Using Metacogs to Collaborate With Students to Improve Teaching and Learning in Physics

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Metacognition: ‘thinking about one’s own thinking’
- Petros Georghiades

Abstract

Where are the Physics Students?

As a beginning teacher of Physics 11 and 12, I have observed enrolment trends in secondary sciences at my school and in British Columbia (BC). I became concerned about the large discrepancy in the number of students enrolling within the senior science courses. BC data indicates that more students choose to enrol in chemistry and biology than in physics. For every two students choosing to take Physics 12, there are three students choosing to take Chemistry 12, and eight students choosing to take Biology 12 (Nashon, 2003). I wondered what I could do as a teacher to encourage more students to enrol in Physics 11 and at the same time improve my practice.

I work at a suburban public high school in the Fraser Valley as the Senior Physics teacher. Most of our students come from lower socio-economic families. The student population is full of capable students, but based on published provincial reports (including participation rates in Provincial Exams), our school performs below average. I have been at the school for three years, and I have been studying for my Masters in Education (Curriculum Studies) for the past two years. As a graduate student, I was encouraged to consider the ways action research could help me learn from my practice while improving student learning and understanding in my Physics 11 class (which would hopefully lead to higher enrolment rates).

After reading Arhar and Buck (2000) and Collins (2004), I decided to conduct a teacher-student collaborative action research inquiry into the teaching and learning of Physics 11. I support the definition of action
research that states “...action research is geared towards improving the researcher, as well as the research situation and research participants” (Arhar & Buck, 2000, 328). I also used Collins (2004) description of action research as “...collaborative, participatory, targets ethical issues, and includes students” (347). My intentions were to conduct an inquiry that sought student input about their views of effective teaching and learning because I believe students can provide valuable insight for teachers.

Using a collaborative approach, my Physics 11 class and I investigated the factors that influence the students’ views of physics, and what can be done to improve student attitudes, perceptions, and understanding of physics. In addition, as a class, we developed and implemented strategies aimed at making physics instruction more student-friendly, enjoyable, meaningful, and engaging while enhancing conceptual understanding. This action research inquiry spanned two and a half months of a semester and involved one Physics 11 class of twenty six students.

**Purposes of the Study**

The purposes of this collaborative action research were to:

1. use action research to improve my practice and provide insight into student learning in Physics 11;
2. understand how students in my class perceive physics;
3. elucidate the topics students excel in and which topics they struggle with;
4. enhance student’s interest and motivation to continue with physics or physics related professions;
5. influence future enrolment in Physics 11/12 by enhancing the positive image of physics among students in my school through collaborative planning; implementation and evaluation of successful instructional strategies; and
6. introduce my students to metacognition.

**Literature**

Research in physics education over the last twenty years has found a number of factors contributing to low enrolment in high school. Some of the factors continually sited in the literature are:

1. Low enrolment of females;
2. Students’ insufficient mathematical abilities;
3. Students’ attitudes and perceptions about physics; and
4. The content of traditional physics curricula

(Angell, Guttersrud, Henriksen, & Isnes, 2004; Carlone, 2004; Haussler & Hoffmann, 2000; Nashon, 2003; Sheppard & Robbins, 2003; Woolnough, 1994).
The following four sub-sections (Enrolment, The Math-Physics Problem, Student Attitudes and Perceptions, and the Curriculum) summarize the major concerns. In each of the sections, I will discuss the topic as it specifically addresses the low status of physics among high school students. The articles selected were limited to research that has been completed in the last twenty years. (I used a variety of online searches including Academic Search Premier, EBSCO, and the World Wide Web to locate relevant articles.)

**Gender Issues Affecting Enrolment**

The issue of low enrolment in physics education is a concern of many physicists and educational researchers, as widely expressed in the literature (Angell et. al., 2004; Nashon, 2003; Sheppard & Robbins, 2003). The most significant factor affecting enrolment rates according to the literature I have found is the lack of girls choosing to take physics courses (Carlone, 2004; Haussler & Hoffmann, 2000; Woolnough, 1994). Unfortunately, physics still seems to be perceived as a male gendered course. In the last three years, I have noticed that fewer girls than boys are enrolled in my class. I have also heard (on numerous occasions) girls in my class discussing their lack of interest in the topics being covered, and how they feel physics is “just for boys.” Despite my efforts to be more supportive of girls, the enrolment in my physics classes is still overrepresented by boys.

Carlone (2004) argues that girls in high school physics classes are more concerned about maintaining their student identities, rather than actively participating in physics class. She suggests that girls in high school physics classes are not concerned with understanding the true nature of physics as a discipline, but are concerned mainly about their grades. Carlone (2004) claims girls take physics as a means to an end route to a college degree. From my experience, I agree with Carlone in that many of the girls in my physics class (when asked) are taking physics because they need it as a prerequisite for entrance into college or university faculties of science. I have yet to hear a girl disclose their interest in pursuing a physics related career! Many boys in the class express their interest in engineering, but I have not yet heard such a claim from any girls.

**The Math-Physics Problem**

“Mathematics is such a major component of physics to a point where without it; no meaningful understanding of physics can be claimed” (Nashon 2003, 4). The lack of student competence in mathematics as a significant deterrent from physics is present in virtually all of the research concerned with physics enrolment. Current research suggests
that students have generally low mathematical abilities (algebra, and applying their knowledge in context) compared to what conventional physics courses require (Gill, 1999; Woolnough, 1994), students struggle with graphical analysis (McDermott, Rosenquist, & van Zee, 1987; Rosenquist & McDermott, 1987), and students have a difficult time using symbols in formulae (De Lozano & Cardenas, 2002; Sherin, 2001)

As Gill (1999) states, most students who enter physics courses do not have sufficient math skills, and those that do, lack the ability to apply them in context when solving problems. Thus, he claims, teachers overestimate students' mathematical abilities (specifically algebra and interpreting graphs), and these problems are amplified because graphs and their algebra are foundational to physics. From my own experience, I have found that most of my students have mediocre algebra/graphing skills and lack the ability to apply their skills in different situations. McDermott, Rosenquist, and van Zee (1987), and Rosenquist and McDermott (1987) discuss the difficulties students have with algebra and graphing in physics class, while providing valuable suggestions for teachers about how to address these problems. These two articles reassured me that students' meagre math skills pose difficulties for students in most physics classrooms, and not only my own.

I have also noticed that the majority of students in physics completely lack confidence when using their math skills to solve problems. Many of these students struggle with algebra, and fail to connect what they learn about linear functions in their math class with practical physics problems in the kinematics section of the course. Ledermen (2001) urges teachers to horizontally integrate math and physics so when students learn concepts in one discipline, they can transfer their knowledge to the other discipline.

Attitudes and Perceptions

Research by Nashon (2003) suggests that there are three major reasons affecting students’ choice in taking Physics 12. He states the following factors:

1. Math phobia;
2. The physics teacher’s beliefs and attitudes; and
3. The counsellors or student advisors in the school.

From my own experience, I would add that the nature of the student is
also a large factor in the decision making process. When looking at my school, less than 10% of the students go on to post-secondary education. If these students avoid post-secondary education, there is little incentive for them to take physics (which they perceive to be difficult). Woolnough (1994) also agrees by claiming that much of a student’s decision to take a physics class depends on the nature of the student (their abilities), their background (specifically their family), and the value placed on physics related careers in the country where the student resides.

Sheppard and Robbins (2003) assert that “diminishing enrolment in physics is due to students finding physics too abstract, too mathematical, too much like college courses, too geared towards examinations, and too dependent on textbook learning” (422). Haussler and Hoffmann (2000) claim there are three major problems science teachers face today:

1. the need for science curricula to meet the needs of the students and society of today;
2. the decline in students’ interest towards science; and
3. lower achievement in students’ course marks.

As I mentioned in the Enrolment section, girls in particular seem to have less interest in physics compared to biology. Most science teachers I have worked with are truly passionate about teaching their discipline, so does this suggest teacher enthusiasm is not enough to instil interest in students? I suggest we need to include more student input into teaching practices and learning strategies in class in order to make physics instruction more meaningful to students.

Nashon (2003) claims the appeal of the physics teacher plays a large role in determining the number of students that enrol in a physics course. Sadler and Tai (2001) found that students believe effective physics teachers are patient and are capable of approaching problems from many different ways rather than teachers who merely have high content knowledge. She and Fisher (2002) argue “if teachers wish to develop better attitudes in their students toward science, then they should use challenging questions, give more encouragement and praise, show nonverbal support, and be understanding and friendly” (74).

Curriculum

The curricular framework of physics is also a topic that is discussed in journals, especially when referring to student input about how they feel about physics. Many of the researchers who are writing on this topic discuss the issue in terms of what is lacking in the physics curriculum (Bencze, 2000; Gill, 1999; Haussler & Hoffman, 2000). These authors
typically make a distinction between the traditional versus the applied curriculum.

Traditional physics is considered to be heavily weighted towards theory and quantitative problems, while the applied physics is heavily weighted towards conceptual understanding and applying qualitative and quantitative physics concepts in context. Studies suggest the benefits of an applied curriculum are increased student attitudes, increased motivation, and a better conceptual understanding of the topics (Carlone, 2004; Haussler and Hoffmann, 2000; Ledermen, 2001; Reid, 2003; Woolnough, 1994). This review of the literature provided a framework for articulating the research questions relevant to my classroom.

Research Questions

1. In what ways can I gather feedback from my students to better understand a) their perceptions and beliefs about physics; b) the problems they are experiencing with the Physics 11 class; c) what instructional practices best meet their needs?

2. In what ways can I modify my teaching practices based on the feedback I receive from students?

3. By having my students write about their learning, can I help introduce them to metacognition?

Research Methodology

Given that I was interested in developing a successful model of physics instruction with lasting positive potential to affect future perceptions of, attitudes about, enrolment, and academic successes in physics in my school, a teacher-student collaborative action research inquiry was deemed appropriate for the questions I wished to explore (Arhar & Buck, 2000; Collins, 2004; Holly, Arhar, & Kasten, 2005).

I most closely followed the interpretivist research paradigm because I was attempting to understand my students’ perspectives about learning Physics 11 (Sipe & Constable, 1996). I was interested in learning about teaching from my student’s point of view and how I could adapt my teaching to this specific group of students. Collins (2004) inspired me to collaborate with my students and seek their input into how Physics instruction and learning could be improved. “A perspective that seems suitable for classroom research is one of participatory, collaborative action research. It is ecological in the sense that it includes all the significant actors in a classroom research setting,
including the children” (Collins, 2004, 349).

Collins (2004) also describes the importance of including students in collaborative action research to improve the communication about teaching and give “valuable insight into classroom structures. What activities are motivating? Which result in what kinds of learning? What conditions promote the best engagement?” (353). He then suggests that having students participate in metacognitive activities can engage them in the research process and is a method of presenting data in a natural context.

The creation of the Metacogs arose from reading articles about student journal writing in science classes (Etkina, 2000; Hand, Hohenshell, & Prain, 2004; Prain & Hand, 1996). These authors suggest there are great educational benefits for students when they write about their learning, such as identifying their strengths and weaknesses in their learning of science. I wanted to adopt these practices of journal writing with my students, but I also wanted them to start thinking about how they learn new information and what learning strategies or techniques they should employ to help them the most.

Methods

Throughout this research, I kept an electronic journal detailing the collaborative planning process/dialogue that I created with my students. The journal recorded in-class observations of students’ comments and reactions to instructional strategies that were designed to improve their understanding of physics concepts. In addition to my observations, I wrote reflections on and interpretations of the observations I made in class. On each of my journal entries, I left room for coding and I wrote summary statements of actions that I believed necessary the next time I teach the course. I found this journal format suitable to my needs for several reasons. It allowed me to record my observations and reflections on the same page. It allowed me to code my work according to categories representing recurring themes. Having an electronic file allowed me to easily go in and add comments/reflections that occurred later in the project. And it allowed me space to analyze what actions I would take to improve my teaching (and therefore complete the spiral of the action research process).

Metacognition and The “Metacogs”

Metacognition is frequently defined in the literature as ‘thinking about one’s thinking’ or ‘learning about one’s learning’ (Conner & Gunstone, 2004; Dahl, 2004; Georghiades, 2004; Georghiades, 2000; Stillman & Galbraith, 1998; White & Frederiksen, 1998). Based on the literature about metacognition, an important part of learning science is to have
students reflect about how they approach problems, organize concepts, address their weaker areas, and identify their strengths (Adey & Shayer, 1993; Conner & Gunstone, 2004; Dahl, 2004; Georghiades, 2004; Stillman & Galbraith, 1998).

I explained the term metacognition to my class and how I hoped the research would help them improve their understanding of physics. The Metacog was a handout where students responded to various prompting questions about each major topic we studied, the problems they were having, how they were learning the material, their strengths and weaknesses, and how they felt the instruction I provided could be improved. I assigned the Metacog as a regular assignment, and I collected it twice a week for the duration of the study.

I used the Metacogs to provide me with information that I could address with the entire class about concepts and issues raised by the students. After collecting and analysing the students’ Metacogs, I usually spent about ten minutes in the following class discussing the implications of their responses and how I was interpreting them. The student input allowed me to reflect and then modify my subsequent lessons to address concerns that students had. For example, in the first week of the study, students wanted more examples of conversions between the metric system prefixes because they felt I was not giving enough. I would never have known this unless I asked them. Student-teacher collaboration, analysis, instructional planning, implementation, and evaluation were ongoing and cyclical (Arhar & Buck, 2000). The collaborative process allowed me to receive a continual source of input on model physics instruction through the eyes of my students, helped me ascertain “what my students really think” when learning physics, and provided them with an opportunity to improve their metacognitive skills.

Data Analysis

The term ‘Metacog’ was originally used as the name for the reflective journal as an abbreviation of the word metacognition. However, after I started to say the word “Metacog” more frequently over the duration of the research project, I began to visualize a symbolic meaning for the term. I began to look at the cogs on a wheel and how they can fit together with the cogs on another wheel; one turning the other.
I started to see that perhaps with practice, if the cogs on the wheels in my students’ brains were set in motion, then perhaps these cogs would start to turn other wheels, even wheels that may have never been turned before. The process of ‘thinking about thinking’ became very important to my teaching because it could help some students interconnect concepts and adapt personal learning strategies. It also had the potential to reach beyond my physics class and students could integrate this practice into their learning of other school subjects.

After collecting the Metacogs, I qualitatively analyzed the student responses and documented my findings. Using the students’ Metacogs, my own journal, and the analysis of student responses in the Metacogs, I coded all of the data into five categories: APK – Applying Knowledge, M – Math Issues, PK – (student’s) Previous Knowledge, CP – The Collaborative Process, and TP – Teaching Practice.

These categories were created due to their high frequency occurrences during the data analysis and because they specifically addressed my research questions. I used triangulation between the three sources of data I collected and I found that cross-referencing the data helped support my findings. For the purpose of this writing, I will discuss only the use of the Metacog journal in the collaborative process and the impact it has had on my teaching practices. In terms of the data I have collected, I will only discuss the data that I have coded CP (Collaborative Process) and TP (Teaching Practices) because I feel this is most valuable to a wider teacher audience.

**Evaluating the Metacogs**

The Metacog journal was definitely a highlight of this collaborative process. It allowed me to gain specific insight into questions I had about my teaching and student learning. I learned quickly that the prompting questions must be written in a clear manner. The questions I asked were sometimes interpreted differently than my intentions, and some of the students didn’t understand the questions at all. For example, one student didn’t know what the word ‘implementing’ meant, so answering that prompt was meaningless to him. I also was guilty of putting words into my student’s heads. On one occasion, I asked them to identify what they found difficult when using algebra, and one student asked, “What do you mean?” As a teacher, I naturally responded by giving an example, which in turn, became the answer many students wrote in their Metacog.

As my prompting questions became clearer, and as the students got more experienced writing in their Metacogs, their responses became better at clarifying their personal approaches to learning. Here are
some Metacog examples of the prompting questions (Q) and student responses (S), *(See Appendix)*:

**Example 1**

Q: How do you think you did on the multiple choices section of the exam? Explain.

S: A few questions got me thinking and for one I had more than 1 possibly right answer but other than that it was fine.

Q: Was your prediction correct on the multiple choices section of the exam? Explain.

S: It was the ones I thought were easy that I got wrong. I need to stop and think before I move on. The ones I thought were hard I got right.

**Example 2**

Q: Do you prefer rearranging the letters in the equation first, then subbing the numbers, or do you prefer putting the numbers in the equation first, then solving for the unknown letter? Why?

S: I prefer to arrange the letters then sub-in the numbers. Their's (sic) more of a chance I'll miss a digit with numbers first.

Q: What do you find most difficult when using these equations?

S: Finding the equation with the correct variables.

**Example 3**

Q: Do you prefer rearranging the letters in the equation first, then subbing the numbers, or do you prefer putting the numbers in the equation first, then solving for the unknown letter? Why?

S: I like to rearrange the letters first. It is a lot easier to me! I have always done it and been taught this way.

Q: What do you find most difficult when using these equations?

S: Figuring out which variables are which in the given question.

**Improving Teaching and Learning in My Physics Class**

The analysis of the Metacog entries allowed me to reflect on my teaching. I have discovered two major themes I need to work on to improve my instruction. I need to minimize my assumptions about
student abilities, and I need to become more flexible. In the following paragraphs, I will discuss how the Metacogs have provided me with the insight to make these changes.

One of the difficulties students had learning physics during the study was a recurring theme that was linked to my assumptions. After continual analysis of my responses to the Metacogs, I realized that most of my faults as a teacher come from my predisposed assumptions of student abilities. From the data analysis, it became apparent that I am assuming students’ abilities are greater than they are which is supported by the research done by Gill (1999). I assumed period and frequency were relatively easy concepts for students. I assumed converting between metres per second to kilometres per hour (and vice versa) was a relatively easy task. I assumed drawing a tangent line on curved slopes (graphing) was a skill that most students knew how to do. I assumed that I gave enough calculation examples in my notes. I assumed that after spending three weeks talking about acceleration and velocity that students would know the difference between the two.

My assumptions about students and their abilities have drastically affected my practice. In contrast to my assumptions, I found that students actually like seeing many examples of questions, and when students appear to be disengaged from the lesson, they may not be. In the past, I have simply changed teaching strategies when I felt students were not engaged in the lesson I was giving, which may in fact contribute to a poorer understanding of the topic being presented. In accordance with the purpose of my research project, I started to include more examples in my lessons, and I tried to stop worrying about the engagement of my students (to a certain extent). I found that the students responded positively to this and it seemed to improve their attitudes and performance in the class.

The collaborative environment in my class was context specific, but many learning styles (visual, kinaesthetic, auditory etc.) surfaced in the Metacogs. The student responses re-enforced the importance of using a variety of teaching methods. From my observations and analysis of the Metacogs, it appears that boys generally prefer lab work more than girls, and that girls prefer more written work than boys do. This confirmation that ‘good instruction’ includes a variety of teaching styles is refreshing and it has forced me to think about being flexible when choosing teaching styles for certain topics.

The main reason I need to become more flexible when teaching is
because too often I found myself teaching students as though there is only one way to do something. For example, for the last few years I have told students always to re-arrange the physics formula first (algebraically) before substituting in the known quantities and solving for the unknown. The only reason I actually taught this way is because that is how most textbooks, physics teachers, and math teachers tell students how to do it. The Metacogs allowed me to discover that about one third of the class preferred substituting in known quantities first, then re-arranging the formula to solve for the unknown.

Upon reflection, I asked myself, “Does it really matter which way they do it?” The answer in my head is decidedly “No.” This was an eye opening moment in my research project. I asked myself how many times I teach something and tell a student, “No, you must do it like this” (I am hoping that I am not the only teacher who is guilty of this!). Ultimately, I have become flexible in this specific matter, and I tell students to solve calculations whichever way they feel more comfortable. I challenge teachers to think of the ways they teach things while not allowing students to find their own means. At the end of the class, does it really matter how a student learns?

The collaborative experience I have gone through with my physics class has been very positive for me. It has shed light on my teaching practices and has allowed me to identify aspects about my teaching in which I hope to improve. It has forced me think critically about my actions, perceptions, and beliefs about students and about how they learn. It has allowed me to address the needs of the class as well as the individual needs of the students by allowing me to be aware of the difficulties in the class.

Encouraging students to reflect on their learning and provide me with feedback about my instruction helped shape the learning environment and provided the platform for an enjoyable, meaningful research project. The efforts I am making to improve physics instruction seem to be helping the physics enrolment at my school. Over the last two years, Physics 11 enrolment has increased from three blocks to five blocks in the timetable, and Physics 12 enrolment has improved by about 10-15%!

References


**About the Author**

**Jeff Campbell** is currently teaching Senior Physics at Chilliwack Secondary School, which gives him the rare opportunity to teach at a school in which he was a former student. His main interests at the school are increasing student enrolment in Physics, and coaching basketball.