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"Physics is not an easy subject; it requires a high degree of dedication" (Jordan 1994). This is a common belief about physics. As a student and teacher of science, I have many memories of friends, students and colleagues sharing their feelings about physics: "Physics is boring." "Physics is difficult." "Physics is for boys." "Physics is only for intelligent students." "Physics is irrelevant, not like biology, which can be related to my body." "Physics is strange, and only crazy people like Newton do it." In today's technological and information society, "more money and jobs can be found in other fields" (Jordan 1994) that do not call for as much rigour as physics. Moreover, as Jordan notes, there is an "increasing lack of importance attached to science . . . in the curriculum" in the U.S. All of these factors would appear to be the cause of the decline in student interest in physics. In Pakistan, even though science is emphasized from elementary school through university, the attitude that physics is boring and difficult still prevails, particularly among female students. This attitude, I have come to believe, is the result of the problematic teaching of science in general and physics in particular.

From my own experiences in teaching and working with inservice science teachers for about a decade in Karachi, Pakistan, at the Aga Khan University Institute for Educational Development (AKU-IED),[1] I know that many teachers have become interested in the basic concepts and questions that physics addresses. Teachers have realized that, although the language of physics may be abstract and mathematical, physics topics can be appreciated in the teaching and learning of other subjects, such as biology. Also, even without our knowing formulas or Newton's laws, force, motion and gravity affect us all. In this article, I share reflections from my inservice graduate teachers at AKU-IED. These teachers graduated in 1998 from the one-year Advanced Diploma Subject Specialist Teacher (SST) Programme in science. It was during this field-based program that I first interacted with them in my capacity as a coordinator and facilitator of the program. One teacher (I will call her Nina) later participated in my research study toward my Ed.D. from 1999 to 2002 (Pardhan 2002).

The Change in Nina's Teaching

At the beginning of the second stage of my collaborative action research, Nina shared the following thoughts about her teaching of biology:

> Particulate nature of matter and it is applied in biology! When we did the PSTS packages[2] . . . I thought it is physics. But now when I come across it in biology I realize it is not only physics and I ask you [the researcher] questions about this just like my students ask me questions. (Pardhan 2002, 121)

Nina's words suggest that her perception of physics has changed. At the beginning of the SST program some years ago, Nina's view of physics was as follows:

> I never liked physics at school. . . . The teacher taught straight from the textbook [and used the] lecture method. . . . Once I remember my physics teacher was teaching us reflection of light. She showed us a

candle reflected in a mirror and gave an oral textbook explanation of the image. This I never understood and that is the reason I never liked physics because most of the terms were not well understood by me.

This vignette reveals that Nina's science teachers were good at textbook theory but never engaged the students in practical experiences. Consequently, Nina pursued a B.Sc. honours degree with a subject combination in biological sciences only. She then taught predominantly high school biology for about 20 years before enrolling in the SST program in 1997. Nina describes her teaching strategies prior to the SST program as primarily providing explanations and notes—"rote learning rather than conceptual learning"—because that is the way she had been taught. Louden (1991, vi) writes, "Teachers teach in the way they do not just because of the skills they have not learnt. The ways they teach are also grounded in their backgrounds, their biographies, in the kinds of teachers they have become."

Nina's time in the SST program influenced her practice. By the end of the program, Nina had enhanced her pedagogical skills and pedagogical content knowledge:[3]

> The change that I feel in me is in the making of lesson plans, using different strategies, looking for new and innovative activities such that my students benefit from them by understanding and applying the science knowledge gained in their everyday life and future career. . . . I have become more eager to make science learning interesting and effective for my students.

When asked what science she was referring to, Nina responded,

> It is biology I am teaching, but now I am also using physics particulate nature to explain ideas like diffusion and osmosis. . . . While teaching biology, when it comes to any math concepts . . . I find it difficult. . . . I have no one to help [me]. . . . I nowadays collect books [and] read and try out exercises [to] try to understand the math behind and the given explanation for the question, Why are cells [meaning human] small in size? . . . After doing the activities myself I get a better understanding and feel comfortable helping students understand the *why* of the questions.

Nina moved from teaching for memorization to teaching for understanding. She also wants to enhance her own conceptual understanding of biological concepts using an interdisciplinary approach. Mathematics and "its science counterpart" (Brotherton n.d.)—physics—were Nina's least liked subjects before her SST experiences. She now recognizes the importance of applying these two subjects in her own field of interest. As a result, she is motivated to go beyond the content of the biology textbook to enhance her own and, in turn, her students' conceptual understanding. In a departure from the way she learned science, she is modelling the interconnectedness of biology, chemistry, physics and mathematics in the hopes that students will then also take an interest in math and physics.

What Led to This Change in Nina's Teaching?

> Right from the beginning I have been weak in this subject [physics]. I never got a proper coaching in it, and my interest was never in it. I had learnt so many words, but I could never relate to them until I saw you [the researcher] during the Subject Specialist Teacher Programme . . . giving [a variety of relevant] practical examples in physics for reflection of light and virtual image formation . . . and then we discussed image formation. . . . I still remember it, though it was done only once. Another example [is] when you gave a demo for the movement of the gas particles [and showed] ammonia gas and hydrochloric acid in a glass tube moving from opposite ends of the tube and making a white cloud. . . . If I had learnt it in that way then I would have been interested in physics. (Pardhan 2002, 81)

Nina's teaching was influenced by the way she was taught in the SST program. This strengthens my belief that interest in physics is related to how learners are taught. I was fortunate to have had a teacher who used experiments, models, visuals (such as charts) and explanations to help students understand physics and math concepts. This teaching, along with other factors (such as my interest, dedication and parents' support), led me to pursue a career as a teacher educator specializing in physics. I taught my students (other teachers) in the way

I had learned, and they seemed to enjoy the lessons and did well on the exams. However, during my initial teaching encounters and experiences at AKU-IED with visiting faculty from the University of Oxford in the areas of science and mathematics, I realized that my teaching—even though I used demos, models and class discussions—was not challenging, constructive, interactive and reflective. This realization was triggered by my exposure to a new perspective on how people learn—the constructivist perspective.

Theoretical Perspective

After studying the writings of such pioneers in constructivism as Cobb and Steffe (1983), Driver (1989) and Scott (1987), I realized that central to teachers' pedagogical content knowledge (Shulman 1986) is knowledge of how learners construct scientific and mathematical concepts:

> Learning outcomes depend not only on the learning environment but on what the learner already knows: Students' conceptions, purposes and motivations influence the way they interact with learning materials in various ways. (Driver and Bell 1986, 444)

Thus, students' lack of interest in physics is not the result of just the "lack of importance attached" (Jordan 1994) to the subject; how physics is delivered in the classroom plays a more important role (Shulman 1986; Driver and Bell 1986).

I recognized the importance of considering the psychological and experiential dimensions of learning rather than just the content. The shift must be from teaching for memorization to teaching for conceptual understanding. Thus, teachers must have knowledge about the most meaningful and powerful ways to represent subject matter and understanding (Shulman 1986). Reflecting on my own teaching practice, I came to understand that, even though I used demos, discussions and models, I did more talking and doing; in the process, I did not engage my students in their own knowledge construction and reconstruction. From Shulman's work, I learned that for a teacher to teach conceptually, the teacher must have conceptual understanding of the content.

With these insights, I designed my SST science program through a focused and interactive approach involving basic concepts in science, particularly physical science. The steps followed a cyclic pattern: pre-test (eliciting teachers' prior ideas), constructing knowledge, adapting knowledge, post-test (assessing change) and reflection.

Program Framework

The program's four major themes allowed the teachers to explore the basic concepts of science for Grades 1–8 as per Pakistan's national curriculum:

- "Understanding Materials and Why They Change"
- "Understanding Energy"
- "Understanding Forces"
- "Understanding Living Things and the Gases They Exchange"

An individual Primary School Teachers and Science (PSTS) package was devoted to each theme. I adopted and adapted these PSTS resource materials from a University of Oxford project for the following reasons:

- The content covered most of the basic concepts in Pakistan's national curriculum.
- The packages were easily accessible.
- The teachers were competent in the language of instruction (English).
- The packages were based on research into the alternative conceptions of teachers and students.
- The packages required the use of low- or no-cost materials that were easy to access or improvise.
- The packages used a variety of strategies—analogies, mind maps, models, thought experiments and investigations.
- The packages were based on the constructivist approach.
- The hands-on activities did not require a laboratory. They could be done in the regular classroom or even at home.
- The packages used a sequential approach to help students move from intuitive ideas to scientific ideas.
- Most important, the format of the packages modelled the pedagogical-content-knowledge approach.

The program used the constructivist approach to increase the teachers' knowledge of the basic concepts of matter, energy, forces and living things. It involved five phases: three face-to-face phases at AKU-IED alternating with two field-based phases of about three months, when the teachers returned to their classrooms. During the field-based phases, the teachers adapted and implemented contextually relevant materials from the packages and other sources. They then reflected on and re-planned or redesigned their action plans and moved to higher levels of comprehension of content, pedagogy and pedagogical content knowledge. This curriculum-revision process took the form of the four-step conceptual-change model detailed in the following section.

The Four-Step Model for Conceptual Change

Step 1: Pre-Test

The pre-test for each theme consisted of 20 items adapted from the PSTS package. The items were designed to measure teachers' initial content knowledge. For example, the items on the pre-test for the theme "Understanding Materials and Why They Change" explored teachers' understanding of basic concepts such as states and physical properties of matter (dissolving, melting/freezing, boiling, phase change, temperature change) and chemical properties using simple familiar reactions (rusting, burning, respiration) in terms of the particulate nature of matter. In each of the first 17 items, the participants had to identify the correct statement(s) about the specified concept. For example, item 6 read as follows:

a. During change of state the effect of the attractive forces between particles is always weaker.
b. During change of state the volume of the substance always changes.
c. During change of state the temperature of the substance goes up during melting and boiling and down during solidifying and condensing.
d. During change of state the distance between particles remains the same.
e. During change of state the number of particles involved remains the same.

Items 18–20 were semistructured, requiring written responses. For example, item 19 read as follows:

Read the paragraph carefully and then complete the table.

A piece of tissue paper was placed flat on a table. Half a teaspoon of water was poured into the centre of the tissue paper. The tissue paper was then left on the table for one hour.

Observation	Possible reason
Initial (just after pouring the water):	
After one hour:	

Step 2: Constructing Knowledge

In this step, teachers' active participation with peers and facilitators through interaction with the structured materials was facilitated. The teachers were encouraged and given opportunities to challenge their understanding of the concepts through application to new situations and daily-life encounters. Here, the teachers were actively constructing, deconstructing and reconstructing their knowledge.

Step 3: Adapting Knowledge

Following the enhancement of their content knowledge, the teachers were required to adapt—or, in Shulman's (1986) words, "to transform"—their personal science content knowledge to various grade levels and to make connections between science disciplines or topics. This critical and challenging step tested teachers' "ways of representing and formulating the subject that make it comprehensible to others" (Shulman 1986, 9). The teachers prepared unit plans on selected topics to be taught during the field-based phase, which they subsequently implemented and reflected upon.

Step 4: Post-Test

The post-test, the final step, was intended to indicate teachers' learning of the concepts. The post-test had the same format and number of items as the pre-test, but to minimize the influence of recall, items 1–17 and statements within each item were shuffled. Furthermore, some of the statements were modified to convert correct statements to incorrect statements and vice versa. For example, item 6 of the pre-test became item 9 of the post-test and read as follows:

a. During change of state the number of particles involved remains the same.
b. During change of state the temperature of the substance goes up during melting and boiling and down during solidifying and condensing.
c. During change of state the effect of the attractive forces between particles is always stronger.
d. During change of state the volume of the substance always changes.
e. During change of state the distance between particles changes.

The semistructured items were also modified. For example, item 19 read as follows:

> When you enter a cold room immediately after a hot bath or shower
> a. How would you feel?
> b. Why?

Salient Features and Considerations

To facilitate the conceptual-change process in light of the contextual needs of the teachers, other salient features of the program needed modification and consideration. Considerations were as follows:

- Using an interactive and provocative approach employing central constructivist principles
- Engaging in advance and ongoing planning; preparation; and identification, acquisition and distribution of appropriate materials (packages, equipment, relevant readings, handouts, instructions)
- Formulating guidelines (instructions, expectations, supplementary readings, activities) to facilitate teachers' work
- Building in relevant and appropriate tools for assessment (formative and summative), including pre- and post-tests with special consideration to conceptual equivalency between the two

All of the program's 14 teachers—13 females (including Nina) and 1 male—showed significant improvement in content knowledge as measured by the pre- and post-tests. The teachers attributed this to the way in which they were taught. One teacher wrote the following reflection:

> The discussions [we have] to engage and clarify our ideas [and] our views about the content knowledge [are] helping a lot. . . . I really have to think very hard to engage my [students] in activities which are interesting as well as challenging. I am collecting and writing the things so that I can implement [them] . . . to allow [my students] to think and work in a better way for understanding.

The teachers acknowledged that the structured program had made a difference in their conceptual understanding, and they were determined to apply what they had learned in their own classrooms. Though the program was structured, its format allowed the teachers to share and clarify their own thinking, as this teacher noted:

> The use of the science packages was a big challenge. At first by looking at the activities it seemed like child's play, but when we started doing those activities and started to think about the various aspects I realized that it was not an easy job. Compressing the solid, liquid and gas (air) with the plunger in a syringe gave a hands-on experience. I also realized how important it is to do the experiments before introducing [them] in the class [and] how important it is to have a clear understanding of our own concepts. Another very important concept which was mixed up in my mind was clarified. . . . I realized how important these sessions are which make us think and clarify [our] concepts by asking, sharing the views with colleagues as well as our facilitators.

Conclusion

Nina represents many teachers, especially female teachers, with whom I have interacted at the AKU-IED who frowned when the words *physics topic* or *physics concept* were mentioned before formal instruction and engagement in an active-learning process. Many of these teachers have now "developed a comfort level for the subject" (Brotherton n.d.) through the conceptual-change model. Many female teachers have told me, in happy and enthusiastic voices, "Had I learnt it this way then, I would have been interested in physics. I would have been teaching physics. I would have had a better understanding of things around me." As Brotherton emphasizes, "It is possible to encourage the . . . female student to believe in herself and her ability in physics."

Nina and several of the other teachers entered the program with science anxiety, particularly with regard to physics and chemistry. They also held predominantly traditional beliefs about teaching and learning. Their realization that their own understanding of basic science concepts, especially in physics, is crucial to enabling their students' conceptual understanding provided a necessary condition for a change in their beliefs and attitudes. The program design and delivery allowed the teachers to strive for greater conceptual understanding of concepts such as energy, force, properties of matter and particulate nature of matter, and motivated them to be more responsible for their own learning.

Notes

1. AKU-IED was established in 1994 with a vision to be instrumental in education reform and improvement in Pakistan. To this effect, it offers a two-year M.Ed. program in teacher education and shorter certificate and advanced-diploma programs. The short-term programs are offered in five areas: social studies, science, math, English and primary education. For more details, visit www.aku.edu/ied/index.htm.

2. Resource materials from a U.K. project called Primary School Teachers and Science (PSTS) (out of the University of Oxford) were adapted for the SST program.

3. Shulman (1986, 9–10) writes, "Within the category of pedagogical content knowledge I include for the most regularly taught topics in one's subject area the most useful forms of representations of those ideas, the most important analogues, illustrations, examples, explanations and demonstrations—in a word, ways of representing and formulating the subject that make it comprehensible to others. Pedagogical Content Knowledge also includes an understanding of what makes the learning of specific topics easy or difficult; the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons."

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