

J P T E O

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MAKING AN IMPACT

I first began working with the Modeling Method of Instruction in 2001 when I was awarded an Eisenhower grant to hold a professional development workshop for inservice high school physics teachers. Subsequently, I received another Eisenhower grant in 2003, and a NCLB Improving Teacher Quality grant during 2005, both for the purpose of hosting additional Modeling Method workshops. During these summers I have had the pleasure of working with expert Modelers, and seeing their great enthusiasm for teaching both subject matter and students. These dedicated educators have been so very good to share their knowledge, skills, and experiences with new Modelers each year. These teachers are really making an impact on improving teacher quality - the most significant factor in student learning. David Hestenes and Jane Jackson at Arizona State University, the "home" of the Modeling Method, are to be congratulated on their hard work on behalf of this approach first developed by Malcolm Wells.

Ever since I started hosting Modeling Method workshops, I have been extremely impressed by the ability of whiteboarding to impact the quality of classroom discourse and student learning. During these and other workshops I have facilitated, as well as my regular teaching of physics methods courses for my 40 or Physics Teacher Education majors here at Illinois State University, I have been introducing teachers to whiteboards and Socratic dialogues.

This summer, during my 3-week Chicago ITQ Science Project workshop, I saw the need for some sort of systematic and integrated treatment of the processes of whiteboarding and Socratic dialogues. I subsequently reviewed key literature, and assembled information that I have been sharing with my Modelers ever since through our State of Illinois Modeling listserv. This finally led to me writing a paper that appears in this issue of *JPTEO*. I can only hope that this article has the intended impact.

Ever since 2001 I have been repeatedly barraged with requests for additional whiteboards following my various workshops. It has not always been the teachers who have attended my workshops who have wanted whiteboards. It has often been their colleagues who have seen the impact that whiteboarding and Socratic dialogues have had on student learning after "my" teachers have returned to the classroom with whiteboards in hand. Unfortunately, I've been unable to fulfill these requests because

the whiteboards I had been providing have always been produced on campus using university resources. Finally, following years of being unable to fulfill requests, I finally decided to set up a small whiteboard production unit in my home - *whiteboardsUSA.com*. Now teachers can acquire the whiteboards they so often want.

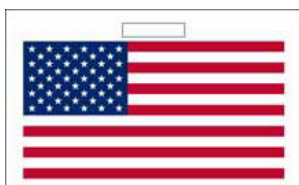
As anyone can imagine, the life of an teacher isn't filled with lots of free time. This is part of the reason why *JPTEO* doesn't always make it out on time; it has to be assembled when time permits at work on campus. I've recently rearrange my work schedule to spend more time at home working on whiteboards. Because of my hectic schedule on campus, I've chosen to begin completing the work of editing *JPTEO* on "company time." That is, some of the time set aside for work with *whiteboardsUSA.com* is now being dedicated to the preparation of this publication. In effect, *whiteboardsUSA.com* has become the first commercial sponsor of *JPTEO*.

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JPTEO

Whiteboarding & Socratic dialogues: Questions & answers

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The pedagogical practice of whiteboarding is becoming more prevalent across the United States, especially with the Modeling Method of Instruction created by Wells, Hestenes, and Swackhamer, and promoted through the efforts of Arizona State University. The Modeling Method, which has at its heart the use of whiteboarding and Socratic dialogues, has twice been identified by the US Department of Education as an exemplary approach to teaching. With the increasing use of whiteboarding, the author provides here a series of questions and answers about this important constructivist approach.

What is a whiteboard?

A whiteboard is a dry erase board of any small, but convenient, size upon which students can write or draw in order to present concepts, charts, maps, tables, graphs, diagrams, or equations. They are used with dry erase markers, and are easily wiped clean with an eraser.

What is whiteboarding?

Whiteboarding is a teaching practice under which students working individually or in groups use whiteboards to describe and explain the results of the observations they have made and/or thinking processes they have utilized. It is an instrument well suited to improving the quality and quantity of scientific discourse in a classroom. Teachers guide students in the use of their whiteboarding work. Typically a cooperative inquiry-oriented project is assigned to student groups. One of the tasks will be the reporting of the groups' findings. Group findings are typically presented by the entire group at the front of class where they might stand the whiteboard on a chalk rest or hang from hooks near the top of the classroom blackboard. Students explain their findings, and ideally will provide multiple representations of the understanding they have developed. The floor is then opened to questions. Teachers and students are allowed to seek clarifications and justifications for student conclusions. Using the whiteboarding approach, teachers hope to change students from "collectors of information to expectant creators of ... coherent understanding" (Wells, Hestenes & Swackhamer, 1995). Whiteboarding is strongly associated with the pedagogical approach known as Socratic dialogues.

What educational purpose do whiteboards serve?

The *National Science Education Standards* (NAS, 1996) note that "inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries" (p. 23). The *Principles and Standards for School Mathematics* (NCTM, 2000) calls for teachers to "encourage students to think, question, solve problems, and discuss their ideas, strategies, and solutions" (p. 18). Whiteboarding can provide an ideal avenue for achieving these goals.

Is the concept of whiteboarding new?

Not really. In many ways whiteboarding is a tried and true method that fell by the wayside with the advent of more sophisticated classroom technology. In many ways, whiteboarding harkens back to the days of the one-room schoolhouse when every student had his or her own slate board and chalk for writing, drawing, and computation, and was responsible for sharing with the teacher and fellow students the work that he or she had done. The teaching approaches used with whiteboards today are much more effective.

Is whiteboarding consistent with authentic best practice?

Whiteboarding enhances and supports the most desirable teaching approaches. Whiteboarding is an effective approach for teachers implementing three research-based principles identified by the National Research Council (2000, 2005) as critical to learning:

- 1. Engaging students' prior understandings.** This is critical to the development of scientific thought, and is central to the teaching approaches known as constructivism and concept change. Preconceptions can strongly influence what students do or do not learn. Whiteboarding allows students to articulate their beliefs and reasoning processes. If flawed

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beliefs and improper reasoning are identified, teachers can confront and rectify preconceptions and flawed logic.

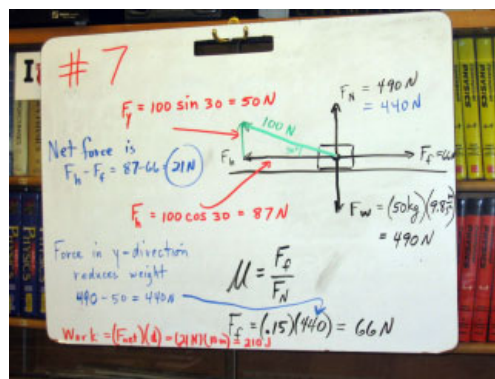
2. **Relating factual knowledge and conceptual frameworks in understanding.** Whiteboarding is an approach through which teachers can implement instructional strategies that engage students in inquiry-oriented lessons and labs, and allows for regular classroom discourse, evaluation, and interpretation of evidence. Students come to know not only what they know, but how they know it.

3. **Emphasizing the importance of student self-assessment and autoregulation.** Whiteboarding provides an excellent opportunity for students to learn from and correct their own mistakes, and to learn from the successes and mistakes of others. It also provides strong personal motivation to help students self-assess and auto-regulate before they make oral presentations. A public presentation of what students know and do not know can prove to be highly motivational.

What is the educational role of whiteboarding as it relates to learning environments and the design of instruction?

Whiteboarding helps teachers make for classrooms and instructional techniques that are learner centered, subject centered, assessment centered, and community centered.

- **The learner-centered classroom** attends to what students think and know, and uses cooperative inquiry practices to help students construct understanding from experiences and logic. Whiteboarding plays a central role in the process by providing a venue for reporting the results of observation and experimentation, and is a forum for formative assessments wherein teachers can identify, confront, and resolve student preconceptions.
- **The knowledge-centered classroom** focuses on what is being taught and how it is being taught. The whiteboarding process allows for students to understand why something is known rather than merely believed. It provides a framework through which students have an opportunity to test and confirm or correct their own ideas and reasoning. The approach is one in which emphasis is placed not only on what students think, but how they think. Students learn more as a result of teacher questioning and remarks.
- **The assessment-centered classroom** allows students the opportunity to make oral presentations in which they identify and explain step-by-step problem solving practices. They publicly state and justify their conclusions. Whiteboarding allows for fellow students to check and critique others' work during the process. It also affords teachers the opportunity to expose deficiencies in student reasoning, evaluate whiteboarding displays, and student presentations.



- **The community-centered classroom** calls for student dialoguing in which students learn to cooperate and communicate. Whiteboarding engenders an atmosphere of questioning. It sets higher expectations for student performance and accountability. Whiteboarding allows teachers to use class time to discuss student-generated ideas rather than merely presenting information. Whiteboarding engages students with their peers in a collaborative learning community. In a way, whiteboarding allows for more than one teacher in a classroom by allowing students with whiteboards to become fellow teachers as well.

Who uses whiteboarding?

Whiteboarding is used by school teachers at all levels and in all subject matter areas. Teachers who are interested in not only what students know, but in how students know what they claim to know, and to what extent they understand what they claim to understand, will make use of whiteboarding. It is not uncommon to see whiteboards used from elementary school through college, and even in professional development activities for teachers. Whiteboarding is perhaps best known today for its use in the Modeling Method of Instruction described more than a decade ago by Wells, Hestenes, & Swackhamer (1995). Whiteboarding is central to the Modeling Method of Instruction (<http://modeling.asu.edu/>). The Modeling Instruction Program was recognized in 2000 by the U.S. Department of Education as one of the seven best K-12 educational technology programs out of the 134 programs evaluated. It was similarly recognized in 2001 by the U.S. Department of Education as one of two exemplary programs in K-12 Science Education.

Why should I use whiteboarding?

MacIsaac (2000) describes a number of reasons why teachers should consider using whiteboarding processes in the classroom. Whiteboarding can assist to increase conceptual understanding among students, foster alternative representations of knowledge, and help students practice step-by-step problem-solving strategies. There are many other reasons to use whiteboarding as well. Among them are improved classroom discourse, enhanced student learning, and increased student

motivation. The quality of classroom discourse is essential in helping students develop a comprehensive understanding of the process and products of science. It allows teachers to check student understanding, and to identify, confront, and resolve student misconceptions. Whiteboarding also provides students with multiple modes and multiple opportunities to learn. Preparing and presenting whiteboard drawings can be a powerful learning opportunity for students. As they prepare whiteboards, cooperative groups necessarily discuss and come to a common understanding of what they are representing, thereby strengthening the learning process. Public presentation results in further clarification, and can be a powerful motivational tool for learning. Most students find whiteboarding to be fun. Experience has shown that students really look forward to opportunities in which they can whiteboard results of discussions, brain storming sessions, or experiments. They enjoy using a variety of colors and formats to show off their work. For many, “fun” translates to “motivation.” Whiteboarding is a great way to develop an engaging, inquiry-oriented classroom atmosphere. Students who have learned using the practice of whiteboarding develop greater understanding, as has been repeatedly shown by research associated with the Modeling Method Workshop Project where Socratic dialogues are critical to the process (Hestenes, 2000).

How does a teacher set the stage for effective whiteboard use in a classroom?

Whiteboards are most effectively used with pedagogical practices such as showing solutions to homework sets or interpreting data from inquiry labs. More specifically, whiteboards are put to their most effective use when students are asked to employ them to demonstrate inductive or deductive reasoning processes, including debating conclusions from evidence. Using whiteboards this way, a teacher can obtain a detailed understanding of student comprehension and thinking processes. Asking students working in small groups to “whiteboard their results” takes advantage of a natural propensity of students to illustrate their data and findings. Even used once or twice, students quickly come to understand the value and meaning of whiteboarding.

Aren't whiteboard presentations essentially the same as student reports?

While this might at first appear to be the case, it is quite untrue. Whiteboarding involves much more than mere student reporting. Yost (2003) made a clear distinction between whiteboarding and reporting when he wrote, “Whiteboarding and reporting actually have different purposes. The report is a presentation intended to demonstrate competence, and is usually graded. Whiteboarding, on the other hand, is an active learning process in which evaluation is an ongoing process designed to probe a student’s prior understanding, and to construct strategies to bring the student to a more complete comprehension.” Reports are often

one-way expressions; whiteboard presentations include substantial back-and-forth communication between teacher and student. In whiteboarding, other students are often asked to join in on the discussion. In the end, two essential goals of whiteboarding are to make explicit student understanding and, when necessary, expose deficiencies in student explanations (Schmitt & Lattery, 2004). Whiteboarding also ensures that students provide a complete evidence-based justification for their conclusions. This is not always the case with mere reporting.

How should a teacher guide groups as they work?

Teachers should manage group composition, arranging students into groups of two or three. Each group should represent a mix of ability levels; girls typically should work as pairs. Students should be assigned roles in the group activity such as leader, recorder, and critic. Student groups should be allowed to work freely on a clearly defined goal, but they should also be monitored for appropriate social behaviors that appear not to be a natural consequence of the socialization process of school. Teachers should keep an eye on student frustration levels. While learning comes from hard work, frustration can impede the process if not kept at appropriate levels. Move among the student work groups periodically asking such questions as “Why did you choose to do that?” and “What conclusions have you reached so far?” Avoid being a source of information, and avoid making prescriptive or value statements.

How does a teacher implement oral whiteboard presentations?

Many whiteboard presentations will begin with the teacher restating the initial problem that led to the whiteboarding presentation. The first group is allowed to make an uninterrupted presentation. This presentation might be made by one or all of the students in the group. The whole group is responsible for the content of the whiteboard presentation, and each is individually accountable for the learning associated with the process. Following the initial presentation, other students and the teacher are allowed to ask questions of the group or specific individuals. As much emphasis should be placed on the process as the product of learning. Questions posed by the teacher generally should do no more than stimulate independent thinking. Such questioning should, however, clearly help students gain an understanding that is consistent with reality. If students have made a mistake in their experimental or thinking processes, critical questioning by the teacher should help students come to this realization.

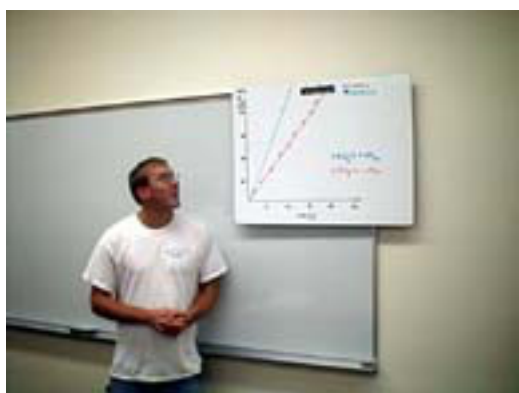
How can a teacher minimize student anxiety?

The anxiety sometimes associated with whiteboarding can have differing motivational effects on students. Students who know that they must make a whiteboard presentation in front of a class – explaining and defending evidence-based conclusions – can perceive whiteboarding as a positive motivator. However, if a

group of students – especially a young group – is not comfortable making presentations in front of class, whiteboarding can be stressful. It proves less stressful for students to present using a circular classroom arrangement. The teacher usually moves behind the students arranged in this configuration.

How should a teacher engage students in Socratic dialogue?

It should be noted that the Socratic method per sé is a discussion process whereby a facilitator promotes independent, reflective, and critical thinking. The conversation that results from using the Socratic method is known as Socratic dialogue. The general goals of a Socratic dialogue are to hold students accountable for learning, make students' conceptual understanding and thinking processes clear to the teacher and other students, help all students



understand how knowledge is constructed from experience, and build autonomy and self-confidence in students' own thinking in relation to a particular question that is undertaken. The teacher never badgers a student or criticizes answers. He or she merely asks students to explain their reasoning which, if flawed, can be quickly corrected by questions seeking clarification.

What if students are hesitant to participate in Socratic dialogues?

It is not unusual at first to encounter student resistance to Socratic dialogues. Students have often been immersed in a classroom atmosphere where they are treated as receptacles to be filled with knowledge. Socratic dialogues require students to become active pursuers of knowledge. In order for students to be more fully engaged in Socratic dialogues, teachers must address the changed classroom climate, and regularly conduct climate setting. Climate setting has two critical components – the role of the teacher and the role of the student. Students need to understand what the authentic role of the teacher is – preparing situations under which students can learn. They must understand that learning is the responsibility of students. Teachers should make clear to students that they might ask questions even if they know the answer; that they might ask “why?” two or three times in a row, and that they might ask student peers to explain and justify their conclusions

on the basis of evidence. It is never wrong to seek clarification or to ask questions that deal with extensions of the problem. Teachers must point out that questioning an idea does not mean that it is wrong. Students need to understand that their role is to speak up, confront apparent fallacies, and ask questions when they don't understand. They must see the educational process as the construction of knowledge in which ideas are based on evidence, clearly stated, and clearly evaluated. They need to know that no question is “stupid,” and that the only poor question is the question that is not asked. Students must assume responsibility for constructing meaning from facts that they have gathered as part of the learning process.

What are the indispensable features of Socratic dialogue as it relates to whiteboard presentations?

German author Dieter Krohn (Heckmann, 1981) has enunciated four essential features of Socratic dialogues. These features have been adapted here to the discussion that naturally arises about how to manage a whiteboard presentation. The four features are:

- 1. Start with the concrete and remain in contact with concrete experiences.** The initial focus in the whiteboard presentation should be on what evidence students have collected. This is consistent with the fact that sciences of all sorts – social, life, and physical – are empirical. That is, conclusions are based upon observable evidence. Whiteboarding, when used in the sciences, should give precedence to facts and the conclusions drawn from them. In the end, the final question should be, are your conclusions consistent with verified facts?
- 2. Ensure full understanding between participants.** Whiteboarding presentations are an opportunity for all students to learn, not just those making the presentation. All students should be held accountable for not only making and defending their own work and conclusions, but for analyzing the work and conclusions of others. All students in a classroom should be engaged in a whiteboard presentation as either presenters or critics.
- 3. Adhere to a subsidiary question until it is answered.** Has an answer to each question along the way been provided? While providing an answer to the original guiding question is critical, the means by which that answer was arrived at is also critical. Have errors been made in any of the processes? Is the line of reasoning correct? Has anything been overlooked? Is the logic defensible? If at any time questions such as these arise, they must be answered before moving on.
- 4. Strive for consensus.** Has the answer to both the original question and subsidiary questions been provided satisfactorily to the agreement of all who have participated in the process? If not, then it's “back to the whiteboard.”

Remember, no form of science – be it social, life, or physical – is the private domain of the individual. Science of all forms works upon the consensus model. Helping students arrive at a final consensus for all questions is useful in helping them understand the values of the research community.

Please provide an example of a Socratic dialogue.

In order to best characterize the nature of a Socratic dialogue, it will pay dividends to see negative as well as positive examples. Consider three types of questioning patterns:

1. Initiation-Response-Feedback (Mehan, 1979). This is the most prevalent form of interaction in the classroom. With this approach, the teacher asks a question, the student responds, and the teacher provides a counter-response. For example,

Teacher: What is the equation one could use to determine the acceleration, given initial velocity, final velocity, and distance?

Student: It's the difference between the final velocity squared and the initial velocity squared all divided by two times the distance.

Teacher: That's correct; v -final squared minus v -initial squared divided by $2x$.

This sort of interaction does little to stimulate student thinking and provides no insight into the process by which the student chose to provide the given response. A common form of questioning that some might confuse with effective dialoguing would be the more interactive "funneling" method.

2. Funneling (Wood, 1998). Sometimes teachers new to Socratic dialogues will assume that the following pattern of question and response is a desirable form of Socratic dialogue. This is not so. Consider the following example:

Teacher: A ball has been dropped from rest from the top of a bridge. What is the speed of the ball when it is 5 meters below the drop point?

[Long pause – no response from the students.]

Teacher: Okay, let's see. What do we know about the acceleration of the ball?

Students: It's 9.8 meters per second squared.

Teacher: Good. Now, are we looking for an average speed or an instantaneous speed?

Students: Instantaneous. We want to know the speed of the ball when it is 5 meters – no more and no less – below the point of release.

Teacher: Precisely! So, how can we find the speed at this point?

[Long pause – no response from the students.]

Teacher: Let's think about it. What equation can we use that relates instantaneous speed and distance? Anyone?

Students: Doesn't it have something to do with the v -squared equation?

Teacher: Yes, v -final squared minus v -initial squared divided by $2gx$ where g is the acceleration and x is the distance.

Students: So, solve for x ; we know that acceleration equals 9.8 meters per second squared.

Teacher: You've got it!

When students respond to the teacher's second question, the funneling process begins. The teacher funnels the students through a series of logical steps until they arrive at a predetermined conclusion. The teacher does the thinking, and the students only need to provide responses to simple questions. They fail to understand the underlying logic and complexity of the problem-solving process – even though they appear to have solved the problem.



A second possible interpretation of funneling is that the teacher is providing scaffolding for the students to learn the problem solving process. This is possible, assuming that students learn well by example. In the science classroom this is often not the case, because the thinking that under-girds the teacher's intellectual process is not clearly evident. Only if the teacher discusses the various questions and why (s)he asked them will it

become clearly evident to students what the purpose of each question was. In such a process of modeling the problem-solving process, leading questions must gradually be removed.

3. Focusing (Wood, 1998). Focusing is very closely related to the process of Socratic dialogue. It consists of the teacher carefully listening to the answers of each student, and pursuing follow-up questions that make clear student thinking. By asking leading questions, students can gently be directed to solving problems, clarifying and justifying their thinking, and learning how to problem solve during the process. Consider the following example.

Teacher: A ball has been dropped from rest from the top of a bridge. What is the speed of the ball when it is 5 meters below the drop point?

[Long pause – no response from the students.]

Teacher: How does one go about solving such a problem? What question do we need to address first?

Students: We need to relate the given variables to the unknown.

Teacher: Okay, so what are the given variables and what is the unknown?

Students: We know that the ball started at rest.

Teacher: So what does that tell us?

Students: The initial velocity was zero.

Teacher: What is the initial acceleration?

Students: Zero; it's not going anywhere to start.

Teacher: Hmm. How does one define acceleration?

Students: It's the rate of change of velocity.

Teacher: So, if the velocity isn't changing to start, how can the ball even fall?

Students: Oh, yeah, it has to have a nonzero acceleration or it won't even move.

Teacher: Precisely! So, what else do we know?

Students: We know the distance, 5 meters.

Teacher: What about the 5 meters?

Students: It's the distance that the ball has fallen when we need to find the final velocity.

Teacher: Is that the ball's final velocity? I mean, won't the ball keep on falling? Maybe the bridge is 15 meters high.

Students: We need to know the speed right at 5 meters.

Teacher: What else might we call the speed at that point?

Students: Instantaneous velocity.

Teacher: Good. Now, we have acceleration, initial velocity, and distance of fall. We are looking for instantaneous velocity. Do we need anything else?

Students: No, we should be able to solve the problem.

Teacher: And how will we do this? How are the variables related?

Students: v -final squared minus v -initial squared divided by $2gx$ where g is the acceleration and x is the distance.

Teacher: And why did you choose that equation? What's wrong with distance equals one-half $g t$ -squared?

Students: That second equation contains an unknown, t -squared. We can't use that equation as a result. We need to use an equation that contains only one unknown; everything else must be known.

Teacher: Excellent. So if we put all the known quantities into the first equation and solve for the single unknown, what do we get? Assume that the acceleration due to gravity is 10 meters per second squared.

Students: 10 meters per second, downward.

Teacher: Very good!

When the students provide answers to questions, the teacher asks for conceptual clarifications of statements or explanations of intellectual processes. The focus here is on the process of solving the problem as well as actually solving the problem itself. Process and product are equally valued. Only if the teacher focuses student attention on the process of problem solving will they come to understand how one reasons their way through such a process. Thinking is made explicit. This also helps the teacher to identify, confront, and resolve any misconceptions that students might have, and helps students learn problem solving through vicarious experiences.

This then is the general nature of the questioning process in the Socratic dialogue?

Generally, but not quite. Socratic dialogues so named will include both focusing and the four essential features noted by Dieter Krohn (Heckmann, 1981). The Socratic dialogue works exceptionally well with the whiteboarding process where students

use inductive and/or deductive processes. To see how this is done, consider the following dialogue of a group of students in front of class who are making their whiteboard presentation. They start with a brief presentation that includes reference to the notes section of Figure 1.

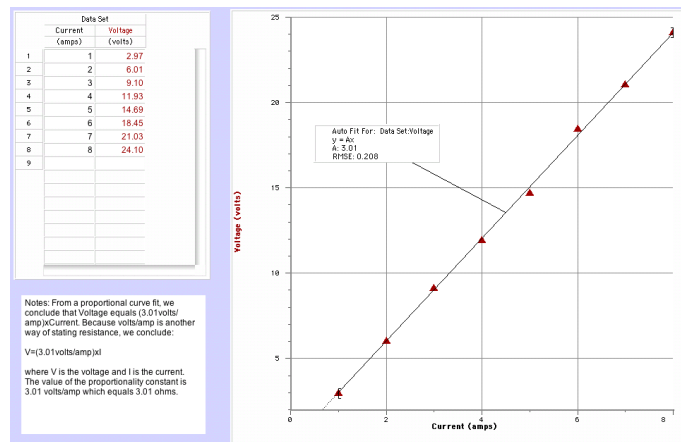


Figure 1. Content of referenced whiteboard presentation.

Teacher: Well done. Now, can you explain to the group why you chose to use a proportional relationship ($y = mx$) rather than a linear relationship ($y = mx + b$) as the basis of your best-fit line?

Students: Because if we had used a linear relationship, the y -intercept, b , would have turned out to be -0.0625 volts, and that's not possible.

Teacher: What's not possible?

Students: You can't have any voltage if the current is zero. Voltage in a circuit will produce current. No current, no voltage.

Teacher: So how does that figure into the relationship?

Students: A proportional best-fit line is most consistent with the physical situation. While a linear best-fit equation might fit the data better, the equation doesn't represent the real world. The physical interpretation is better.

Teacher: So why aren't the data consistent with reality, or are they?

Students: Everyone knows that there is uncertainty in every measurement, and that's what caused the scatter in the data points of the graph.

Teacher: What caused the uncertainty of the data?

Students: Maybe the meter isn't all that accurate, or maybe the connections were a little bit loose or oxidized or corroded. There can be a variety of reasons.

Teacher: So, what does this proportional relationship tell us?

Students: That voltage and current are proportional, and related by a constant.

Teacher: And what is that constant?

Students: 3.01 volts per amp or 3.01 ohms.

Teacher: Is that true in all circumstances, or just the one you were examining?

Students: No, just this one situation. The value of the resistance would be different in other circuits. Perhaps we should have said resistance instead of 3.01 ohms as the proportionality constant. That is, voltage is equal to current times resistance. That would be more general.

Teacher: Okay, did other teams reach the same sort of conclusions from their data?

Students: Yes, but we got different values for the slope.

Teacher: And why might that be?

Students: Because we had different resistance elements. The resistors look different from one another – they have different color bands. Our group got a value of 5.25 ohms for our constant of proportionality.

Teacher: So, would your team agree with other teams as far as general results are concerned?

Students: Yes, we basically got the same result.

Socratic dialogues might be thought of, then, as a type of focusing pattern mixed with a bit of imposed structure. Leading questions are eliminated from the Socratic dialogue because the discussion facilitator must promote independent, reflective, and critical thinking. The teacher avoids any type of funneling pattern that might supplant student thinking. Remember, the general goals of a Socratic dialogue are to hold students accountable for learning, make students' conceptual understanding and thinking processes clear to the teacher, help students understand how knowledge is constructed from experience, and build autonomy and self-confidence in students' own thinking in relation to a particular question that is undertaken in common.

Should whiteboard presentations be scored or graded?

Whiteboarding is part of the learning process. It would be unreasonable to grade the performance of a young violinist who is just learning how to play. Students just learning to play naturally make many mistakes; it's part of the learning process. The goal of whiteboarding is not student reporting; rather, it is used by teachers to assess (not evaluate) and help improve student understanding. Teachers should feel free to grade a final performance, but not the learning process. Hence, it is not usually advisable to score or grade the whiteboarding process itself.

References

- Heckmann, G. (1981). *Das sokratische gesprich: Erfahrungen in philosophischen. Hochschulseminaren*, Hannover: Schroedel.
- Herbel-Eisenmann, B.A. & Breyfogle, M.L. (2005). Questioning our patterns of questioning. *Mathematics Teaching in the Middle School*, 10(9), 484-489.
- Hestenes, D. (2000). *Findings of the Modeling Workshop Project (1994-2000)*. Available: <http://modeling.asu.edu/R&E/ModelingWorkshopFindings.pdf>
- MacIsaac, D. (2000). *Whiteboarding in the Classroom*. Available: http://physicsed.buffalostate.edu/AZTEC/BP_WB/
- Mehan, H. (1979). *Learning Lessons*. Cambridge, MA: Harvard University Press.
- National Research Council (2005). *How Students Learn: History, Mathematics, and Science in the Classroom*. Committee on *How People Learn*, A Targeted Report for Teachers, M.S. Donovan and J.D. Bransford, Editors. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.
- National Research Council (2000). *How People Learn: Brain, Mind, Experience, and School*. Committee on Developments in the Science of Learning and Committee on Learning Research and Educational Practice. J.D. Bransford, A. Brown, and R.R. Cocking (Eds.). Commission on Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.
- Schmitt, J. & Lattery, M. (2004). *Facilitating Discourse in the Physics Classroom*. NCREL Annual Conference, March 11, 2004. Available: planck.phys.uwosh.edu/lattery/_docs/art_mm_fac.pdf
- Wells, M., Hestenes, D. & Swackhamer, G. (1995). A modeling method for high school physics instruction, *American Journal of Physics*, 63(7), 606-619.
- Wood, T. (1998). Alternative patterns of communication in mathematics classes: Funneling or focusing? In *Language and Communication in the Mathematics Classroom*, edited by Heinz Steinbring, Maria G. Bartolini Bussi, and Anna Sierpiska, Reston, VA: NCTM, 167-78.
- Yost, D. (2003). *Whiteboarding: A Learning Process*. Available: http://modeling.asu.edu/modeling/Whiteboarding_DonYost03.pdf
- Yost, D., Groeshel, G., & Hutto, S. (2002) *Whiteboarding Is a Tool, a Learning Experience*. Available: http://modeling.asu.edu/listserv/wb_ALearningExper_02.pdf

JPTEO

What professional knowledge should we as physics teachers have about the use of analogies?

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In this paper an analysis is carried out concerning the professional knowledge desirable for physics teachers in the use of analogies as an educational resource. Within this objective, there is discussion of certain theoretical aspects which need to be borne in mind when analogies are used in physics classes, as well as other aspects connected with the skills or expertise which as teachers we should have in these cases. All this is accordance with the conclusions which derive from educational research

INTRODUCTION

Analogies are comparisons between concepts or phenomena which have certain similarities in common. For example, we resort to an analogy when we compare electrostatic field equations with gravitational field equations, when we explain the meaning of entropy by allusion to the disorder of a room or when we compare the behavior of an atomic nucleus to a drop of liquid. The domain which requires understanding is called the *target*, while what serves as a reference is called the *source* or the *analog*. Table 1 includes some examples of usual analogies used in physics education.

Table 1. Examples of usual analogies used in physics education.

Target	Source or analog
Refraction of light	Rolling wheels deviate as they pass from a hard floor (fast) to a soft carpet (slow)
Refraction of light	Soldiers marching from firm ground (medium 1) into mud (medium 2) and hence are slowed down.
Light waves	Water waves
Wave-particle duality	Mouse running under a carpet
Circuit of direct current	Hydraulic circuit
Electrical current	Students running through a corridor
Pulsars or neutron stars that, at turning, emit radio waves in a narrow beam.	Flashes of light from a lighthouse

There are few studies which analyze how we as teachers use analogies in our day to day practice (Duit, 1991). In spite of this, everything points to the fact that analogies are not always thought up and used in the classroom in a way in keeping with the implications of educational research (Duit, 1991; Dagher, 1995; Oliva et al., 2001). This leads to the need to reflect upon what we as teachers of physics should know about analogies as a classroom resource and what we should be able to do with them.

WHAT WE AS TEACHERS OF PHYSICS SHOULD KNOW

Below, we include an account, with comments, of some of the aspects which as teachers of physics we should know about analogies.

How to justify the use of analogies in human communication and in the teaching of Physics

An important aspect for the teacher is to know and to share the reasons why analogies are useful for communication, especially, for scientific education. Only in as far as the teacher

takes on board and shares these aims, will he or she be in a position to put analogies into practice in a critical way. In this sense, many are the reasons which have been expounded to justify the use of analogies in the teaching of sciences in general, and of Physics in particular. Below are listed some of the reasons most frequently given in the existing literature (Duit, 1991):

- i. They help to understand or clarify concepts and phenomena.
- ii. They bring a phenomenon closer to

something that is familiar to the pupil.

- iii. They change the abstract into concrete.
- iv. They help to visualize phenomena by means of images.
- v. They foster the capacity for abstraction and develop the imagination.
- vi. They can be use as a tool for motivation.

As the reader will observe, these arguments are not independent but closely interconnected. As for example, the conversion of an abstract concept into something concrete can be achieved by visualizing it through an image. In addition, this will serve to make the concept more familiar and understandable.

In this way, we can use the analogy of the “bicycle chain” to illustrate the continuous nature of the circulation of electrical current (Figure 1). We shall be visualizing the circulation of electrons in a circuit, which is complicated and abstract, by means of a succession of links which turn in unison, which is a clear, familiar image and possibly attractive to pupils.

Figure 1. Simile of the circulation of electrical current as the movement of a bicycle chain.



How to analyze the role of analogies in the construction of the physics

Various writers have pointed out the usefulness of the history of science in teaching and in teacher training (Matthews, 1988; Gil, 1991) - a better understanding of scientific theories and the nature of science, an awareness of the difficulties which pupils can experience in their learning, a way of introducing contexts and problematical situations of potential use in realizing conceptual changes for the pupils, etc. It is to be hoped, therefore, that knowledge about historical cases in which analogical thought may have influenced the development of physics, may be of use to the teacher of physics. In this sense, various articles have been published which highlight the role of analogies as used by scientists such as Kepler, Tartaglia, Galileo, Newton, Faraday, Maxwell, etc. (Gentner et al., 1997; Dreistadt, 1968; Oliva, 2004; Oliva & Acevedo, 2004).

For example, the analogy between gravity and the forces between magnets is famous historically, since it forms part of the idea of gravity which authors such as Gilbert or Kepler had (Oliva, 2004). For such authors, gravitational and magnetic forces were the same force. Such an analogy was also present in some of the arguments advanced later by Newton and by Euler, although in this case the analogy stops being a candidate for “truth” and is converted only into a metaphor.

These cases, and many others, are interesting episodes in the history of science which every teacher of Physics should know, especially if the analogies form part of the package of resources which are used in the classroom.

How to make assumptions about the procedural nature of analogical thinking

The learning by analogy is of clearly useful from the point of view of the development of scientific skills (Lawson, 1993).

In particular, in the solving of problems and in the application of ideas that have already been learned to generate further new ideas.

In addition, analogical thinking involves the application of processes such as analyzing, comparing, relating, synthesizing, differentiating, etc. All these process are key elements within the everyday repertoire of the procedures of the physics curriculum.

But, in addition, analogies can turn out useful in order to make forecasts and to develop abilities and strategies typical of modeling processes (Mason, 1994; Oliva et al., 2001).

On the other hand, analogies, as also happens with scientific models, have their merits but also their limitations. With the result that finding the useful features of an analogy and the limits in its application turns out to be good training for learning how to judge the value of the models and theories of science (Glyn et al., 1991; Heywood & Parker, 1997). In fact, the awareness and acceptance of limitations which analogies have, could be useful in order to understand the limitations and approximate nature of scientific models. With this in mind, indirectly, a less dogmatic image of science is being provided and a contribution made to the development of minds which are more open and ready to change prejudices and preexistent ideas.

How to understand the importance of the pupil’s activity and the monitoring role of the teacher

The current literature suggests that one of the principal limitations of analogies has been in the processes on which their use is based. Most often, analogies are considered as artifacts which the teacher invents and transmits to the pupils. However, if we keep in mind the constructivist premises of learning which Driver & Bell (1986) point to, we ought to assume the importance to devote more time and effort to ensuring that the pupils make sense of the analogy that has been developed (Clement, 1993). Coherent with this, I would be inclined towards imagining an analogy as something which is generated through a series of activities.

Nevertheless, it is clear that not all analogies can be considered to be educationally useful. In this sense, I think that the construction of analogies on the part of the pupils should not be an autonomous process but should be accompanied by constant feedback deriving from the teacher and the learning materials. The teacher will find it useful to evaluate if the student understands the analogy in the sense required or if, on the contrary, they are misunderstanding it or understand it in a literal sense. It is not enough for the teacher to present an analogy or invite pupils to participate actively in its construction.

How to possess a wide and varied repertoire of well contrasted analogies

For some authors, a basic requirement for an everyday and effective use of analogies is for the teacher to have available a well prepared repertoire of analogies with well tested validity (Duit, 1991; Treagust et al., 1992).

It is always better to resort to analogies which have been thought out in advance and planned during the preparation of the classes rather than to analogies improvised as you go along. Well planned analogies can be analyzed, cleaned up and selected with sufficient time. Meanwhile, analogies invented as you go along run the risk of creating undesirable effects because they are not the fruit of calm reflection and checking. With this comment I do not seek to restrict either the spontaneity or the creativity of a teacher or the pupils. Rather, on the contrary, I think that spontaneity and creativity, when faced with unforeseen situations, constitute positive features to be fostered in both senses. What does seem to me important is that the teacher is systematic and careful in the use of analogies and, of course, critical with regard to analogies improvised in the classroom.

WHAT WE AS TEACHERS OF PHYSICS SHOULD KNOW HOW TO DO WITH REGARD TO ANALOGIES

Although the teacher's knowledge about any strategy or teaching resource is a requirement for the good use of the strategy or resource, it is not a sufficient condition. Beside this knowledge, it is essential to have ready scripts and routines which permit in practice a correct application and adaptation of this knowledge. Let's see what are some of these competencies.

How to pick out the good analogies from the bad

This implies analyzing which are the analogies which should be selected in each case and what are the relationships which need to be established between the analogies and the target. With regard to the point, I have extracted from the bibliography certain guide lines and conditions which analogies should fulfill (Duit, 1991; Oliva et al., 2001):

- i) The source must be more accessible than the target, in the sense that it must refer to a situation with which the pupils find themselves more familiar.
- ii) The source must be concrete and, consequently, must be able to be represented through an image or something tangible.
- iii) The source used must be simplified as far possible. It is not a case of representing by means of the same analogy all and every feature of the object.
- iv) The use of analogies with regard to which pupils may have alternative perceptions or unfavorable attitudes should be avoided.

It would be especially useful to bear in mind all these criteria with regard to analogies improvised by the teacher in the classroom, as previously mentioned.

How to analyze the limitations of the analogies used

As has been said before, an important aspect consists of analyzing with the pupils the limitations of each analogy which is introduced into the classroom. Such an exercise involves an earlier stage of analysis and reflection on the part of the teacher which, on occasions, can turn out to be complicated.

For example, if we use the simile of the hydraulic circuit to illustrate electrical circuits, an important limitation is the interpretation of alternating current. In fact, it is best to show the pupils that in the hydraulic simile the water always flows in the same direction, while with alternating current it is not possible to speak of a net charge flow, although one can speak of transportation of energy.

Another example can be found in the comparison which is usually established between gravitational and magnetic forces, as we shall see in Figure 2. Here I add various points which should be clarified in this respect:

- i) Both phenomena correspond to forces of a different nature.
- ii) Gravitational forces always attract, magnetic forces can either attract or repel.
- iii) All bodies show gravitational forces. Nevertheless not all bodies show magnetic properties, although when these are produced, they are comparatively of greater intensity.
- iv) Although mass is a delimited and isolatable property, it is not possible to isolate pure magnetic poles.

In general, if analogies are treated in this way, clearly establishing what are the limits of validity, it will not turn out to be so important if the analogy is "good" or not in itself. We shall be developing the critical judgment of pupils and their capacity to interpret autonomously the meaning and validity of each analogy.

How to design activities for the generation, development or application of analogies

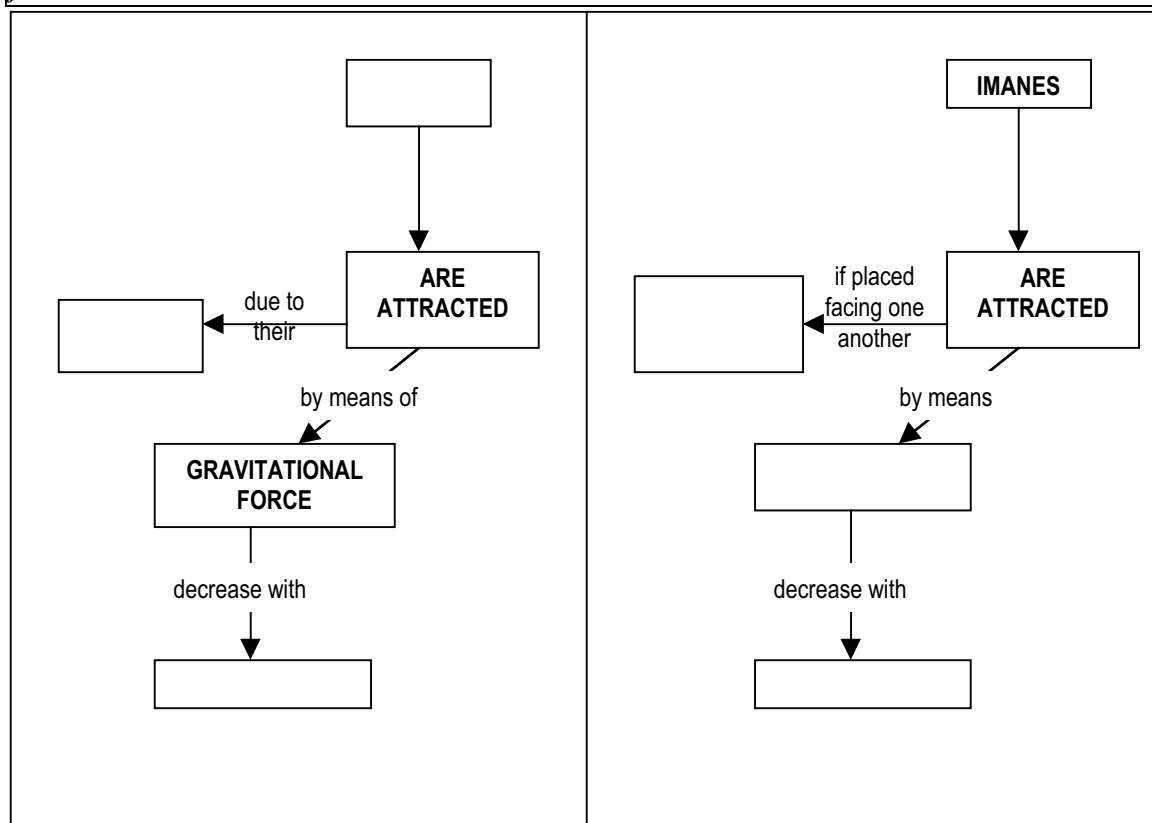
Given the importance of the active role of the pupil in the construction of any kind of knowledge, the question arises: how to transform into activities, conventional analogies such as appear in text books? Or what is the same: How to convert an analogy into a task for the pupils to solve? Although there do not exist recipes or definitive answers to this question, I will try to offer a small catalogue of possible solutions, which does not claim to be complete.

- i) Given that an analogy is presented orally or through a written text, pupils have to make explicit what they have understood from it (Figure 2).
- ii) Given that an analogy is presented orally or through a written text, pupils make forecasts about a phenomenon or a specific experiment using the analogy as a reference point. In figure 1, for example, we could ask the pupils to make use of the analogy of the chain to forecast if the strength of the current which be equal, greater or smaller before or after the light bulb.

Figure 2. Example of an activity to develop an analogy.

Activity: Read the following text carefully and use it to complete the conceptual maps which appear below:

“The Earth and the Sun are attracted to one another through gravitational force. Gravity is a phenomenon which acts at a distance, that is to say, between bodies which do not enter into contact. It may appear somewhat strange to you, but interactions at a distance are quite frequent in your everyday life. For example, if you take two magnets and place them facing another at a certain distance, you will see that the magnets are attracted or repelled, depending on whether you face like or unlike poles together. As you can test, magnets act upon one another at a certain distance, even if there is a vacuum between them. This force decreases with the distance. In the same way, two objects placed at a certain distance, exercise a gravitational force on one another due to their mass. Also in the case the force decreases as the distance increases.”



How to create sequences of activities which integrate analogical resources

Each time that an activity is proposed in the classroom, it has to be positioned inside a learning sequence. It is to be hoped, in the same way, that activities which propose the use of analogies appear inserted into a definite sequence, with a definite thread and accompanied by activities of a very different type.

One aspect which seems very important to me is to place this resource in learning sequences directed towards conceptual change.

In this sense, I suggest a combined use of

iii) Given a metaphor, pupils have to reconstruct the complete analogy. For example, we could suggest the metaphor of the structure of a metal as a crystalline net, asking the pupils to explain and develop the idea.

iv) Given an analogy provided by the teacher or the text book, pupils have to establish the limits of validity of the analogy. For example, we could ask the pupils for the limitations of the analogy presented in Figure 1.

v) An analogy is suggested but it is presented in an incomplete form. Pupils have to complete and justify the relationships which are presented. Figure 3 shows a concrete example in which an electrical circuit is compared with a hydraulic one.

vi) Design of self generated analogies (Wong, 1993). These are personal analogies which the pupils themselves invent, individually or in groups.

analogies in different moments of the teaching process and in line with different aims: such as “advance organizer” “embedded activator”, “post synthesizer”.

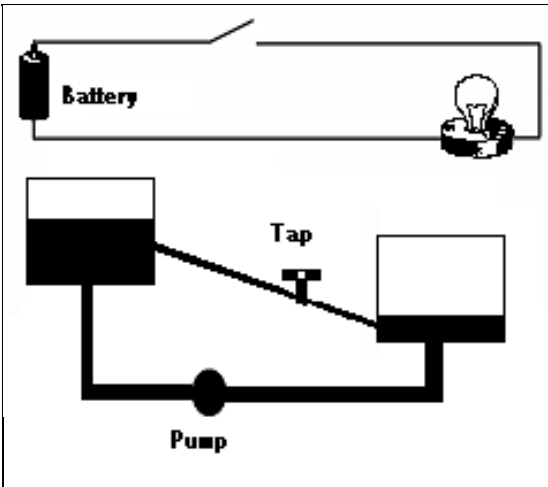
It would be especially interesting to consider the role of the analogies in the conceptual change strategies. These involve a necessary but insufficient step of conceptual conflict in the students. At some moments pupils have to generate new ideas which compete with the initial ones, this is a crucial moment in which analogies can play a vital part in allowing intelligible and plausible new ideas to be generated which can be transferred from another domain better known to the pupil.

How to monitor pupils adequately in the construction of analogies

An important feature is the search for a balance between the level of initiative allowed to the pupils in the construction of an

Figure 3. Example of an activity to construct an analogy.

Activity: To understand how an electrical circuit functions you may find it useful to compare it to a water circuit (see the figure). In the water circuit a pump is able to move the water maintaining the difference in levels between the two deposits. Starting from this idea, fill in the chart in which appear the correlations between the elements of the two systems.



ELECTRICAL CIRCUIT	WATER CIRCUIT	JUSTIFICATION
	Water	
Battery		
	Tap	
Potential difference	Difference in height	
Strength of current		
	Pipes	

analogy and the task of management which the teacher must exercise in order to monitor their understanding (Oliva et al., 2001). Such a balance constitutes a point which is both crucial and complex, a challenge for the teacher. If the tasks which are set are too open-ended, there is the risk of generating confusion and learning misconceptions. But if, on the other hand, only one possible answer is considered, namely the one that the teacher has thought out or established, then we shall restrict the pupil's initiative and creativity.

Reconciling the two positions implies the adoption of a position between the two. It would involve, at the start, accepting all the hypotheses which pupils propose, although subjecting them later to discussion and criticism in the classroom through dialogue and negotiation pupil to pupil and teacher to pupil.

How to combine and integrate the use of different analogies to illustrate the same target

The construction of an analogy is not made in a linear and unidirectional from, but through an interactive process between the target and the source. Through such a process the meaning given to an analogy is gradually modified (Oliva et al., 2001). Thanks to this, the opportunity arises to use different analogies to illustrate the same phenomenon which it is wished to teach (Duit, 1991; Heywood & Parker, 1997). A good example to illustrate this point would be a combination of the analogies in figures 1 and 3.

This multiple use of analogies should be understood in two ways. On one side, as a form of emphasizing and limiting the relevant facets of the target which it is proposed to illustrate. On the other, as a tool which encourages the evolution through a range of changing notions of the target. Each one of these would

bring different additional features to the mental model of the pupil, or at the same time modifying those features which are inadequate.

TO SUM UP

In this article I have carried out an analysis of the main parameters which typify the professional knowledge required by teachers of Physics in the use of analogies. For

this purpose the most important findings and recommendations which follow from educational research are explained in each case. To be precise, I have spent time in analyzing different features connected with knowledge and skills, including not only theoretical knowledge which the teacher should have in the subject, but also practical competencies which determine practice in the classroom.

In the background of the proposed debate, there lies a model of teaching with analogies which are been already justified and described in previous works (Oliva et al., 2001). Such a model tries to respond to the constructivist approach to the teaching/learning of science. In it the elaboration of the meaning of an analogy is understood as the result of a personal construction by the pupil who has to carry it out. Not autonomously but in close interaction with the teacher and other pupils.

Finally, I would like to point out that one of the basic elements for judging this, as for any other, model lies in the possibility of obtaining positive results about its usefulness when the analogies called into play are posed in this way. In this sense, I should indicate that although it is too soon to draw conclusive results in this respect, some of the studies that have been carried out appear to show promising data in the domain of the interpretation of physical phenomena and changes in the state of matter (Oliva et al., 2003). We hope in the future to continue bringing data towards this end, and to contribute from now on in the consolidation of proposal leading to the a more useful and constructive use of analogies in Physics classes.

REFERENCES

- Dagher, Z.R. (1995). Review of studies on the effectiveness of instructional analogies in science education. *Science Education*, 79(3), 295-312.
- Dreistadt, R. (1968). An analysis of the use of analogies and metaphors in Science. *Journal of Psychology*, 68, pp. 97-116.
- Driver, R. & Bell, B. (1986). Students' thinking and the learning of science: a constructivist view. *School Science Review*, 67, 443-456.
- Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education*, 75(6), 649-672.
- Gentner, D., Brem, S., Ferguson, R., Wolff, P., Levidow, B. B., Markman, A. B. & Forbus, K. (1997). Analogical reasoning and conceptual change: A case study of Johannes Kepler. *Journal of the Learning Sciences*, 6(1), 3-40
- Gil, D. (1991). ¿Qué hemos de saber y saber hacer los profesores de ciencias? *Enseñanza de las Ciencias*, 9(1), 69-77.
- Gilbert, R. & Reiner M. (2000). Thought experiments in science education: potential and current realization. *International Journal of Science Education*, 22(3), 265-283.
- Glyn, S.M. (1991). Explaining science concepts: A teaching with analogies model. In S.M. Glyn, R.H. Yeany and B.K. Britton (Eds.), *The psychology of learning science*. Hillsdale, N.J.: Lawrence Erlbaum.
- Heywood, D. & Parker, J. (1997). Confronting the analogy: primary teachers exploring the usefulness of analogies in the teaching and learning electricity. *International Journal of Science Education*, 19(8), 869-885.
- Lawson, D.I. & Lawson, A.E. (1993). Neural principles of memory and neural theory of analogical insight. *Journal of Research in Science Teaching*, 30(10), 1327-1348.
- Matthews, M.R. (1988). A role for History and Philosophy in science teaching. *Educational Philosophy and Theory*, 20(2), 67-81.
- Oliva, J.M^a (2004). El papel del razonamiento analógico en la construcción histórica de la noción de fuerza gravitatoria y del modelo del sistema solar (Primera parte). *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, 1(1), 30-43. Online: http://www.apac-eureka.org/revista/Volumen1/Numero_1_1/Vol_1_Num_1.htm.
- Oliva, J.M^a y Acevedo, J.A. (2004). Pensamiento analógico y movimiento de proyectiles. Perspectiva histórica e implicaciones para la enseñanza. *Revista Española de Física*, 18(4), 56-61.
- Oliva, J.M^a; Aragón, M^a.M.; Mateo, J. y Bonat, M. (2001). Una propuesta didáctica, basada en la investigación, para el uso de analogías en la enseñanza de las ciencias. *Enseñanza de las Ciencias*, 19(3), 453-470.
- Oliva, J.M^a; Aragón, M^a.M.; Bonat, M. Mateo, J. (2003). Un estudio sobre el papel de las analogías en la construcción del modelo cinético-molecular de la materia. *Enseñanza de las Ciencias*, 21(3), 429-444.
- Treagust, D.F., Duit, R., Joslin, P., & Lindauer, I. (1992). Science teachers use of analogies: Observations from classroom practice. *International Journal of Science Education*, 14(4), 413-422.
- Wong, E.D. (1993). Self-generated analogies as a tool for constructing and evaluating explanations of scientific phenomena. *Journal of Research in Science Teaching*, 30(4), 367-380.

Environmental physics: Motivation in physics teaching and learning

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Environmental topics can be used to increase student interest in the study of physics. Interdisciplinary connections can be applied. This paper presents analysis of the content of physics at basic and secondary levels in the Czech Republic. The environmental topics that are suitable for inserting into the study of physics are pointed out. Some examples and experiments are recommended for use in the process of teaching and learning physics are mentioned.

1 Introduction

Physics is often an unpopular subject in the Czech Republic. From the point of view of our students, physics is difficult - a lot of mathematics is needed for studying and understanding the subject. One way to motivate students to study physics is to solve problems that are closer to students' lives, to do simpler and nontraditional experiments, to teach with multimedia, and to use interdisciplinary connections. Environmental physics as a science integrates many disciplines and includes a number of important topics of our lives. Environmental physics can be a powerful way to show students the significance of modern science.

We are living in a world of information technologies and techniques. Technology and science are not the same, but they interact. How to manage the growth of population, for instance, is a question concerning the environment, society, culture, economics, and science. Environmental physicists not only study the environment, but also give us basic experimental and theoretical methods for studying environmental problems.

Basic problems studied by environmental physicists can be pointed out:

- energy (based on thermodynamics – heat transfer, heat engine, renewable energy sources, reducing pollution),
- noise (acoustics),
- spectroscopy,
- transport of pollutants (transport physics, Navier-Stokes equation),
- greenhouse effect, weather and climate, physics of the atmosphere.

These topics can be presented on different levels from basic school to university level physics. Problems involving environmental themes and physics can be an important aid for doing interdisciplinary projects. These projects lead to student activities in the classroom as well as at home.

The analysis of school physics textbooks for basic and secondary schools in the Czech Republic was conducted. Not all the topics have the same relevance for inserting environmental elements into the teaching and learning of physics. Our experience

of teaching environmental physics will be summarized in this article.

2 Educational program in the Czech Republic

Since 2004 a new framework of curriculum, the so-called General Educational Program, has been tested at basic schools. The main idea is to boost interdisciplinary connections. The subjects with similar orientations (science, humanities) were clustered into groups. Physics together with biology, chemistry and geography are connected into the topic called “Humans and Nature”. This educational program allows freedom for the teacher in organizing the teaching process so that more interdisciplinary topics and problems closer to the students lives can be inserted into the physics curriculum. This approach makes it easy to include more environmental problems in physics teaching and learning.

In the Czech Republic the subject “Physics” is taught beginning with the 6th grade (11-year-old children). Sixth grade physics is only an conceptual course as students are not prepared with sufficient mathematics to study physical principles and laws. The only mathematical equation used is the calculation of density. For environmental physics the topic “Properties of Matter” can be used. Here the importance of water to our lives on Earth can be shown. Water is a substance studied not only in physics but also in biology, chemistry and in geography. A huge number of problems can follow from the discussion about water such as pollution, consumption, water cycle, flooding, sea and water properties, etc.

In the 7th grade we chose the topic “Mechanical Properties of Liquids and Gases”. Environmental elements can be pointed out while discussing Archimedes' principle (aquatic organism, the function of heart, effects of changes in atmospheric pressure).

The 8th grade physics curriculum contains topics concerning work, energy and heat. These are the most important problems studied by environmental physics. A number of effects can be taught in physics – heat transfer, power, energy sources, and the greenhouse effect. Other parts of 8th grade physics are acoustics and weather. These are topics that can include a lot of motivating problems – malignancy of noise (headphones, discotheque, mobile telephone) and climate – weather and climate, global warming.

In the content of 9th grade physics we can find electromagnetic effects, alternating current, current conduction in fluids and gases, electromagnetic radiation, nuclear energy, and Earth and Universe. The basic content can be enlarged – electricity generation, lightning, gas tube, UV radiation, UHF radiation, RTG radiation, advantages and disadvantages of nuclear power stations, and nuclear weapons. The topic “Our Planet in the Universe” allows us to discuss the assumptions of the origin of life (Earth – Sun distance, temperature, atmosphere, importance of the Sun, etc.).

Secondary school physics allows teachers to discuss more topics concerning the problems of environmental physics. Students have a better mathematical basis; therefore, many more physical principles and laws are taught. Below is an overview of basic contents where environmental subject-matter can be inserted (according to the educational program for the age from 15 to 18 years):

- Mechanics of the point of mass and rigid body – movement of organism (inertia, friction, action and reaction – octopus).
- Gravitation field – Kepler’s laws – seasons, influence on the organism.
- Mechanics of fluids and gases – energy of streaming water, wind erosion.
- Molecular physics – diffusion, osmosis, thermodynamic laws – work, energy, heat, circle diagram, efficiency of heat engines.
- Mechanical vibration and waves – energy of sea waves, in acoustics the problem of noise, ultrasound.
- Electrical current – technical progress, economy of technical devices, electric pulse and heat motion.
- Magnetic field – our Earth is a huge magnet (solar wind protection).
- Alternating current and electronics – influence of technics on live and environment.
- Optics – interdisciplinary relations to biology, photosynthesis, ozone hole, greenhouse effect, black body radiation.

3 Environmental physics teaching - examples

Environmental elements in the physics lesson can be included in solving problems, and doing projects or experiments. We can find out about the greenhouse effect, global warming and climate change using information in literature, on the Internet and through journals. Environmental physics teaching can be realized for example using the topic of the greenhouse effect. At secondary school level we can solve the following examples:

1. The emission spectrum of the Sun has its peak wavelength at $\lambda = 507$ nm. Find the surface temperature of the Sun. (*Solution:* Wien’s law, $T = 5720\text{K}$).

2. The average surface temperature of the Moon is about -18 °C. Assume that the Moon’s radiation is like that of a black body, solve the wavelength of the radiation with maximum intensity. Find the range of the electromagnetic spectrum for this radiation. The Earth and the Moon are similar bodies, why is the average surface temperature of the Earth 15 °C and not -18 °C? (*Solution:* Wien’s law, $\lambda = 11.4$ mm, infrared radiation, greenhouse effect).
3. What is the reason of different surface temperatures of Venus (500 °C), Earth (15 °C), Mars (-47 °C). (*Solution:* Different composition of the atmosphere, distance from the Sun).
4. Compare the process in a glasshouse and the greenhouse effect.
5. Describe the effect of global warming.
6. What are greenhouse gases, what is their function?
7. What do you know about ozone?
8. Give reasons why it is important to plant trees, to recycle waste, to use disposable things, to walk or ride a bike instead of going by car, to decrease energy release (insulation, switching off the lights).
9. Brown coal contains 70% carbon and 30% spoils. One thermal power station burns 200 tons of coal in a hour. How much CO_2 is put out? (*Solution:* $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$. In one hour the station burns 140 tons of carbon and uses 373 ton of O_2 . The one hour production of CO_2 is 510 tons.)
10. One car uses about 7 liters of gasoline – C_8H_{18} per 100 km. The gasoline density is 0.7 g/cm³. How much CO_2 is released, when the car is driven 100 km? (*Solution:* $\text{C}_8\text{H}_{18} \rightarrow 16 \text{CO}_2 + 18 \text{H}_2\text{O}$. The car needs 4.9 kg gasoline for 100 km, 17 kg O_2 and 4.1 kg carbon. The amount of CO_2 is about 15 kg.)
11. One tree consumes about 16 kg carbon a year. How many trees do we need for consuming all CO_2 that is produced by one car driven 10,000 km per year? (*Solution:* 94 trees).
12. One km² of forest produces 870 tons of O_2 per year. The average area of forest accrue for one thermal power station in Northern Bohemia is about 250 km². How long does it take to use up CO_2 produced by 1 station per day? (*Solution:* photosynthesis $\text{H}_2\text{O} + 6 \text{CO}_2 + \text{sunshine} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2$, 15 days).

Analyzing experimental data

Using various resources, students are able to find data about CO_2 concentration during the last 250 years, and about average Earth temperature. The data can be put down in a table and examined. For example, Table 1 shows the data about CO_2 emission in some EU countries in 2001 (EEA 2003).

4 Experiments

The teaching and learning environmental physics deals not only with introduction to subject matter, but with experiments also. The analogy between the glasshouse and the greenhouse effect can be used. Students have in many cases their own glasshouses at home in the garden, or they have visited a botanical

Table 1: CO₂ Emissions

Country	Emission in 2001 (in kg/inhabitant)
Czech Republic	12,450
Belgium	12,392
Luxembourg	12,314
Estonia	12,307
Finland	12,035
Ireland	11,577
Netherlands	10,901
Germany	10,443
Greece	10,187
Denmark	9,905
Great Britain	9,141
Poland	8,529
Austria	8,150
Italy	8,032
Slovenia	7,904
Spain	7,770
Slovakia	7,678
France	6,825
Portugal	6,130
Sweden	6,298
Hungary	5,932
Lithuania	4,508
Latvia	2,887

explain the effect at basic and secondary schools it is important to do experiments. Some very simple experiments are provided later in this article, are based on the principles of black body radiation. They can be provided at physics lessons in various types of schools.

4.1 Colored vessels

Concept: Body warming and cooling depends on the color of the surface.

Motivation: Why are polar bears white? Why is the temperature during summer inside a dark colored car higher than in a light one?

Material: 4 cans, 4 paints (white, black, red, green), hot water, 4 thermometers, stopwatch

Method: At first the cans are painted with different colors. The first experiment is to realize the effect of color on a summer day. The black can and the white one are placed on the window. A few minutes later we ask one student to touch the cans – which one is warmer? In the second step an equal amount of hot water is put into the 4 cans. Thermometers are put into the water in each can. Students read the temperature, and the data are entered in a table. The interval for reading the temperature is 2 minutes. The registered data are analyzed, and a graph is constructed. The reason is that the cooling depends on the color.

Discussion: Find more examples, where we can use this effect?

glasshouse. Very simple experiments demonstrate the importance of solar radiation and advantages of using the energy from the Sun. Simple experiments are the first step for understanding the greenhouse effect.

Although the greenhouse effect is taught in the 8th grade of the basic school, the fundamentals of the process often can be understood only later. To

4.2 Insulation

Concept: The aim is to show how we can easily stop energy dissipation with insulation.

Motivation: Insulation is important not only from the economic point of view. We can find examples in nature (feathers, fur). The principle is the same – air is a poor heat conductor. When convection is eliminated, air can be a very good insulating material.

Material: 2 glasses, 2 thermometers, hot water, watch

Method: Fill two glasses with hot water and read the temperature. Record the values. Insert one glass in a box and fill the free space with newspaper. Read the temperature in both glasses at 5 minute intervals (the second one is standing on the table in the same way as in the beginning). Compare the results and interpret them after 30 minutes.

4.3 Model of a sunray heater

Concept: Heating water in our households is very expensive. We can lower the domestic consumption of warm water or use the energy of solar radiation.

Motivation: A very primitive sunray heater consists of a solar collector, tubes, insulated container, and water. The collector is placed on the roof, has a black color and is covered with glass. The glass has the same function as in the glasshouse – hold back the heat. The water in the tubes is heated and collected in the vessel.

Material: paper box, tinfoil, clear plastic sheet, glass, black color, thermometer

Method: A paper box is cut in half – so that a trilateral prism is created. Now we clip up one of the base. The inside walls of the box are covered with tinfoil. The missing walls are replaced with the clear elastic sheet. The glass will be colored black and filled with cold water. A thermometer will be put in the water. The glass will be stick in the box. Solar radiation passes through the plastic sheet. Students record the temperature.

Discussion: Other materials and other colors can be used.

4.4 The Sun as an energy source

Concept: Not all energy from the sun can be used efficiently. Solar collectors are only one example how to collect energy from the sun, but there are a lot of factors that influence how much energy can be collected – geographical location, season, weather, etc.

Motivation: This experiment allows students to measure the amount of solar radiation that can be used for heating water.

Material:

3 test tubes, thermometer, graduated cylinder, magnifying glass, watches, slide gauge, black paint

Method: One of the test tubes is painted black, the second one is only half painted, and the third one is unpainted. Now we determine the area of the inflowing light - the surface of the magnifying glass. The diameter d must be measured, the surface

is found according to $P = \pi d^2/4$. Ten milliliters of water is placed in one of the tubes. Students measure the temperature t_1 of the water. The tube is placed in the sunrays, that are concentrated into one point by the magnifying glass. After 5 minutes we read the temperature again. It is at temperature t_2 . We replace the tube and repeat the measurement with the partially colored test tube and then with the pure one. We find the available heat $Q = mc(t_2 - t_1)$, where $c = 4180 \text{ J/kg}^\circ\text{C}$ is the specific heat capacity of water. The mass m we obtain from the density and volume. The available heat on 1 m^2 in one second is $A = Q/tP$, where t is the total time of measurement.

4.5 Greenhouse effect in a jar

Concept: This experiment helps the student to understand the greenhouse effect.

Motivation: Other activities can be included – reading experimental data, drawing conclusion, discussion, alignment model – reality.

Material: 2 thermometers, 1 jar or pure glass, watches, desk lamp

Method: Students are divided into groups. Each group has two thermometers. They are placed on dark paper some centimeters under the desk lamp. About after three minutes each group reads the temperature on the thermometers. Now one of the two thermometers is covered with the jar. The students read the temperature at both thermometers. After about 10 minutes we finish the experiment and discuss the results. Later we can cover the thermometers with a jar filled with CO_2 and compare it with the temperature changes in the jar filled only with air.

5 Conclusion

Experiences with the application of environmental problems in physics teaching and learning have been positive. The students are motivated to do a lot of out-of-school activities in addition to the compulsory physics lessons. They take part in various science projects with an environmental and ecological context. For example, in our region (Moravia) 45 schools took part in ecological projects (Clean up the school, Ozone, Acid rain, Energy – blow the lid off energy savings, Water, Recycling). These projects are presented at Ecology Days at school exhibitions. Very popular are student presentations in connection with important events with an environmental context – 16th September (International day of ozone protection), 14th November (The day without cars), 16th November (Non-smokers day), 21st April (The day against noise), 22nd April (The day of the Earth), and 5th June (World's day of environment). The enthusiasm of students for these events is enormous because they are motivated in various science projects with problems that are close to their everyday life. So the application of problems that are studied in physics and other subjects in practice can be seen.

This paper shows only a briefly overview of environmental activities in physics lessons that are recommended to our teachers. The activities are presented here from the point of view of the Czech educational program. Similar topics and problems are

taught in other countries too. Our life is limited from some physical properties that cannot be changed – such as the position of the Earth in the Solar system, the distance from the Sun, and the size of the Earth and its mass. The influence of the human activities leads to changes in the atmosphere. The greenhouse gases evoke climate changes. The Czech Republic is a country that produces a lot of greenhouse gases, especially CO_2 . The Czech electricity producer – CEZ – exports 1/3 of its yearly output – 19 TWh of electricity. This entails the burning of 15 million tons of coal. This export will be stopped during the next ten years. Our government proposes to reduce the amount of yearly CO_2 production to 8.5 tons per inhabitant. Industrial plants are not the only producer of CO_2 ; emission from traffic accounts for 8.27% of the total amount of CO_2 . That's why it is necessary to educate children and even their parents about environmental problems. By educating them, we can enlist their help in saving the environment and nature. Teachers have the opportunity to cooperate with “green” organizations. In the Czech Republic the group “Friends of the Earth” is very important. Various ecology projects are solved in schools where interdisciplinary connections between physics, biology and chemistry can be used.

References

- Boeker, E., van Grondelle, R. (1999). *Environmental Physics, second edition*. New York: John Wiley, England.
- Botkin, D.B., Keller, E.A. (2000). *Environmental science, 3rd edition*. John Wiley, New York.
- Holubová, R. (2003). What can we hear. *Mathematics-physics-informatics, 13(8)*, 468-473.
- Holubová, R. (2003). Application of physics by the study of material properties. *Mathematics-physics-informatics, 13(3)*, 155 - 162 .
- International Energy Agency (2003). *Key world energy statistics 2003*. Paris.
- Kolářová, R., Bohunek, J. (1998). *Fyzika 6*. Prometheus, Praha.
- Kolářová, R., Bohunek, J. (1998). *Fyzika 7*. Prometheus, Praha.
- Kolářová, R., Bohunek, J. (1999). *Fyzika 8*. Prometheus, Praha.
- Kolářová, R., Bohunek, J. (2000). *Fyzika 9*. Prometheus, Praha.
- Svoboda, E. et al. (1991). *Prehled stredoakolské fyziky*. SPN, Praha.

Some didactic and epistemological considerations for the introduction of basic knowledge on physics of semiconductors in secondary school

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In this article, we expose the educational need to provide to the pupils a basic and integral formation in Electronics, since the basic levels of School. Like this, the pupils will be able to face up with success the challenges of a scientific and technologically advanced society. Likewise, we considered that a suitable Electronics understanding requires of basic knowledge on physics of semiconductors. For it, we describe the scientific dimension of the Electronics (Physics of Semiconductors) and we give epistemological and didactic reasons that defend its integration in the Sciences Curriculum of Secondary Education [14-16 years old].

1. INTRODUCTION

We are immersed in a society where Electronics and its products occupy one of the most important places today; its presence is notorious nowadays in our job, at home, in education, in the culture and even in our leisure (Méndez 2000). We can affirm, even, that Electronics development has been the origin of our concept of Modern Society (Rosado 1995). This is the main reason because Electronics is considered a very important element today for the basic formation of people (Jolly 1998).

For some years, it has been demanded an appropriate place for Electronics in school curricula from the lowest levels (Rosado 1995, 2000). The idea is, next to “scientific literacy” (Acevedo 2004), the introduction of a new term “technological literacy” (Buch 2003), and Electronics as one of its essential pillars. This literacy, that we could call it “electronic literacy”, must qualify everybody, men and women, to understand not only a world full of electronic products but to analyze it critically and take decisions and also to participate in innovations for giving answers to needs and demands of our societies.

2. ELECTRONICS AS AN ELEMENT OF PHYSICS CURRICULUM

Today, Electronics is introduced in the last years of Secondary [14-16 years old] in the Curriculum of Technology in Spain; its didactic treatment is based on an approximation in blocks of electronic systems (Geddes, 1984). Nevertheless, besides its technological component, Electronics is an experimental science; not in vain, the advances in Physics of Solid State—especially in Semiconductor Solids— have been the main cause of the eminent development of this field (Méndez, 2000).

It has been the cause of a considerable reduction in the dimensions of electronic sets, and at the same time they have increased their utilities and contributions. So a basic scientific and adequate formation of young people in Electronics requires also a study of its scientific component: the basic aspects about physical behavior and structure of semiconductor materials (Robles et al., 1993).

From an epistemological point of view, we can say, therefore, that the own study of Electronics begins with semiconductors (Alcalde, 1999). Besides, the attention to the Electronics, in the environment of scientific education, is an indispensable requirement to create in students a more correct image of the present development (Valdès et al., 2002), and, particularly, a vision of the unity that Physics and Electronics constitute, that has given rise to the Physical Electronics. Besides, from a didactic point of view, this integral vision of Electronics has a direct repercussion in the quality of its teaching/learning.

This situation has been resolved in advanced countries of our environment, as France (Desmarais, 1986; Gaude 1989; Polev, 1989), United Kingdom (Summers, 1985; Ellse, 1987; Boyes, 1990) and Finland (Lavonen & Meisalo, 2000, 2003; Lavonen, Meisalo & Lattu 2002), in which, since more two decades ago, Electronics is a one more part in the curriculum of Sciences [Physics] in the basic levels of teaching.

3. PRESENT SITUATION OF ELECTRONICS IN PHYSICS CURRICULUM IN SECONDARY EDUCATION

We have talked before about the reasons that consider Electronics as an essential aspect in the basic scientific education today. Although, this question is evident, in our country it has not yet been paid attention to it. If we do a detailed analysis

about the curriculum of Physics and Chemistry in Secondary Education, and about the books that are being used in our classroom, we can find that they do not contemplate the study of basic contents of Electronics.

In the same way, if we review the published works in the last years in prestigious magazines of Teaching of Sciences, we observe the scarce presence of Electronics in the basic scientific education. This is a fact that can be generalized to other technological aspects that should be present in the curricula of Sciences (Valdès et al., 2002). And it is that, as Bybee (2000) indicates a lot of professors and investigators in Teaching of Sciences limit to identify technological education with the use of computers in the classrooms and school laboratories.

With all this, we can ask ourselves: why that lack of attention to Electronics in the scientific education in the basic levels of teaching? Thinking about this question is a special matter and very important too, and even surprising that, in our times, a very little interest in Electronics exists, and in Technology in general, from Sciences curricula designers and investigators in Teaching of Sciences. Although the answer to this question is complex, because there are a lot of causes, we are going to enumerate some of them that we think are essential.

3.1 Reasons of insufficient attention to the Physical Electronics in the Physics Curriculum in Obligatory Secondary Education

There are different factors that do today, that the attention to the technological dimension, and particularly to electronics, is insufficient in the scientific education in the basic levels of teaching in our country. One of these factors is the rhythm with which curriculum designs of sciences are brought up to date, this actualization is not in harmony with the scientific and technological advances in our world, as they keep an academic stagnation of several decades (Rosado, 1995).

In fact, only some decades ago, the implication of the Technology in the global situation of the world, in the scientific activity and in the life of the common people, was a lot of less notable than today. We can think, for example, about the meaning for our society, science and culture in general, have had the technological advances obtained during the last two decades in the field of Computer Science and Communications (Castellano, 2000). Consequently, we find that curricula of Sciences are found anchored in the time, and they have not yet assumed the change and the need to guarantee contents that, nowadays, are an intrinsic part of the society in which we live; contents which are related to Electronics, should form a part of the basic and integral formation of the present teenagers.

Another factor is related to the fact that there is not much time ago, Sciences Teaching has not been established like a specific and important field of knowledge and investigation (Valdès et al., 2002). Inevitably, this process has been preceded of a period of fractionate and incomplete process, in which all the fields of Sciences have not been attended (Gil, Carrascosa y Martínez, 2001).

A consequence of this has been the lack of attention to Technology, and especially to Electronics, in the environment of the scientific education. Though, the incorrect epistemological conceptions — as the fact of not consider the scientific component in the study of Electronics — constitute one of the main obstacles for the renewal of the scientific education (Fernández et al., 2003).

Finally, we cannot forget another factor that, in a direct form, is influencing in the inattention to Electronics contents in the scientific education: the lack of preparation of curricula designers and sciences professors in aspects of Electronics and Physical Electronics (Rosado, 1995, 2000); and, as a result of it, the resistance to change and to innovation in present textbooks.

4. PHYSICS OF SEMICONDUCTORS AS FRAMEWORK OF PHYSICS-ELECTRONICS INTERRELATION IN THE BASIC SCIENTIFIC EDUCATION

The use of semiconductor materials, in the production of elements and electronic devices, has supposed one of the greater advances inside the world of Electronics in general (Rosado, 1995), and of Computer Science in particular (Robles et al. 1993). This fact was recognized, in 2000, with the Nobel Prize of Physics, granted to Jack Kilby [1959], by the invention of the integrated circuit, and to Zhores Alferov and Herbert Kroemer [1957-1963] by the development of the heterostructures of semiconductors that are used in communications.

Consequently, the teaching of Physics of Semiconductors is presented like the framework of suitable contents for the integration of Physical Electronics in the curriculum of Sciences in Secondary School. Its inclusion should provide the students a complete and a deeper vision of Electronics, as well as a capacity of critical analysis and of comprehension of the aspects related to this discipline, that form part of its routine environment (Rosado and Garcia Carmona, 2002, 2004). But, besides justifying why teaching Physics of Semiconductors in Secondary School, it is convenient to be asked: *How to teach it?* and *what to teach?* of Physics of Semiconductors in this level.

4.1 How to teach Physics of Semiconductors?

The teaching of Physics of Semiconductors should not be conceived as an "applied science" oriented, exclusively, to explain the operation of certain electronic devices by specific principles or scientific concepts. We must have present that the electronic devices, in its creation and development, continue diverse and complicated roads; so, they constitute complex systems formed by a great diversity of elements (Valdès et al., 2002).

In this way, some of these elements are created thanks to the contributions of the Physics of Semiconductors, with the application of concepts and scientific theories of the behavior of the semiconductor solids; but other develop by experimentation, without keep in mind theories or scientific principles. Therefore, the role of the teaching of the Physics of Semiconductors should not be that of examining the operation of such devices, but much better illustrating the principles and scientific concepts that are

declared in the semiconductor materials (Rosado and Garcia Carmona, 2002), present in the electronic devices.

When we think about how to teach Physics of Semiconductors in the basic levels of teaching, it is precise to keep in mind that students already possess several ideas or conceptions of some topics related, direct or indirectly, with it; though, the comprehension and explanations that give to these phenomena do not correspond, in numerous cases, with the scientific theories. According to the investigations in psychology of the thought, it is owed, among others causes, to that the scientific reasoning does not seem to be the natural or conventional form, with which people confront habitually, their problems (Pozo and Gómez Crespo, 1998), and this supposes an obstacle to learn Physics.

Consequently, the main purpose of the teaching of Physics of Semiconductors should be becoming experienced pupils with a mental construct, coherent with the scientific method, which permits them to reach a significant learning of the concepts. In this sense, the process of teaching/learning in Physics of Semiconductors will be effective in the measure in which causes the conceptual change, by which the pupils incorporate to their cognitive structure the scientific concepts of this discipline. The constructivism arises in that way (Marín, 2003) as the suitable educational paradigm for the learning of the Physics of Semiconductors in Secondary School.

4.3 What to teach of Physics of Semiconductors?

The Physics of Semiconductors is a discipline that is composed of laws and principles related to the Physics of the Solid State, Quantum Mechanics, Statistical Mechanics, Electromagnetism, etc. Likewise, it is a discipline that evolves and develops with the rhythm that the different fields of Physics with which are related to. Therefore, it is not easy to decide which contains should be taught in a first introduction to this thematic in the level of Secondary School.

One of the indispensable questions, at the moment of carrying out a selection of contents of Physics of Semiconductors for Secondary School, will be to analyze with detail the curriculum of Sciences in which it is going to be integrated. In fact, we should have presented the framework of contents in which we can connect some basic notions of Physics of Semiconductors, in a rational and progressive way. In the curriculum of Sciences (Physics and Chemistry) of Secondary School, contents that have a direct relation with those of Physics of Semiconductors are formed by the thematic blocks referred to Electricity and to the Unit and Diversity of the Matter.

Besides having present the curriculum, it will be necessary to pay special attention to those contents that, by its characteristics and degree of difficulty, are the most suitable ones, according to the cognitive and psychological capacities of the pupils of the educational level to which we refer it (Rosado and Garcia Carmona, 2002).

Finally, the contents of Physics of Semiconductors selected, instead of being the last purpose of the process of learning, should

be constituted as the 'medium' by which students build their knowledge and they acquire a vision of Electronics from a scientific environment. Consequently, the selection of the Semiconductors Physics contents, for the level of obligatory Secondary [12-16 years], will be the adequate one in the measure that contribute to the following purposes:

- a) They must be useful and practical, so they help students to resolve routine situations of their more nearby environment in relation to Electronics.
- b) They must be intelligible for students, and with its continuous use favors the analytic critical reflexive and creative spirit, in relation to the world that surrounds to Electronics.
- c) They must be presented in a way that its teaching is narrowly connected with the immediate reality of the student, leaving from their own interests. Therefore, it should be introduced an order and to be established the bonds among the social emotional and physical facts of their environment (Rosado and Garcia Carmona, 2004).

5. CONCLUSIONS

In sight of what we have exposed, we obtain the following conclusions:

1. The important scientific-technological advance of the last years, in the field of Electronics, presents the need to provide to teenagers an adequate and basic formation in this thematic one from the basic levels of teaching. The study of Electronics will permit teenagers to acquire a capacity of critical analysis and of comprehension of the scientific-technological aspects, related to Electronics that form part of their routine environment.
2. There are epistemological reasons and sufficient teachings that support the integration of Basic Electronics contents in the curriculum of Sciences [Physics and Chemistry] in Secondary School [12-16 years old]. Its inclusion in the scientific education should provide students a complete and a deeper vision of Electronics, at the same time that should serve like a complement and a support in the study of the contents of this matter included in the Area of Technology.
3. We propose the teaching of Semiconductors Physics notions as a way of approximation to the Physical Electronics in the basic scientific education. Not in vain, the large advances in this field of Physics have been which have favored the eminent development of Electronics to our days.
4. The role of teaching of the Physics of Semiconductors, in Secondary School, should be that of illustrating some of the principles and scientific concepts that are declared in the semiconductor materials present in the electronic devices, and not that of examining the operation of such devices.
5. Finally, the integration and consolidation of basic contents of Physics of Semiconductors, in the curriculum of Sciences [Physics and Chemistry] in Secondary School, requires of the start of didactic investigations directed to:
 - a) Design, application and evaluation of didactic materials of Physics of Semiconductors in the classroom, according to the present tendencies in Investigation in Sciences Teaching.

b) Analysis of students' comprehension and difficulties of learning on Semiconductors Physics notions, integrated in the curriculum of Sciences [Physics and Chemistry] in Secondary School.

c) Study of Physics and Chemistry professors' ideas, preconceptions and perspectives, in relation to Physics of Semiconductors and its teaching in the obligatory level in Secondary Education. All with the idea to promote programs of teachers' training, that they do feasible its teaching/learning in this educational level.

6. REFERENCES

- ACEVEDO, J. A. (2004). Reflexiones sobre las finalidades de la enseñanza de las Ciencias: educación científica para la ciudadanía. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, 1(1), pp. 3-16.
- ALCALDE, P. (1999). *Principios Fundamentales de Electrónica* (3ª ed.). Madrid: Paraninfo.
- BYBEE, R. (2000). Achieving technological literacy: a national imperative. *The Technology Teacher*, septiembre de 2000, pp. 23-28.
- BUCH, T. (2003). CTS desde la perspectiva de la educación tecnológica. *Revista Ibero-Americana de Educação*, 32, pp. 147-163.
- DESMARAIS, D. (1986). Semiconducteurs et dioses. *Bulletin de L'Union des Physiciens*, 683, pp. 735-750.
- FERNÁNDEZ, I. et al. (2003). El olvido de la Tecnología como refuerzo de las visiones deformadas de la Ciencia. *Revista Electrónica de Enseñanza de las Ciencias*, 2 (3). Available: www.saum.uvigo.es/reec/volumenes/volumen2/Numero3/Art8.pdf.
- GIL, D., CARRASCOSA, J. y MARTÍNEZ, F. (2001). Una disciplina emergente y un campo específico de investigación. En Perales y Cañal (Eds.), *Didáctica de las Ciencias Experimentales*. Alcoy: Marfil.
- JOLLY, W. P. (1998). *Electrónica* (6ª ed.). Madrid: Pirámide.
- LAVONEN, J., y MEISALO, V. (2000). Science teachers and technology teachers developing electronics and electricity courses together. *International Journal of Science Education*, 22(4), pp. 435-46.
- LAVONEN, J., MEISALO, V., y LATTU, M. (2002). Collaborative Problem Solving in a Control Technology Learning Environment, a Pilot Study. *International Journal of Technology and Design Education*, 12, pp. 139-160.
- LAVONEN, J. y MEISALO, V. (2003). Current Research Activities in the LUONTI Project. *Media Education Publication*, 8, pp. 307-338.
- MAIZTEGUI, A. et al. (2002). Papel de la Tecnología en la educación científica: una dimensión olvidada. *Revista Iberoamericana de Educación*, 28, pp. 129-155.
- MÉNDEZ, E. (2000). La era de la Información, al fin reconocida. Premio Nobel de Física 2000. *Revista Española de Física*, 14 (4), pp. 64-66.
- POZO, J. I. y GÓMEZ CRESPO, M. A. (1998). *Aprender y enseñar Ciencia*. Madrid: Morata.
- ROBLES, M. et al (1993). *Física Básica de Semiconductores*. Madrid: Paraninfo.
- ROSADO, L. (1995). *Microelectrónica para Profesores de Ciencias y Tecnología*. Madrid: UNED.
- ROSADO, L. (2000). *Guía Didáctica. Microelectrónica y Microordenadores para Profesores de Ciencias*. Madrid: UNED.
- ROSADO, L. y GARCÍA CARMONA, A. (2002). Programa-guía sobre Física de Semiconductores en la Electrónica de la Educación Secundaria Obligatoria. En Rosado, L. y Cols. (Eds.), *Didáctica de la Física y sus Nuevas Tendencias (Manual de 2002)*, pp. 775-846. Madrid: UNED.
- ROSADO, L. y GARCÍA CARMONA, A. (2004). El entorno del alumno como marco de referencia en la enseñanza de la Física. En Rosado, L. y Cols. (Eds.), *Didáctica de la Física y sus Nuevas Tendencias (Manual de 2004)*. Madrid: UNED.
- SETZER, V. W. (2000). La misión de la Tecnología. *Contexto Educativo*, 4. Available: www.contexto-educativo.com.ar/2000/4/nota-8.htm.
- SUMMER, M. K. (1985). Electronics 11-18: a coordinated programme for the School Physics Curriculum. *Physics Education*, 20 (2), pp. 55-61.
- VALDÉS, R. et al (2002). Implicaciones de las relaciones Ciencia-Tecnología en la educación científica. *Revista Iberoamericana de Educación*, 28, pp. 101-128.

Reflections from pre-service science teachers on the status of Physics 12 in British Columbia

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A study of preservice science teachers' views about their decisions to take Physics 12 while at high school indicated that mathematical knowledge, the physics teacher, the nature of physics activities, prior experience and knowledge in previous foundation physics courses, and gender and role model were key to their decision-making process. The need for the study arose out of a concern expressed in the literature and the author's experience of studying teachers, that many of them teach the way they were taught. Moreover, they have considerable difficulties freeing themselves from the ineffective aspects of this modeling. It is also important in gaining insights into pre-service teachers' beliefs, knowledge and attitudes about the status of physics in high school since these perceptions in part can detrimentally impact their understanding of teacher education modeled instructional strategies. Besides, the pre-service teachers are likely to proceed into their professional practice with these perceptions, which may be desirable or undesirable to the practice of teaching. Insights gained from these perceptions are invaluable in the planning, development and implementation of physics teacher education programs and instructions that are learner-centered (those which attend to learners' perceptions) - models likely to be modeled during professional practice. This paper discusses revelations from the science teacher candidates' reflections. Special attention is given to instruction related issues, since it can be argued that effective instruction does impact students' decisions about physics. Thus, the paper challenges high school physics instructors to take deeper responsibility of teaching their subject including the provision of remediation in requisite experiences and knowledge on which canonically correct understanding of intended physics concepts depends.

Introduction

Many high school science students in British Columbia (BC) take Chemistry 12 or Biology 12 rather than Physics 12 as reflected in provincial exam participation rates from 1996 to 2003 (physics: chemistry: biology 1:1.5:2 or 2:3:4) (BC Provincial Standard Report 5015B). Different stakeholders have different perspectives on this trend in BC or elsewhere. Each individual's or groups of stakeholders' perspectives are enlightening and informative. For instance, teacher educators, pre-service teachers, teachers and students can provide perspectives that can shed light on possible factors that impact high school students' decisions about Physics 12 or equivalent.

As part of a broader study involving selected groups of high school teachers and students, this case study elicited pre-service science teachers' perspectives on why high school physics enrolments are consistently low. Through questionnaires and interviews, perspectives of pre-service science teachers from one of BC's universities were collected on factors impacting high school students' decisions about Physics 12. Although the focus is on the BC context, those who had secondary education elsewhere were advised to reflect on the equivalent of Physics 12 that they experienced at high school.

On the surface, it might appear odd to survey this group of participants because 1) they are already successful professionals in science or science related professions, 2) they constitute a tiny part of all the stakeholders 3) things are likely to have changed since they were in high school, and 4) not every one of them had their high school education in BC. But there are mitigating factors that make it prudent to seek their perspectives. These include: 1)

their own experience will affect their understanding and implementation of teacher education-offered instructional strategies, 2) some of their past experiences are likely to be confronted on practicum or when they qualify as physics teachers, 3) research has shown that some teachers tend to teach the way they were taught (Blanton, 2003; Matthews, 1994), 4) a teacher's attitude is very much shaped by his/her experience lived, 5) understanding pre-service teachers' experiences, beliefs and attitudes can help in preparing teacher education programs that offer viable solutions to some of the fears they may subtly hold, 6) breaking free of the ineffective models of teaching they may have been exposed to as students, and 7) it is pedagogically prudent to explicate what pre-service teachers' views of the status of Physics 12 or equivalent are before seeking the perspectives of the practicing teachers and students in high schools. Moreover, since the author is a teacher educator looking at the issue of under enrolment in Physics 12 or equivalent, determining pre-service teachers' perspectives on the status of Physics 12 or equivalent provides a basis for extended study involving high school science teachers and students.

Instead of hypothetically speculating on the factors impacting high school students' decisions about Physics 12 or equivalent, participating pre-service teachers were asked to reflect on their own experiences when they themselves made similar decisions in high school. Their perspectives on this issue are just as important as the perspectives of teachers and students. Teachers' attitudes are shaped by their prior experience and can impact their students' performance and beliefs about physics. Understanding pre-service teachers' perspectives on an issue such as this is a way of understanding their innermost perceptions about physics instruction.

Questionnaire and interview responses revealed that *mathematical* and *instructional* factors as well as the *nature of physics activities* are key factors which influenced the participants' decisions concerning Physics 12 or equivalent. Additional factors which surfaced during interviews and not revealed from questionnaire responses included: *counselors* (which the author considers to be a derivative of the other factors) who are reckoned as playing a very significant role in influencing students' decisions about subject/course choice; and *gender and role model* (came from very few teacher candidates, but worth sharing since they bear on the gender imbalance noticed in most physics class enrolments).

In this paper I argue that physics teachers and students should be co-mediators (Anderson, 2003) in the teaching and learning of physics. This must include "sharpening the tools of physics", e.g., mathematics and remedial lessons. In addition, teachers need to rethink their instructional approaches and adopt teaching styles informed by constructivist theories of teaching and learning. The importance of students' prior knowledge, which must include mathematical competencies, is underscored. This knowledge should be considered when planning instructional activities. Predict-Observe-Explain (POE) type of activities (Gunstone, 1994) are also underscored because of their potential to elicit students' preconceptions, which according to Kelly (1955), influence how students understand and interpret new information or experiences.

Review of literature

How high school physics curriculum is organized and taught affects the way the would-be physics majors perceive the subject and its content. Perhaps the question here is: what counts as physics education? This question resonates with a similar one raised by Hodson (1998) about what counts as science education. Whether the question is about physics or science education in general, it can attract a variety of responses. Different stakeholders (students, pre-service and in-service teachers, curriculum designers, etc.) might respond differently to this question.

Whatever the response, which might be indicative of what physics education is, this paper embraces Weizsacker's and Juilfs's (1957) characterization of physics: "experiments, active, inquisitive and skillful intercourse with nature" (p. 11). Weizsacker and Juilfs underscore the importance of mathematics in the teaching and learning of physics concepts by saying: "The tool of conceptual thought in physics is mathematics for physics treats of the relations between measured, that is numerically determined" (p. 11). In the same vein, Fisher (2001) seems to concur with this view by stating that physics is to a large extent concerned with mathematically defined entities and recommends a deliberate focus upon quantitative modeling. However, while acknowledging the importance of the qualitative aspects of physics, he accords this a lesser status by saying that qualitative modeling plays a minor role of promoting understanding of the 'rules of play' of microscopic entities that lead to macroscopic

descriptions. I disagree and argue that this view is problematic since in his view quantitative and qualitative aspects of physics are complementary. Nonetheless, it is most likely that students who are very deficient in mathematical competencies will not consider taking more senior physics courses, such as Physics 12. But *mathematics* is not the only factor effecting students' decisions about taking more senior physics courses. Rather, it is one of many that include students' prior experience with learning physics. Prior experience or knowledge is now widely recognized as in part impacting students' learning of new material (Dobrin, 1997; Driver, 1983, 1989; Gunstone, 1994; Kelly, 1955). Teacher attitudes, beliefs and practices, students' beliefs and study skills, and student advisors (counselors) affect students' decisions regarding which course/subject to pursue.

Behar-Horestein, Pajares, and George (1996) determined that *teachers' beliefs* affect students' academic performance after comparing their performance before and after a curriculum innovation (cf. Lumpe, Haney & Czerniak, 2000). Amongst the emergent themes of this study is the complaint often raised by teachers about not being consulted before curriculum changes are introduced. The researchers expressed pessimism about the success of the innovation. As a consequence, there was no change in the students' mean grade despite their (students') preference for the innovation. In the same vein, Adams and Salvatera (1998) found that many times structural and programmatic changes in scheduling were unaccompanied by changes in teachers' practices. They concluded that static teacher behavior limited the effectiveness of broader organizational changes. On the other hand, *students' views of intelligence*, as the Jones, Slate, Blake, and Sloas (1995) study show, correlate students' study habits and how they view certain subjects. Jones et al. determined that students who held an incremental view of intelligence scored higher on the Study Habits Inventory scale across the grades than those who held an entity view of intelligence. These findings are of interest to the current study since it is after grade 11 physics that students in BC high schools decide whether or not to take Physics 12. If academic study habits involve memorization then obviously such students might find Physics 12 content challenging. In any case instruction related factors could also influence students' decisions about taking senior courses in physics.

Snyder (1998) determined that *interviewing students through problem solving* is an effective means of evaluating them and their special needs; and that setting time for this provides the teacher with opportunities to understand individual students and diagnose specific learning problems. Of course, problem solving utilizes mathematical knowledge and skills, which Weizsacker and Juilfs (1957) consider important. But this is one of the many teaching strategies available to pre-service and in-service teachers. Therefore, teacher education programs can be a valuable resource in this respect. Graber (1998) investigated the influence of teacher education on a high school teacher's instructional behavior and determined that student teaching was the means by which a pre-service teacher can predict the difficulties he/she is likely to carry into induction. The study further revealed that

being provided with principles of good teaching does not necessarily mean being able to translate automatically the principles into effective teaching behavior.

Halpen (1992) cites data published by the Educational Testing Service (ETS), which revealed among other things, the inability of high school graduates in USA to use basic algebra or evaluate the appropriateness of scientific procedures. In the same vein, a study by Norvilitis, Reid and Norvilitis (2002) revealed that everyday performance on the physics quiz had a strong correlation between physics grades achieved previously and the highest level of mathematics taken. Apart from mathematical factors, the nature of physics activities and the significant influence these activities have on students' decisions about Physics 12 or equivalent were revealed.

In a study of the activities that can increase the involvement of non-participating students, Green (1995) determined that students participate best when the activities involve *assigning cooperative group tasks* and also when the work has an *element of creativity*. This is a very important study relevant to the current research. Perhaps many students make subject/course choices based on the nature of activities the

teachers present. Certainly the nature of physics activities or tasks and how they are organized and executed affects decisions students make about physics. Shepardson, Moje and Kennard-McClelland (1994), in a study to determine the impact of science demonstration on children's understanding of air pressure, noted the lack of challenge to students' preconceptions and recommended the use of demonstrations that challenge children's preconceptions and promote understanding as is conveyed in Gunstone's (1994) Predict–Observe–Explain (POE) and Posner et al.'s (1982) conceptual change models. The demonstration in a way should cause cognitive conflict or dissonance in the minds of learners (Posner et al. 1982). McRobbie, Lucas and Boutonne (1997) and Osborne (1998) have revealed problems with the nature of demonstration activities which teachers use. These studies raise questions about the contribution demonstration activities make to the overall student learning.

In summary, emergent from the literature review is the view that 1) mathematics is an important tool of physics instruction, 2) teachers' and students' attitudes and beliefs influence students' perceptions of physics, and 3) the nature of physics activities also influences these perceptions. Moreover, the choice of

Provincial exam data

	Physics (%)	Chemistry (%)	Biology (%)	Math (%)
1996/97	13.5	23.6	27.7	38.2
1997/98	13.5 (7,795)	23.6 (13,680)	28.3 (15,878)	38.5 (23,048)
1998/99	14.3 (8,425)	23.6 (14,184)	28.6 (16,435)	38.4 (23,997)
1999/00	13.9 (8,745)	22.7 (14,660)	28.5 (17,578)	37.0 (24,544)
2000/01	13.8	22.4	29.2	38.2
2001/02	13.9	22.1	30.7	34.4
2002/2003	13.7	23.1	32.1	36.7

Table 1: BC Provincial Exam Participation Rates [Source: Government Standard Report 5015B, 1996 –2002] [www.bced.gov.bc.ca/exams.]

	Physics (As & Bs) (%)	Chemistry (As & Bs) (%)	Biology (As & Bs) (%)	Math (As & Bs) (%)
1997/98	47.0 (3,663)	50.0 (6,840)	36.4 (5,779)	40.7 (9,380)
1998/99	51.9 (4,372)	43.1 (6,113)	38.8 (6,376)	40.0 (9,598)
1999/00	56.7 (4,958)	44.7 (6,553)	40.0 (7,031)	42.3 (10,627)

Table 2: Percentage As & Bs [Source: Government Standard Report 5015B, 1997 –2000] [www.bced.gov.bc.ca/exams.]

	Physics (%)	Chemistry (%)	Biology (%)	Math (%)
1997/98	86.1 (6,711)	85.2 (11,655)	79.1 (12,559)	83.2 (19,175)
1998/99	85.4 (7,194)	84.5 (11,985)	79.1 (13,000)	82.9 (19,893)
1999/00	87.3 (7,634)	83.9 (12,299)	79.7 (14,009)	83.4 (20,469)

Table 3: Success (C- to A) Rates [Source: Government Standard Report 5015B, 1997 –2000] [www.bced.gov.bc.ca/exams.]

pedagogical models that teachers employ is a key influence on student attitudes and subsequent pursuance of physics and physics-related professions.

The Study

This research employed an intrinsic qualitative case study approach (Stake, 1998; Merriam, 1998) involving science teacher candidates in a Teacher Education Program (TEP) at a Canadian university. The author of this paper investigated the perspectives of the physics, chemistry, and biology teacher candidates on the decisions they made (as high school students) about Physics 12 or equivalent. Factors that influenced their decisions were discerned using two questionnaires: one for physics and the other for biology/chemistry pre-service teachers. Follow-up interviews were similarly developed and conducted to elucidate further on the questionnaire findings.

Most of the participants, though varied in age (between 26 and 50 years), completed their high school education in BC. A few had their secondary education outside Canada and BC. Those who did not have their secondary education in BC were given the option of reflecting on their own experience as high school students making decisions about an equivalent physics course. This study is important because the perceptions of the participants are indicative of beliefs and attitudes that influence physics pedagogy.

Procedures

A two-stage approach was employed in data collection and analysis. BC Ministry of Education data on provincial exam participation rates, pass rates, percentage score of A's and B's and the total number of students who took physics, chemistry, biology, and mathematics examinations in very recent years were examined. The findings from the analysis (Tables 1-3) informed the construction of questionnaires and interview questions. Tables 1 and 2 show participation rates in BC provincial exams from 1996 to 2003 and the percentage A's and B's in the 1997 – 2000 physics examinations. Table 3 shows the overall success rates in four subjects from 1997 - 2000. The fact that the success rate for physics remained constantly low also fueled the desire to seek perspectives of the would-be science teachers (pre-service science teachers).

Table 1 suggests that the ratio of students taking Physics 12, Chemistry 12 and Biology 12 remained almost constant from 1996 to 2003. In this case, the ratio of Physics to Chemistry to Biology has remained 1: 1.5: 2. The data in Table 2, shows the number of students writing physics and chemistry exams increased steadily from 1997 to 2000 by about 500 annually, while biology increased by about 1000 and mathematics increased by about 600 exam writers annually. These figures might mean some improvement in the numbers of those who write physics exams and by implication an increase in the number of those who choose to take Physics 12. But, if the number of those rewriting the exam is high, then there is a high possibility that

the number of those taking Physics 12 is likely not to have changed significantly. There are many reasons that could explain this. Whichever way the numbers are examined, the picture remains that Physics 12 is not attracting as many participants as Chemistry 12 or Biology 12. The participation rates in physics exams most likely reflect BC's Physics 12 enrolments.

As much as teaching the way we were taught might be a great idea, I advocate a cautious approach to that way of teaching since success in physics under whatever circumstances does not necessarily imply good instructional approaches.

Forty-five (seven physics and thirty-eight chemistry/biology) teacher candidates completed the questionnaire; nineteen indicated a willingness to be interviewed (Fontana & Frey, 1998) to clarify responses.

Outcomes

Initial "surface" analysis (Miles & Huberman, 1994) of responses to questionnaire items revealed several key factors including:

1. Ability to do mathematics
2. The physics teacher and instructional styles
3. The nature of physics content and activities
4. Model female physics teachers
5. Method of studying physics
6. Prior experience from previous introductory physics courses

Students' ability to do mathematics as portrayed in the literature, emerged as a very important factor in the learning of physics. Some participants owed their success in physics to their understanding of mathematics. Others blamed their problems in physics to their own inability to do mathematics:

- John: I was interested in the math and problem solving in geometric optics.
Mary: Some of my friends did not like mathematics hence physics also.
George: I enjoyed problem solving and anything that was thought to be difficult.
Phillip: I was afraid there would be learning of equations.

The physics teacher was portrayed as someone who could inspire students to take physics. Also, the physics teacher was portrayed as someone who could drive students away from physics as conveyed in the following statements:

- George: My high school had good physics teachers and program.
Jane: My physics teacher was not passionate about it and did not teach us.
Humphreys: I did well though my teacher was not particularly good. All we did in physics 11 was copy notes and solve text problems. There were no hands-on activities.
Grace: My physics 11 teacher was so bad that I could not put myself through it again.

- Eric: Teacher was unwilling to spend sometime outside the classroom.
- Anita: It wasn't content; it was the teacher.
- Peter: I was taught by physics teachers who were really boring, super strict.

The nature of physics content and activities was cited by a number of students from the two groups conveyed as having impacted their decisions regarding Physics 12 or equivalent. This view is illustrated in statements from the following participants:

- John: Practical questions about why and how things work were answered.
- Andrew: All we did in physics 11 was copy notes and solve text problems. There were no hands-on activities. [See also the "physics teacher" above],
- Jane: Material was regurgitated from textbooks.
- Peter: Too much note writing and lots of word problems.
- Sam: Content was very difficult.
- Phillip: Previous physics topics involved too much math.
- Agnes: Physics not really applicable to my life.
- Andrew: Physics seemed far removed from real life – "dry"
- Peter: General impression that physics was boring, dry, hard and for nerds.

Prior Knowledge and experiences, which necessarily includes prior understanding of mathematics, were cited by many students as one of the key influences on their decisions regarding Physics 12 or equivalent:

- Humphreys: I did well in Physics 11.
- Fred: There was a rumor that the physics guy was not good.
- George: Science was my favorite.
- Phillip: I had difficulties with math.
- Annette: I was not a good math student.
- Sam: I started failing because of the math since marking was about correct numbers.

Interview questions centered around key issues of pedagogy, the nature of physics content and teacher attitudes and beliefs. During the interview, other factors germane to those mentioned emerged. These include: the role of school counselors, who were portrayed as "wielding" great influence on students' course decisions. Three of the interviewees said that counselors influenced their decisions about Physics 12. They revealed that marks received in each subject were monitored and compared to university entry requirements. If a counselor felt that taking a certain subject in which dismal performance could lower a student's mean score or grade with the consequence of jeopardizing his/her chances of getting into university, then the advice to such a student would be not to enroll in the subject. This is consistent with findings by Wilson and Rossman (1993) in a study that examined the issue of mandating academic excellence and high school responses to state mandated curriculum.

Issues of gender and student decisions about physics emerged from two of the nineteen interviewees (one male and one female). The male interviewee, who was a pre-service physics teacher, felt that some of the would-be female physics majors dropped out of the subject due to the lack of model female physics teachers: "Perhaps more positive female teachers could have attracted more girls". Implicit in this view is the idea that the proportion of females in the physics classes was inadequate. It may also convey the "blame-the-victim" type of mentality, which has pervaded some of our physics classrooms. As if to echo the male participant's view, a female biology/chemistry teacher candidate said: "[I] could have been encouraged if there were more girls." This made sense since being the only female student in a male dominated class could have intimidated her. It takes the teacher's sensitivity and effort and to some extent the female student's determination to "survive" in such an androcentric (Harding, 1991) class. There is extensive literature regarding issues of gender in science (see for example, Rennie, 2000; McGinnis, 2000; Atwater, 2000; Harding, 1991; Howes, 2000; Brickhouse, 2001). However, the point raised in this study is significant and enlightening. It reinforces the fact that there is under representation of women in physics; a factor that sends mixed messages to would be female physics majors.

Also revealed was the claim that physics teachers make unrealistic assumptions about students' knowledge of mathematics. Instead, some of the interviewees argued that a good physics teacher should also be a good mathematics teacher. Such a teacher should be able to provide effective remedial lessons in requisite mathematics. Further, some pre-service physics and the majority of chemistry/biology teachers envisioned a model in which physics teachers minimized the quantitative aspects at the initial stages and eased the students into this aspect by starting with remedial lessons on the appropriate mathematics.

In addition, several teacher candidates described the nature of physics they wished to see as conveyed in the statements below:

- Phillip: Offer a physics course with less emphasis on calculations, though not a sound foundation for university work in physics.
- Peter: Physics being portrayed as for all and not for socially inept intellectuals.

The issue of study skills came up with contrasting views from the two groups of participants. Several pre-service physics teachers felt that memorization has no place in physics:

- John: Biology had too much memorization. It's not possible to memorize [in physics].
- Jane: [Physics] requires understanding.

These representative statements imply that those who did not take Physics 12 or equivalent took other subjects in which facts are memorized. The counter claim came from some biology/chemistry teacher candidates who thought that there were too many facts including formulas to be memorized in physics. They

asserted that biology being a human subject comprises facts that do not necessarily have to be memorized, but can be experienced and remembered easily as conveyed in the following statements:

Annette: Chemistry and biology had less mathematics and no memorization of formulas.

Agnes: Biology and chemistry are more related to real life; physics [is] about pulleys, levers, and torque – concepts that [don't] matter too much in everyday life.

Though “remembrance” and “memorization” are distinctly different, some physics teacher candidates seemed to equate them. Interviews with some physics teacher candidates revealed a desire to see physics teaching approached differently. This group of candidates felt that some physics teachers have the habit of introducing the mathematical aspect rather too early. Their view was that conceptual physics should precede the quantitative aspect of physics, which should be introduced gradually- i.e., emphasizing conceptual understanding as the students are eased into the quantitative (mathematical) aspect before engaging them into full blown mathematical relationships and problem solving. Two of the physics teacher candidates interviewed further suggested that it might make things easier (better) if physics teachers identified the necessary mathematical tools for appropriate topics and prepare remedial lessons as a way of ensuring that their students have the requisite mathematics to understand the intended physics topics/concepts.

One of the physics teacher candidates felt that physics was being introduced too late (in grade 11) in high school as a subject. He suggested that it should be introduced right from senior elementary classes: “Introducing the physics subject from senior elementary classes. Introducing physics in grade 11 and 12 is counterproductive.” When reminded of the fact that physics topics are already part of the BC grade 7, 8, 9 and 10 science curriculum, he responded by saying that

Physics is a stigmatized subject and it should be accorded the prominence that subjects like mathematics are receiving. Introducing [it earlier] would prepare the students to appreciate the fact that physics is not just mathematics, but has other non - mathematical components.

Of course this candidate had a very important point to make. Such curriculum organization could even advantage students in the sense that they may recognize the usefulness of mathematics early enough and might in turn improve their overall performance in mathematics.

Several points emerged from the study in the form of inferences, which are significant to the inquiry and the preparation of pre-service physics teachers. The majority of the teacher candidates from both groups underscored the value of mathematics in physics, with some equating physics to mathematics. Others implicitly described physics as though it were another branch of mathematics. Justifiably, they conveyed the picture of some high school instructors, who right from the start introduce physics concepts mathematically. This is not to negate the central role mathematics plays in physics, but rather

to underscore the unique relationship between mathematics and physics. Perhaps because of mathematics’ inseparable relationship with physics, it is prudent for physics teachers to provide special remedial in appropriate mathematics.

From the data, the “physics teacher” is portrayed as inspiring or uninspiring. Instructional styles and how the physics teachers relate to the subject they teach impact students’ decisions about subject choices. In this connection, motivation of students who “try” is crucial.

Many chemistry/ biology teacher candidates described physics content and activities as “dry”. Again this seems to point to “the physics teacher”. The nature of activities is important to the way students perceive their future status in the subject. The participants from both groups repeatedly underscored the importance of the hands-on activity approach. One of the female participants revealed that she did not continue with physics due to the problems she experienced in mechanics. Perhaps teachers need to reorganize their curriculum planning, and implementation, say, from the current UNIT approach to the SPIRAL approach – where concepts are developed spirally from one grade level to another.

One male physics teacher candidate implied in his responses that perhaps the shortfall in the Physics 12 enrolment is because the girls’ proportion is inadequate. In the same vein, a female chemistry/biology teacher candidate explicitly said she was intimidated by being the only female in her Physics 11 class, further confounded by the lack of a model female physics teacher on the staff. Again, a teacher who is gender sensitive can reverse this kind of situation.

Implications for physics teaching

This study suggests that a physics teacher’s pedagogical practice affects greatly students’ perceptions of physics. The perceptions of Physics 12 that pre-service teachers hold are indicative of their beliefs and attitudes about physics and how it ought to be taught. Therefore, modeling pedagogy, which we teacher educators consider desirable can greatly influence the practice our pre-service teachers will take into their classrooms. Constructivism (Anderson, 2000; Anderson et al., 2003, Ausubel, 1963, Driver, 1983, Kelly, 1955, Nashon, 2003) makes students’ prior knowledge central to their instructional planning and implementation.

Students’ prior knowledge has been established to, in part, influence the learning or understanding of new information (Anderson, 2000, 2003; Driver, 1983, Kelly 1955, Nashon, 2003). It is also a fact that knowledge of mathematics is key to in-depth and elaborate understanding of physics, given its modeling power (Kline, 1980, Norvilitis, Reid & Norvilitis, 2002; von Weizsacker & Juilfs, 1957). Therefore, it is prudent for physics teachers to establish the level of mathematics knowledge their students have before introducing them to physics concepts whose understanding is mathematics dependent. In this case, part of the prior knowledge is mathematical. There is a possibility that this knowledge, which is part of a student’s preconceptions, is

anomalous. This has to be brought to surface and meaningfully challenged before introducing the students to the desired physics concepts that are mathematics-dependent since faulty conceptions could be transferred into the new conceptualization (Nashon, 2003). In other words, physics instruction should aim at rectifying incorrect conceptual foundation before introducing new concepts which are dependent on what the students already know.

A student's encounter with the "reality" rooted in experience should facilitate the construction of knowledge since his or her prior concepts mediate new conceptualizations. According to Blanton (2003): "This ... encounter with reality helps students evaluate the accuracy of their "knowledge" as they explain the reasons for their interpretations of the results. For this method to be successful students must be equipped with the tools to help them make accurate [interpretations]" (p.125).

In this case, the nature of lesson activities matters. Discrepant events (Gunstone, 1994) are important in eliciting students' preconceptions and readying them for conceptual change – creating in them a state of conceptual conflict (what in Piagetian terms is referred to as cognitive dissonance). Gunstone (1994) has suggested a "Predict – Observe – Explain" (POE) strategy that involves asking students to predict outcomes of events, which they have to justify before being given the opportunity to experiment and make observations. Usually the observations are in conflict with the predictions, thus forcing the students to search for alternative explanations. Explaining predictions most likely reveals frameworks that inform students' interpretations of new events (Driver, 1989; Kelly, 1955).

Physics is often portrayed as a subject for the gifted and difficult, and viewed with contempt. Students are often prevented from majoring in physics by teachers who are complacent about this discriminatory conduct. Some teachers demand too much mathematics regardless of their students' level of mathematical competency. On the other hand, teachers who create friendly learning environments have better chances of attracting more students into senior physics courses – those who in systematic ways provide counter experiences, and systematically provide meaningful and relevant remedial lessons in appropriate mathematical topics. Physics teachers should be reflective and critical of the effects of their instructional strategies on student learning and interests. Reflective practice (Schon, 1983) involves understanding how a teacher's actions might impact students' decisions about future choices.

If a deliberate effort to attract more students into physics (Physics 12) is made by all concerned with physics education, the possibility exists that the current status of Physics 12 as perceived by the participants in this study will improve. Appropriate instructional tools, such as analogies (Nashon, 2000, 2003, 2004) and concept maps, recognizing students' preconceptions can improve the status of Physics 12 or equivalent. Physics teacher preparation programs should make deliberate effort in sensitizing science teacher candidates to the challenges that physics students confront by encouraging them to carefully plan physics curriculum and instruction in ways that address the

issues revealed in this study and especially those that fall within the locus of their control.

Although the participants in this study may not be the appropriate group to provide perspectives on the current status of physics 12 or equivalent, their insights provide a basis for further research. Given that they are soon to become science teachers, their reflections reveal their view of physics education, which they are likely to take into teaching

References

- Anderson, D. (2003). Visitors' long-term memories of World Expositions. †*Curator*, 46(4), 400-420.
- Anderson, D., Lucas, K.B., & Ginns, I.S., (2003). Theoretical perspectives on learning in an informal setting. *Journal of Research in Science Teaching*, 40(2), 177-199.
- Anderson, D., Lucas, K.B., Ginns, I.S., Dierking, L.D. (2000). Development of knowledge about electricity and magnetism during a visit to a science museum and related post-visit activities. *Science Education*, 84(5), 658-679.
- Adams, D. C and Salvatera, M. E. (1998). Structural and teacher changes: Necessities for successful block scheduling. *The High School Journal*, 81(2), 98 – 106.
- Aikenhead, G. S (1996). Science education: Border crossing into the subculture of science. *Studies in Science Education*, 27, 1 – 52.
- Atwater, Mary M. (2000). Females in science education: White is the norm and class, language, lifestyle and religion are nonissues. *Journal of Research in Science Teaching*. 37(4), 386 – 387.
- Ausubel, D. P. (1963). *The psychology of meaningful verbal learning*. New York: Grune & Straton
- Behar-Horenstein, L. S; Pajares, F and George, P. S. (1996). The effect of teachers' beliefs on students' academic performance during curriculum innovation *The High School Journal*. 79(4), 324 – 332.
- Blanton, P. (2003). Constructing knowledge. *The Physics Teacher*, 41(2), 125 – 126.
- Brickhouse, Nancy, W. (2001). Embodying science: A feminist perspective on learning. *Journal of Research in Science Teaching*. 38(3), 282 – 295
- Bridgman, P. W. (1960). *The logic of modern physics*. New York: The Macmillan Company.
- Dobrin, S. I. (1997). *Constructing knowledges: The politics of theory building and pedagogy in composition*. New York: State University of New York Press.
- Driver, R. (1983). *The pupil as a scientist*. Milton Keynes: Open University Press.
- Driver, R. (1989). Students' conceptions and learning in science. *International Journal of Science Education*. 11, 481 – 490.
- Fisher, B. (2001). The big crunch – models in physics meet the real world. *School Science Review*. 83(303), 75 – 85.
- Fontana, A. & Frey, J. H. (1998). Interviewing: The art of science. In N. K. Denzin & Y. S. Lincoln (1998), *Collecting and*

- interpreting qualitative materials (pp. 47 – 78). Thousand Oaks: SAGE Publications.
- Green, P. (1995). What types of learning activities are more likely to increase the involvement of non-participating students? In S. A Spiegel, A. Collins, & J. Luppert (Eds.), *Action research: Perspectives from teachers' classrooms* (pp.17 – 32). Tallahassee, FL: SouthEastern Regional Vision for Education. .
- Gunstone, R. F. (1994). The importance of specific science content in the enhancement of metacognition. In P. Fensham, R. F. Gunstone and R. T. White (Eds.), *The content of science: A constructivist approach to its teaching and learning* (pp. 131 – 146). Washington DC: Falmer Press.
- Harding, S. (1991). *Whose Science? Whose knowledge? Thinking from women's lives*. New York: Cornell University Press.
- Halpen, D. F. (1992). A cognitive approach to improving thinking skills in the sciences and mathematics. In D. F. Happen (Ed.), *Enhancing thinking skills in the sciences and mathematics* (pp.1 – 14). Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.
- Hodson, D. (1998). *Teaching and learning science: Towards a personalized approach*. Buckingham: Open University Press.
- Howes, E. W. (2000). Developing research that attends to the “All” in “Science for All”: Reply to Atwater. *Journal of Research in Science Teaching*. 37(4), 394 – 397.
- Jegede, O. J. (1995). Collateral learning and the eco-cultural paradigm in science and mathematics in Africa. *Studies in Science Education*. 25, 97-137.
- Jones, C. H; Slate, J. R; Blake, P. C and Sloas, S. (1995). Relationship of study skills, conceptions of intelligence, and grade level in secondary school students. *The High School Journal*. 79(1), 25 – 32.
- Kelly, G. (1955). *The psychology of personal constructs: A theory of personality*. Volume One. New York: Norton.
- Kline, M. (1980). *Mathematics: The loss of uncertainty*. New York: Oxford University Press.
- Lumpe, A.T; Haney, J. J & Czerniak, C. M. (2000). Assessing teachers' beliefs about their science teaching context. *International Journal of Research in Science Teaching*. 37(3), 275 – 292.
- Matthews, M. R. (1994). *Science teaching: The role of history and philosophy of science*. New York: Routledge.
- McGinnis, J. R. (2000). Practitioner research and gender-inclusive science education: Reply to Atwater. *Journal of Research in Science Teaching*. 37(4), 388 – 390
- Miles, M. B. & Huberman, A. M. (1986). *Qualitative data analysis*. Thousand Oaks: SAGE Publications.
- Nashon, S. M. (2004). The nature of analogical explanations high school teachers use in Kenya. *Research in Science Education*. 34, 475 – 502.
- Nashon, S. M. (2003). Teaching and learning high school physics in Kenyan classrooms using analogies. *Canadian Journal of Science, Mathematics and Technology Education*. 3(3), 333 – 345.
- Nashon, S. M. (2000). Teaching physics through analogies. *OISE Papers In STSE Education*. 1, 209 - 223.
- Nashon, S. M. (2001). *Learning and Teaching high school physics through analogies: A case study of Kenyan classrooms* (A doctoral thesis, University of Toronto.
- Norvilitis, J. M., Reid, H. M and Norvilitis, B. M (2002). Success in everyday physics: The role of personality and academic achievement. *Journal of Research in Science Teaching*. 39(5), 394 – 409.
- Osborne, J. (1998). Science education without a laboratory? In J. Wellington (Ed.), *Practical work in school science: Which way now?* (pp. 156 – 173). London: Routledge.
- Posner, G., Strike, K.A., Hewson, P.W. & Gertzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*. 66(2), 211-227.
- Rennie, L. J. (2000). Equity in science education: Gender is just one variable: Reply to Atwater. *Journal of Research in Science Teaching*. 37(4), 391 – 393
- Roth, W. M, Campbell, J. M., Lucas, K. B. and Boutonne, S. (1997). Why may students fail to learn from demonstrations? A social practice perspective on learning in physics. *Journal of Research in Science Teaching*. 34(5), 509 – 533.
- Schon, D. (1983). *The reflective practitioner*. New York: Basic Books.
- Shepardson, D. P.; Moje, E. B. & Kenmard-McClelland (1994). The impact of a science demonstration on children's understandings of air pressure. *Journal of Research in Science Teaching*. 31(3), 243 – 258.
- Sherin, B. L. (2001). How students understand physics equations. *Cognition and Instruction*. 19(4), 479 – 541.
- Snyder, R. F. (1998). A clinical study of three high school problem solvers. *The High School Journal*. 81(3), 167 – 176.
- Stake, R. E. (1988). Case study methods in educational research: Seeking sweet waters. In R. M. Jaeger (Ed.), *Complementary methods for research in education* (pp.251 – 1277). Washington: American Research Association.
- Stake, R. E. (1998). Case studies. In N. K. Denzin and Y. L. Lincoln (Eds.), *Strategies of qualitative inquiry* (pp. 86 – 109). Thousand Oaks: SAGE Publications.
- Weizsacker, C. F. Von and Juilfs, J. (1957). *The rise of modern physics*. New York: George Braziller, Inc.

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