Challenges facing high school physics students: An annotated synopsis of peer-reviewed literature addressing curriculum relevance and gender

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High school students have traditionally been taught physics by way of lectures, non-participative demonstrations, and cookbook laboratories. Not surprisingly, students leave the physics classroom with vague understandings of physics as a science and way of understanding our world. This problem is exasperated for female students, whose interests and culture are not addressed by typical examples and applications of physics. Challenges facing adolescent physics students can be addressed by cooperative learning in a supportive classroom culture and curricula tailored to meet the interests of all physics students in a concrete manner. Students' learning experiences can be drastically improved so they leave high school with a solid conceptual understanding of physics and its impact on their lives. In this manuscript, I present and discuss the classroom application of an extensive literature base addressing these above issues for use by working physics teachers and scholars of classroom physics teaching.

Introduction

Adolescents traditionally begin their formal study of physical science in middle school. They most often progress in the sequence of biology, chemistry, and eventually a senior elective if they continue their study of science (Lederman, 1998). Of these electives, physics is widely considered to be the most academically demanding. Even after instruction students often believe that physics is tremendously difficult and incomprehensible to a majority of the general population (Knight, 2004). The roots of this situation lie not only in the subject's demanding subject matter as a reputed "hard science," but also because of the abstract nature of physics as it is traditionally presented (via mathematical formalism).

Many former physics students remember physics as their "*worst* subject" (Knight, 2004), and nearly always these memories include images of a lecturer and associated experiments in a laboratory. Concerning the former image, Arons eloquently writes,

> …research is showing that didactic exposition of abstract ideas and lines of reasoning (however engaging and lucid we might try to make them) to passive listeners yields pathetically thin results in learning and understanding except in the very small percentage of students who are specially gifted in the field. (1997, p. vii)

Knight notes that the *standard* laboratory experiences wherein students "verify" theories or "discover" principles of physics produce little or no measurable benefit (2004, p. 20). Both lectures and standard laboratories have been shown to be flawed by current physics education research (PER) and science education research (SER). The story is often worse for females, whose interests were found to lie more in the natural and social applications of physics by Hoffman, Häussler, and Lehrke (as cited by Hoffman, 2002) and also by Stadler, Duit, and Benke (2000). Unfortunately, Hoffman, Häussler, and Lehrke (as cited by Häussler & Hoffman, 2002) found that these aspects of physics are seldom addressed by traditional curricula. Rather, when contextual references are made in the physics classroom they often focus on topics which are biased toward males such as sports, cars and military due to the historical prevalence of males in physics.

Over the past twenty-five years the field of Physics Education Research (PER) has come into its own and can readily supply a multitude of ways to combat the deficiencies of lectures and standard laboratories (Knight, 2004). Specific measures can be implemented to improve the appeal of physics to female students while retaining its lure for males. Hence, we will review applicable literature and draw from personal experience to suggest specific teaching techniques that can be used to lessen the above pedagogical challenges facing physics students of both genders. This literature is featured in the bibliography and in separate online bibliographies.

Literature Review

Students' attitudes toward science grow increasingly negative as they progress through school (Simpson & Oliver as cited by Kahle & Meece, 1994; Weinburgh, 2000) and even during college (Redish, Steinberg, & Saul, 1998). Though overall enrollment in high school physics has risen over the past decade (Neuschatz & McFarling, 1999), students' conceptual understanding of basic kinematics measured after traditional instruction, though marginally improved, remains deficient (Hake, 1998; Sokoloff & Thornton, 1997). Van Heuvelen (as cited in Knight, 2004) refers to the expository methods utilized in traditional physics instruction as, "…very ineffective—the transmission is efficient but the reception is almost negligible."

The situation is exacerbated for adolescent females who have more negative attitudes toward science and are less confident in their science abilities than males (Simpson and Oliver as cited by Kahle & Meece, 1994; Weinburgh, 1995). Though now females' enrollment in physics nearly equals that of males (Neuschatz & McFarling, 1999), girls and women do not achieve at the same level as their male peers (Bacharach, Baumeister, & Furr, 2003; Labudde, Herzog, Neuenschwander, Violi, & Gerber, 2000). The behavior of male physics students affects the learning process of females (Jones & Wheatley, 1990), as does the behavior of their teachers (Jones &Wheatley; Labudde et al.). Context has an important influence on female learning (McCullough, 2004; Pollina, 1995; Stadler, Duit, & Benke, 2000), but it has been found that topics and examples which interest females are also of interest to their male peers (Hoffman, Häussler, and Lehrke as cited by Hoffman, 2002). Curricula can therefore be differently constructed so as to meet females' needs while remaining appropriate for male students.

Physics curricula that challenge students while offering choices have been found to increase student motivation and encourage responsibility (Pintrich, 2003). Cooperative or collaborative classrooms have the ability to engage students and decrease the frequency of adverse gender interactions if an atmosphere of respect is maintained (Pollina, 1995). Cooperative classrooms encourage active learning, wherein engaged students construct their own meaning of concepts at hand (Knight, 2004; MacIsaac & Falconer, 2002) .A summary of this review can be found in Appendix A.

Applications

The findings from this literature can be directly applied to high school physics classrooms to provide an equitable and friendly learning environment for all students. Techniques to be considered include the following: offering students choice and promoting responsibility, creating a cooperative learning environment, fostering positive male adolescent behavior, equitable treatment of all students, and curriculum relevance to the real world. Specific suggestions will draw from the author's personal observations and accounts recorded by physics education researchers.

Choice and Responsibility in the Classroom

An example of a curriculum which offers students a choice in what they study is that exemplified by L. Hiller from North Tonawanda High School for his Regents and Advanced Placement (AP) courses (personal communication, Spring 2004). At the beginning of the semester, each pair of students in a laboratory section picks a theme to investigate for the duration of the semester. Available themes include sports, forensics, engineering, music, and computer investigations. Students select each five-week lab from a list centered upon the chosen theme. Each of these 5-week labs investigates a topic that has been covered in class discussion. General direction is given to each pair of students both at the beginning and throughout the five-week experiment, but in Mr. Hiller's six years of teaching no pair of students has performed an experiment in the same manner. At the end of the five-week laboratory, each pair of students presents their experiment to their section (L. Hiller, personal communication, Spring 2004). Each team is given five minutes and a whiteboard (MacIsaac & Falconer, 2004) to present their investigation and findings to the class. Data is typically presented in the form of graphs and diagrams and, if feasible, the apparatus is demonstrated. After their presentation, each team answers questions from their peers and the teacher, who is demanding not only with regard to what was presented but also considering alternative investigations and interpretations that could have been taken, data analyses, and further study.

Student responsibility can be easily effected by treating students as responsible adolescents (L. Hiller, personal communication, Spring 2004). At the beginning of each unit Mr. Hiller gives each student a packet of information and assignments to complete over the course of the topic. Advanced Placement (AP) students have the opportunity to complete extra problems from the textbook to compensate for lower marks earned during each topic. Additionally, students are given the due dates for their packets at the beginning of each topic. It is their responsibility to complete each topic by the date it is due; late assignments are not accepted. The author has observed the use of this technique and it is readily apparent that students are comfortable with this format. This technique works well for encouraging students to be responsible simply by treating them as mature individuals.

Creating a Cooperative Learning Environment

A cooperative or collaborative learning environment is one where students learn by working together to understand concepts rather than passively absorbing information. Traditional attempts to create such an environment have included the use of demonstrations and laboratory experiments. The author's personal experience has been that typical demonstrations do not deeply engage students. Standard laboratories have become the realm of rubrics and data sheets and are of little benefit to students (Knight, 2004). Conversely, a cooperative classroom is one where the instructor serves more as a facilitator of learning and students are active learners (Henry, 2001).

A cooperative classroom can be created in a number of ways (Knight, 2004). L. Hiller creates a collaborative environment by encouraging student participation through the use of collaborative classworks and laboratory experiments (personal communication, Spring 2004). W. Garlapo uses remote polling devices (personal communication, February 17, 2004) while Henry (2001), MacIsaac, and Falconer rely on whiteboards (2004). The precise method by which a teacher creates a collaborative environment is not critical, but it is important that this environment be friendly to females while offering all students the chance to work together and learn from doing rather than by being told.

Collaborative environments create a more social learning experience and are therefore more attractive to females by nature (Pollina, 1995). However, these benefits can be offset by poor group formation. Left to their own devices, students typically form groups with their friends. Possible arrangements of three students are: two males and a single female, two females and a lone male, or homogenous groups. Groups with two boys and a lone girl often result in the alienation or passivity of the solitary girl (K. Cummings, personal communication, April 17, 2004; MacIsaac & Falconer, 2004). To avoid this pattern, teachers need to find a way to eliminate this situation by creating groups themselves or by changing natural groupings.

Fostering Positive Male Adolescent Behavior

Detrimental male behavior in the physics classroom comes in several forms: the well known calling out (Kahle & Meece, 1994; Stadler, Duit, & Benke, 2000), commandeering superior laboratory equipment (Gillibrand, Robinson, & Osborn, 1999), and the dominance of both a teacher's time and attention (Robinson, 1996; Streitmatter, 1998). Teachers have traditionally tried to foster positive male behavior in a variety of ways.

One obvious way to deal with the calling out of male students is the creation of a rule explicitly forbidding this behavior at the beginning of a course. An alternative measure is that taken by Mr. Workman (Pollina, 1995), a teacher who created a collaborative environment only to have participation stifled by male students calling out frequently. He instigated a new rule where each student or group of students quietly wrote down the answer to the problem. Mr. Workman would then walk around the room and confirm whether the answer was correct or the student(s) needed to work further. Whiteboards (MacIsaac & Falconer, 2004) can serve as an effective medium for this interaction, creating a record of work that could be both easily examined by the teacher and shared with the rest of the class as desired.

The tendency of males to commandeer the best laboratory equipment and monopolize a teacher's time can be counteracted primarily by the teacher being aware of the interactions in the classroom. Additionally, a teacher could assign groups of students to a specific stations and rotate the superior equipment, but at the expense of creating additional work for him or herself. An alternative is letting students retrieve their equipment in a rotating order, assuming that they could identify the best equipment.

The last male behavior which can negatively affect adolescent learning of physics is the tendency to monopolize a teacher's time. Kelly (as cited by Stadler, Duit, & Benke, 2000) established that males "dominate the conversation between the teacher and students" in science classrooms (p. 418). Males have been known to cut ahead of female students who have been patiently waiting in line, which can result in female students feeling marginalized (Streitmatter, 1998). To avoid this, teachers needs to be particularly aware of which students have been waiting to speak with them and the order in which students arrived. Similarly, teachers should be aware of the time they spend with laboratory groups, regardless of the gender composition of the groups.

Equitable Treatment of All Students

Though Jones and Wheatley observed that "male teachers asked significantly more direct questions of students than female teachers" (1990, p. 866), they found no differences by student sex. However, Karp and Yoels found (as cited by Jones & Wheatley, 1990) that at the college level female teachers show no preference with respect to gender while male teachers ask more direct questions to male students. This inequality with respect to student gender may be the result of the character of answers that students typically provide. Teachers tend to appreciate responses from male students; the answers are usually succinct and can be modified to illustrate the teacher's point (Stadler, Duit, & Benke, 2000). Conversely, answers from female students are generally more drawn-out and specific in nature. Teachers who are insensitive to gender issues may resent these types of questions, for not only does it take longer to listen to a female student's answer, it is also more complicated to redirect a precise answer than the typical short statement of a male student (Stadler et al.).

A strategy for assuring all students are fairly called upon by a teacher is to buy a deck of cards for each class (K. Hover, personal communication, September 2001). Each student's name is written on a card, and equal opportunity is ensured through choosing students by cycling through the deck rather than having students raise their hands or by picking randomly. Variations on this technique can be created by creating categories rather than specific names, possibilities include a student "on the soccer team, born in July, whose first name begins with J, etc." A difficulty that can arise from the use of this technique is the assignment of a difficult question or problem to a low-achieving student. When this happens the author usually admits to the class that the problem is difficult and ask that the student give the problem a try, but also tell the student that they can "tag-team" anyone in the class (including the instructor if necessary) for assistance. When considering the deck of cards technique, it should be noted that every card in the deck cannot be used, and also that the teacher never makes a complete rotation through the deck during a class. The deck of cards is rather kept in order and the teacher picks up where he or she left off during the next class meeting.

Another way that teachers discriminate between students on the basis of gender is by the type of questions that they ask. Female students are more likely to answer open-ended questions while males prefer closed questions (Stadler, Duit, & Benke, 2000). This suggests that to equitably address a class, teachers should address different types of questions to students depending on their gender. However, open questions require the extension of concepts to ideas beyond what was directly considered in class. This process helps students form what Arons (1997) terms "operational definitions" of concepts and is crucial to their conceptual understanding of physics. Open-ended questions should be utilized as often as possible and directed to students of each gender with identical frequency. The use of open-ended questions should not merely occur during class, but should also be extended to assessments in the form of conceptual questions or essays (D. MacIsaac, personal communication, May 6, 2004). Both formats encourage females and males alike to apply their sociological knowledge of physics and represent a substantial step toward achieving a gender-equitable classroom.

Curriculum Relevance to the Real World

Physics teachers and textbook authors routinely use abstract scenarios or male-biased scenarios to give students an opportunity to apply concepts. However, "in comparison with the boys, the girls have less experience with and interest in physics and technology" (Labudde, Herzog, Neuenschwander, Violi, & Gerber, 2000, p. 148). This frequently puts female students at a disadvantage, for when real-world context is provided for physics examples and problems, it is often removed from female students' experiences.

Abstract problems are very efficient ways of providing an opportunity for students to apply their physics knowledge and problem solving skills. Unfortunately, they do not connect to students' lives and provide very little motivation for solving the problem. Rennie and Parker (as cited by McCullough, 2004) found that "…appropriate contexts make problems easier to visualize and more interesting." Problems of this nature have been termed "context-rich problems" (Context Rich Problems, n.d.) and serve the same purpose as equivalent abstract problems while allowing students to connect to the scenario. It is no surprise that Rennie and Parker (as cited by McCullough) found that students preferred concrete problems over abstract problems. Additionally, Hoffman, Häussler, and Lehrke (as cited by Hoffman, 2002) found that:

> Girls in particular respond very sensitively to a change of context. On average, girls expressed a relatively high interest in natural phenomena and phenomena that could be perceived by the senses. They placed a high value on references to mankind, social involvement, and the practical applications of theoretical concepts. (p. 451)

Context-rich problems provide a fertile ground for students to apply their knowledge while working toward a definite goal and maintaining a sense of how the current topic applies to their environments, and should be used whenever possible. However, the nature of these problems needs to be tailored to meet the needs of all physics students.

Physics teachers and textbook authors have often relied on the mainstays of bullets, hockey pucks, rockets, and race cars to illustrate physics concepts or describe scenarios for problems in terms that students can relate to. Indeed, two of the most popular textbooks in the nation for high school students (Neuschatz & McFarling, 1999) show few examples that are specifically targeted toward female students. Chapter 2: Linear Motion of Hewitt's *Conceptual Physics* (1998) includes numerous examples to cars, planes, and basketball players, but only one reference to ballet. The equivalent chapter in Halliday, Resnick, and Walker's *Fundamentals of Physics* (2001) contains references to cars, trucks, particles in motion, baseballs, armadillos, elevators, and manned projectiles going over Niagara Falls. While the last three examples are not gender biased, the preceding examples are geared toward males. Though textbooks have begun to substitute female subjects into their problems, the scenarios that are presented remain predominantly masculine. This male bias extends even to our assessments, from standard evaluations (Kahle & Meece, 1994) to the Force Concept Inventory (FCI), the current backbone of conceptual mechanics assessment (McCullough, 2004).

As McCullough (2004), Pollina (1995) and Stadler, Duit, and Benke (2000) found, context plays an important role in students' performance with regard to gender. While not advocating a switch from a male bias to a female, it appears that any contextual references made should be at least neutral. There is also evidence that contextual references friendly to females do not hinder males' performance on assessments (McCullough), and Hoffman, Häussler, and Lehrke (as cited by Hoffman, 2002) found that "what is interesting for girls is also interesting for boys, but not necessarily vice versa" (p. 451). Häussler and Hoffman found that "adapting the curriculum to the interests of girls is also advantageous for boys" (2002, p. 885). Since the number of females in physics classrooms is nearly equal to that of males (Neuschatz & McFarling, 1999), both curricula and assessments should be modified to cater to interests of both male and female students. This can be done by including examples of household objects whenever possible, and not just rifles and cars. Female-friendly objects such as those McCullough used to create the Revised FCI (RFCI) would be excellent sources. These may include objects rolling off of a table, shopping scenarios, safety scenarios such as the bicycle helmets described by Häussler and Hoffman (2002), or female oriented activities such as gymnastics or ballet. Also, an effort should be made to connect topics not only to students' experiences, but also to instill an awareness of how the topic affects the rest of the world to embrace female ways of thinking (Stadler, Duit, & Benke, 2000). This will help females feel that the topic is important to their lives and to see how it fits into their global patterns of learning.

Conclusion

Adolescent physics learners face numerous significant challenges in acquiring a robust conceptual knowledge of physics. Though physics will always remain an intellectually challenging subject, it is apparent that as it is presently taught there are numerable distractions and unnecessary challenges resulting from the manner of instruction and an insensitivity to gender issues. Published literature suggests a variety of solutions, summarized in Appendix B. There are many ways to reduce the academic challenges facing physics students, particularly with regard to addressing gender inequalities by reforming classroom culture. By becoming cognizant of gender issues and creating both a cooperative and female-friendly classroom environment, future adolescent physics students of both sexes will better rise to the challenge and enjoy the fulfilling experience of the rich and powerful conceptual understandings of physics.

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Appendix A

Literature review of academic challenges facing adolescent physics learners

Observation or Conclusion	Researcher(s)
Students hold increasingly negative attitudes toward science as they progress through secondary school and into college	Simpson & Oliver as cited by Kahle, J. B., & Meece, J. (1994) Weinburgh, M. H. (2000) Redish, E. F., Steinberg, R. N., Saul, J. M. (1998)
Physics instruction fails to increase or even maintain student interest in physical science	Broome, P. (2001) Häussler, P., & Hoffman, L. (2002)
The percentage of students enrolled in physics is at a maximum	Neuschatz, M., & McFarling, M. (1999)
Traditional instruction does not lead to conceptual understanding	Hake, R. R. (1998) Van Heuvelen as cited by Knight, R. D. (2004) Sokoloff, D. R., & Thornton R. K. (1997)
Females hold more negative attitudes toward science and are less confident in their scientific abilities than males	Simpson & Oliver as cited by Kahle, J. B., & Meece, J. (1994) Weinburgh, M. H. (1995)
Females are no longer a minority in physics classrooms	Neuschatz, M., & McFarling, M. (1999)
Females achieve at lower levels than males do in identical physics classrooms	Bacharach, V. R., Baumeister, A. A., & Furr, R. M. (2003) Labudde, P., Herzog, W., Neuenschwander, M. P., Violi, E., & Gerber, C. (2000)
Male behavior affects the way that females learn	Jones, M. G., & Wheatley, J. (1990)
Context is of particular importance for female learners	McCullough, L. (2004) Pollina, A. (1995) Stadler, H., Duit, R., & Benke, G. (2000)
Topics that interest females also interest males	Hoffman, Häussler, and Lehrke as cited by Hoffman, L. (2002)
Teachers treat students differently by gender, affecting their learning processes	Jones, M. G., & Wheatley, J. (1990) Labudde, P., Herzog, W., Neuenschwander, M. P., Violi, E., & Gerber, C. (2000)
Curricula offering choices and challenges motivate students and foster responsibility	Pintrich, P. R. (2003)
Cooperative classrooms engage students and have the ability to decrease the frequency of adverse gender interactions	Pollina, A. (1995)

Appendix B

A summary of recommendations and suggested implementation techniques for introductory physics teachers

Recommendation	Issue of Interest	Possible Techniques for Implementation
Offering students choice and responsibility	Give students choices	Modified laboratory curriculum (Hiller)
	Promote student responsibility	Treat students like adults
Create a cooperative learning environment	Increase student interaction and engagement	Classworks and small-group activities Laboratory experiments (in groups or as an entire-class activity) Remote polling devices Whiteboards
Equitable treatment of students	Unequal distribution of questions	Deck of cards
	Address questions to all types of students; promote conceptual learning	Open-ended questions
Fostering positive male adolescent behavior	Reduce frequency of calling out	Rules for answering questions Write down answers to questions (whiteboards)
	Equitable lab equipment distribution	Assign groups to tables that already have equipment Regulate the order in which lab groups get equipment Each pair of students works on a different lab (Hiller)
	Equitable Time Distribution	Awareness of students waiting Limitation on time spent with each group
Relate curricula to the real world	Give contextual references that all students can relate to	Include contexts that both females and males are familiar with such as those involving household items or common activities

