however, that "preservice education, no matter how effective, cannot by itself produce continuous improvement" (p. 158).

Aikenhead (2005) noted that teachers demonstrated three orientations towards adopting STSE. Some teachers were supportive; some were committed to pre-professional training, but resisted or even undermined STSE; and some could be persuaded to adopt STSE. Aikenhead listed many reasons why teachers might be unable or unwilling to implement an STSE curriculum: lack of resources, unfamiliarity with transactional and transformation teaching orientations, frustration with combining every day and scientific language, lack of confidence with an integrated content, uncertainty about the teacher's purpose in the classroom, lack of support from both inside and outside the school, pressure to prepare students for university and government exams, greater need for cultural sensitivity with some STSE topics, and preservice teachers' survival mode (Aikenhead, 2005; Rubba, 1991). Preservice teachers who struggled to adapt to an STSE-oriented curriculum lacked confidence in teaching basic science content, and usually repeated undergraduate experiences where the focus was on "lecturing pure content" (Aikenhead, 2005; Forbes& Davis, 2008; Novodvorsky, 2006; Schwartz& Lederman, 2002).

Teachers' self-identity and self-efficacy play an important part in determining which of Aikenhead's (2005) three orientations a teacher will gravitate towards (Pedretti et al., 2008). Part of self-identity is professional self-identity, developed during the undergraduate years when students are socialized into a particular scientific discipline (Aikenhead, 1994). A determining factor would be whether the person can move beyond this socialization to examine other ways of teaching science (Aikenhead, 2003).

In Lumpe, Haney, and Czerniak's (1998)study, teacher participants "believe[d] that including STSE in the classroom [could] develop decision-making skills in students, foster science learning, and provide meaningful applications of science to real life" (p. 17). These teachers felt that STSE could benefit students, but that implementing it also depended on external factors. The authors also concluded that "teachers with fewer years of experience possess[ed] stronger perceived behavioral control, subjective norms, and intent to implement STSE than their more experienced counterparts" (Lumpe et al., 1998, p. 17).

Teachers and preservice teachers' self-efficacy was also an important element in determining their ability to accept and implement an STSE-oriented curriculum:

> *Science teachers . . . with low self-efficacy resulting from lack of subject matter knowledge use compensatory strategies. . . . [Those] with high self-efficacy employ instructional strategies that favor academic self-directedness and open-ended problem solving. (Yoon et al., 2006, p. 15)*

Ways of increasing preservice teachers' self-efficacy included using cases and case methods that allowed for multiple points of entry (i.e., scaffolding; Yoon et al., 2006). A combined "foundations of education" and "curriculum and instruction in science education" course also proved useful, as did basing activities on inquiry-oriented approaches (Sherman, 2007). Multimedia case studies were used to introduce preservice teachers to STSE, and to examine their adoption of STSE based on their identity as science teachers(Pedretti et al., 2008). The findings indicated that preservice teachers felt confidence and motivation towards STSE in the classroom, but would hesitate to teach these perspectives early in their career (Pedretti et al., 2008).

Science teachers' self-identity and self-efficacy were important in whether they adopted and implemented STSE, because teachers' thinking influences how students learn (Forbes & Davis, 2008). Teachers and certainly preservice teachers require three types of knowledge: content knowledge, pedagogical knowledge, and pedagogical content knowledge (Etkina, 2005).The role of preservice programs is to assist candidates to develop all three knowledge bases (Wenning, 2007) and then to help the preservice teachers to:

> *. . . adapt, modify, and refine existing science curriculum materials. This authentic dimension of practice can be characterized as a teacher's pedagogical design capacity or his or her ability to*

draw on [a] variety of resources to adapt curriculum materials toward constructive ends. (Forbes & Davis, 2008, p. 831)

If preservice teachers feel inadequate in their level of content knowledge, and/or do not have an opportunity to experience STSE-oriented lessons as part of their pedagogical content knowledge instruction, then their pedagogical design capacity will suffer. From the perspective of the preservice physics teacher, the relationships between these knowledges and STSE education are complex and vague, with little clarification in the research literature.

Summary

An examination of research about physics teaching, focusing on what is best for students from physicists' and the science educators' perspectives. A true connection is possible between physics content and the tenets of STSE education, and this could act as a catalyst, moving physics from a gatekeeper science to a gate-opener, whereby physics could become more accessible to the everyday student as well as those who wish to continue studying physics at university. Some research directly connects physics education and STSE, although most of the research focuses on science in general and not on physics specifically. Discussion of ideas, dilemmas, and concerns taken from the literature concerning preservice teacher learning, especially as it pertains to an STSE-oriented physics curriculum has been voiced.

References

Abell, S. K., Smith, D. C., & Volkmann, M. J. (2006). Inquiry in science teacher education. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education. Science & Technology Education Library, Vol. 25* (pp. 173–200). Dordrecht, the Netherlands: Springer.

Aikenhead, G. S. (1994). What is STS teaching? In J. A. Solomon & G. Aikenhead (Eds.), *STS education: International perspectives on reform* (pp. 47–59). New York, NY: Teachers College Press.

Aikenhead, G. S. (2003). Chemistry and physics instruction: Integration, ideologies, and choices. *Chemical Education: Research and Practices, 4*(2)*,* 115–130.

Aikenhead, G. S. (2005). Research into STS science education. *Educacion Quimica, 16,* 384–397.

Akarsu, B. (2010). Science education research vs. physics education research: A structural comparison. *European Journal of Physics Education, 1,* 13-19.

Alsop, S., & Pedretti, E. (2001). Science, technology and society. In S. Alsop & K. Hickes (Eds.), *Teaching science* (pp. 193–208). London, UK: Kogan Page.

Alsop, S., & Watts, M. (2000). Facts and feelings: Exploring the affective domain in the learning of physics. *Physics Education, 35*(2)*,* 132–138.

Beichner, R. J. (2009). An introduction to physics education research. Retrieved from http://www.per-central.org/document/ServeFile.cfm?ID=8806

Bloom, J. W. (2006). *Creating a community of young scientists* (2nd ed.). New York, NY: Trifolium Books.

Brickhouse, N. W. (2001). Embodying science: A feminist perspective on learning. *Journal of Research in Science Teaching, 38*(3)*,* 282–295.

Bybee, R. W. (1993). *Reforming science education*. New York, NY: Teachers College Press.

Bybee, R. W. (2006). Scientific inquiry and science teaching. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching,* *learning, and teacher education. Science & Technology Education Library, Vol. 25* (pp. 1–15). Dordrecht, the Netherlands: Springer.

DeBoer, G. E. (1991). *A history of ideas in science education: implications for practice*. New York, NY: Teachers College Press.

DeBoer, G. E. (2006). Historical perspectives on inquiry teaching in schools. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education. Science & Technology Education Library, Vol. 25* (pp. 17–37). Dordrecht, the Netherlands: Springer.

Etkina, E. (2005). Physics teacher preparation: Dreams and reality. *Journal of Physics Teacher Education On-line, 3*(2), 3–9.

Forbes, C. T., & Davis, E. A. (2008). Exploring preservice elementary teachers' critique and adaption of science curriculum materials in respect to socioscientific issues. *Science and Education, 17*(8–9), 829–854.

Franz, J. (2010). Improving K–12 science education. *American Physical Society, 19*(7). Retrieved from: http://www.aps.org/publications/apsnews/201007/backpage.cfm

Harrison, D. (2010). An introduction to physics education research. Retrieved from: http://www.upscale.utoronto.ca/PVB/Harrison/PER_Intro/PER_Intro.html

Hart, C. (2001). Examining relations of power in a process of curriculum change: The case of VCE physics. *Research in Science Education*, *31*, 525–551.

Hawkes, B., & O'Meara, J. (2005). *Physics education in Canada*. Retrieved from http://www.cap.ca/pic/Archives/61.2(2005)/editorial.html

Hillel, J. (2005). *Physics education research: A comprehensive study*. Toronto, ON: University of Toronto.

Hodson, D. (1998). *Teaching and learning science: Towards a personalized approach*. Philadelphia, PA: Open University Press.

Holubova, R. (2005). Environmental physics: Motivation in physics teaching and learning. *Journal of Physics Teacher Education On-line, 3*(1), 17–20.

Knight, R. (2004). *Five easy lessons: Strategies for successful physics teaching* (1st ed.). Toronto, ON: Addison Wesley.

Kortland, J. (2005). Physics in personal, social and scientific contexts: A retrospective view on the Dutch physics curriculum development project PLON. In P. Nentwig & D. Waddington (Eds.), *Making it relevant*: *Context based learning of science* (pp. 67–89). Munster, Germany: Waxmann.

Lawrenz, F. & Kipnis, N. (1990). Hands-on history of physics. *Journal of Science Teacher Education, 1*(3), pp. 54–59.

Lederman, J. S.,& Stefanich, G. P. (2006). Addressing disabilities in the context of inquiry and nature of science instruction. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education. Science & Technology Education Library, Vol. 25* (pp. 55–75). Dordrecht, the Netherlands: Springer.

Lederman, N. G., & Lederman, J. S. (2004). Revisioning instruction to teach nature of science. *The Science Teacher, 39.* Retrieved from http://www.nsta.org/main/news/stories /science_teacher.php?news_story_ID=49932&print

Leonard, W. J., Dufresne, R. J., & Mestre, J. P. (1996). Using qualitative problem-solving strategies to highlight the role of conceptual knowledge in solving problems. *American Journal of Physics, 62*(12), 1495–1503.

Lumpe, A. T., Haney, J. J., & Czerniak, C. M. (1998). Science teacher beliefs and intentions to implement science-technology-society (STS) in the classroom. *Journal of Science Teacher Education, 9*(1), 1–24.

Magnusson, S. J., Palincsar, A. S., & Templin, M. (2006). Commuity, culture, and conversation in inquiry based science instruction. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education. Science & Technology Education Library, Vol. 25* (pp. 131–157). Dordrecht, the Netherlands: Springer.

Maloney, D. P. (1994). Research on problem solving: Physics. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (p. 598). New York, NY: Macmillan.

McDermott, L. C. (1991). Millikan Lecture 1990: What we teach and what is learned—closing the gap. *American Journal of Physics, 69*(11), 301–315.

McDermott, L. C. (1998). Research in physics education. *APS News, 7*(1), 8.

McDermott, L. C. (2001). Oersted Medal Lecture 2001: Physics education research—the key to student learning. *American Journal of Physics, 69*(11), 1127–1137.

McDermott, L. C. (2006). Preparing K–12 teachers in physics: Insights from history, experience, and research. *American Journal of Physics, 74*(9), 748–762.

McDermott, L. C., & Redish, E. F. (1999). Resource Letter: PER-1: Physics education research. *American Journal of Physics, 67*(9), 755–767.

McLean, L. D. (1987). *Teaching and learning physics in Ontario in the senior division*. Toronto, ON: Ontario Assessment Instrument Pool.

Metz, K. E. (2006). The knowledge building enterprises in science and elementary school science classrooms. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education. Science & Technology Education Library, Vol. 25* (pp. 105–131). Dordrecht, the Netherlands: Springer.

Nashon, S., Nielsen, W., & Petrina, S. (2008). Whatever happened to STS? Pre-service physics teachers and the history of quantum mechanics. *Science and Education, 17,* 387–401.

Natural Sciences and Engineering Research Council (NSERC). (2011). Discovery grants program. Retrieved from http://www.nserc-crsng.gc.ca/Professors-Professeurs/Grants-Subs/DGIGP-PSIGP_eng.asp

Novodvorsky, I. (2006). Shifts in beliefs and thinking of beginning physics teacher. *Journal of Physics Teacher Education On-line, 3*(3), 11–17.

Pedretti, E. (1996). Learning about science, technology, and society (STS) through an action research project: Co-constructing an issues-based model for STS education. *School Science and Mathematics, 96*(8), 432–440.

Pedretti, E. (2005). STSE education: Principles and practices. In S. Alsop, L. Bencze & E. Pedretti (Eds.), *Analysing exemplary science teaching: Theoretical lenses and a spectrum of possibilities for practice* (pp. 116–126). London, UK: Open University Press.

Pedretti, E., Bencze, L., Hewitt, J., Romkey, L. & Jivraj, A. (2008). Promoting issued-based STSE perspectives in science teacher education: Problems of identity and ideology. *Science and Education, 17*(8–9), 941–960.

Redish, E. F. (2003). *Teaching physics with physics suite*. Hoboken, NJ: Wiley.

Rubba, P. (1991). Integrating STS into school science and teacher education: Beyond awareness. *Theory Into Practice, 30*(4), 303–308.

Saul, J. M. (1998). *Beyond problem solving: Evaluating introductory physics courses through the hidden curriculum* (Unpublished doctoral dissertation). University of Maryland, College Park.

Schwartz, R. S., & Lederman, N. G. (2002). "It's the nature of the beast": The influence of knowledge and intentions on learning and teaching nature of science. *Journal of Research in Science Teaching, 39,* 205–236.

Sherman, A., & MacDonald, L. (2007). Pre-service teachers' experiences with a science education module. *Journal of Science Teacher Education, 18,* 525–541.

Shipman, H. L. (2006). Inquiry learning in college classrooms: For the times, they are, a changing. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education. Science & Technology Education Library, Vol. 25* (pp. 357–389). Dordrecht, the Netherlands: Springer.

Stigler, J. W.,& Hiebert, J. (1999). *The teaching gap: Best ideas from the world's teachers for improving education in the classroom*. New York, NY: Free Press.

Tobin, K., Tippins, D.J., & Gallard, A. J. (1994). Research on instructional strategies for teaching science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (Ch. 2). New York, NY: National Science Teachers Association.

van Aalst, J. (2000). An introduction to physics education research. *Canadian Journal of Physics, 78*(1)*,* 57–71.

van Aalst, J. (2005). Critical details" and physics teaching. *Canadian Journal of Science*, *Mathematics and Technology Education*, *5*(3)*,* 417–422.

Viennot, L. (2003). *Teaching physics*. Dordrecht, the Netherlands: Kluwer Academic.

Wallace, J. & Louden, J. (2000). *Teachers' learning: Stories of science education. Science & Technology Education Library, Vol.7.* Dordrecht, the Netherlands: Kluwer Academic.

Waltner, C., Wiesner, H., & Rachel, A. (2007). Physics in context: A means to encourage student interest in physics. *Physics Education, 42*(5)*,* 502–507.

Wenning, C. J. (2007). A physics teacher candidate knowledge base. *Journal of Physics Teacher Education On-line, 4*(3)*,* 13–16.

Wieman, C., & Perkins, K. (2005, November). Transforming physics education. *Physics Today,* 36–41.

Yoon, S., Pedretti, E., Bencze, L., Hewitt, J., Perris, K., & van Oostveen, R. (2006). Exploring the use of cases and case methods in influencing elementary preservice science teachers' self-efficacy beliefs. *Journal of Science Teacher Education, 17,* 15–35.

Zohar, A. (2005). Physics teachers' knowledge and beliefs regarding girls' low participation rates in advanced physics classes. *International Journal of Science Education, 27*(1)*,* 61–77.