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# Taking 'STOCK' of pedagogical content knowledge in science education

*Harcharan Pardhan and Alan Wheeler*

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Change in the conceptual understanding of experienced science teachers is achievable through focused process-oriented strategies

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*Reflecting on the process through which my misconceptions became clarified, I learned how learners learn science and how it should be taught. (MEd student)*

Much of the current research surrounding teacher knowledge can be traced back to Shulman's (1986) definitive classification of it into:

- subject matter and content knowledge;
- pedagogical content knowledge;
- curricular content knowledge.

This article focuses on the second category, science teachers' pedagogical content knowledge (PCK),

## ABSTRACT

This article focuses on efforts to facilitate the development of MEd science students' conceptual understanding of content, pedagogy and pedagogical content knowledge (PCK). A basic premise of the approach taken was that to teach conceptually, students must learn conceptually. A four-step conceptual process was followed with the participants to help them actively construct knowledge about fundamental science concepts and enhance their confidence and enthusiasm for science teaching. Equivalent forms of an assessment instrument entitled the Science Test of Content Knowledge (STOCK), used as pre- and post-performance measures, revealed a significant difference. The article describes the structured activities built into the approach which employed focused, interactive, and conceptual-change strategies. The general conceptual-change approach taken is presented in relation to broader application in science teacher education.

which includes several aspects: the conceptual level of the learner; how learning actually takes place; and 'the most useful forms of representation of [particular] ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – that is, the ways of representing and formulating the subject that make it comprehensible to others' (Shulman, 1986: 6).

Stofflett and Stoddart (1994), working with teacher education students, claim that a pre-service elementary science course based on an understanding of conceptual-change pedagogy had distinct advantages over a more traditional discourse approach. Students who used conceptual-change strategies made significantly larger gains in their content knowledge than those in a traditional group; gave qualitatively stronger pedagogical responses; and used conceptual-change strategies more consistently in practice. Their research highlighted the importance of personal experience in learning science content and lends strong support to the introduction of conceptual-change strategies into science content courses taken by students both before and during teacher education.

Traditional approaches to science teaching have consistently been shown to be ineffective in enhancing students' conceptual understanding of the subject matter (Hewson and Hewson, 1988). As a consequence, graduates from high schools and university programmes continue to cling to misconceptions similar to those held by children at the elementary level (Greene, 1990). In Pakistan, pre-service teacher education programmes are predominately theoretical in nature, limited in duration, and not in accord with

modern pedagogical practice. A study by Rugh, Malik and Farooq (1991) documented that it was *'the length of academic training and not pre-service teacher training that has an impact on student achievement'* (p. 8). Further, the Pakistan education system is mainly driven by the examination system which reinforces textbook knowledge and places little emphasis on critical reasoning (World Bank, 1996). Despite concerted efforts over the years, science teaching in Pakistan remains largely didactic, dominated by lectures and teacher demonstrations, heavily dependent on textbooks and memorisation (Hoodbhoy, 1998).

One possible reason why reform measures have not been successful in Pakistan could be that they have focused mainly on student learning rather than teacher learning (Korthagen and Kessels, 1999). An assumption was made that if teachers were provided with appropriate curriculum resources and shown how to use them, they would be able to implement them effectively in their classrooms. Yet Shulman's work (1986) suggests that to teach conceptually, the teacher must understand the content conceptually. Many science teachers are seriously lacking in confidence in their subject-matter understanding, and as a result resort to simply transmitting information about science to their students. Breaking this traditional cycle requires an emphasis on teachers as learners and on ways in which change in teachers' conceptual knowledge can be achieved. Any attempt to change teachers' long-standing science content knowledge base, built up over years of prior instruction and experience, will have to incorporate conditions inherent in the conceptual-change process.

This article documents an attempt to develop the pedagogical content knowledge of students engaged in a special science component of an MEd programme, designed to implement Shulman's conception of pedagogical content knowledge (PCK), through a

focused and interactive approach involving fundamental concepts in science. The nine students involved in the study were all experienced science teachers with an average of 9.7 years of teaching.

The programme drew heavily upon constructivist theory for the development of the students' understanding of basic concepts related to matter, energy and forces. A framework was devised for the students to adapt and implement modified packages and other related contextually relevant materials such as those produced by the Primary School Teachers and Science (PSTS) project (e.g. Pendlington, Palacio and Summers, 1993). This curriculum revision process eventually led to the development of a four-step conceptual-change model based on the needs of the students (Figure 1).

### The conceptual-change model (CCM)

#### Step 1: Taking initial 'STOCK'

This step consisted of administering a specially constructed 20-item pre-test adapted from a PSTS package, entitled the Science Test of Content Knowledge (STOCK), as an initial measure of the students' content knowledge prior to elicitation and further exploration of participants' ideas about certain science concepts. Items were designed to explore students' understanding of basic concepts such as states and physical properties of matter (e.g. boiling, melting, dissolving, phase change, temperature changes); and chemical properties with respect to simple familiar reactions (e.g. rusting), in terms of the particulate nature of matter.

In items 1 to 17 students had to identify the correct statement/s in each item. For example, item 9:

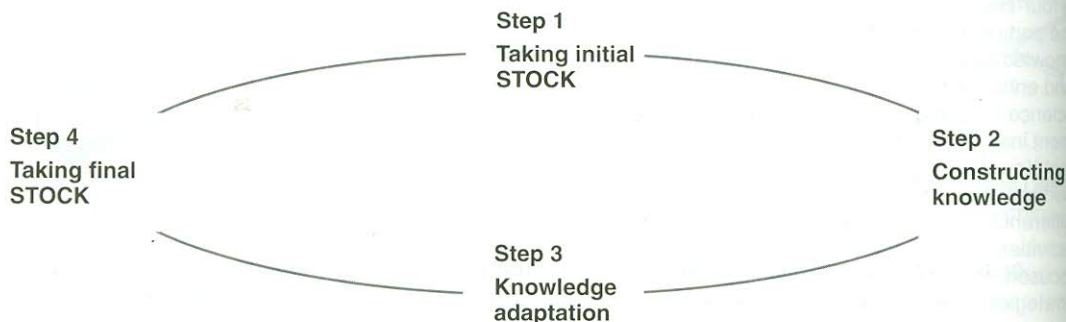


Figure 1 The conceptual-change model.

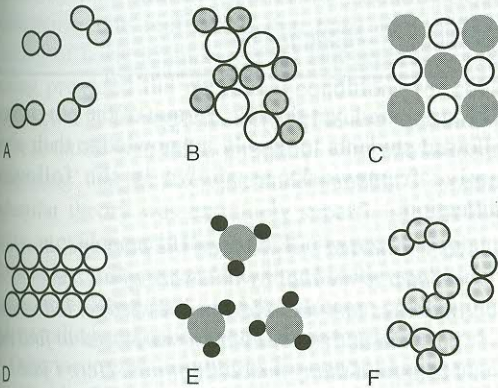
- (a) Boiling occurs both at the surface of, and throughout, the liquid.
- (b) The boiling point is lower if the atmospheric pressure is lower.
- (c) Liquids boil at 100 °C, which is called the boiling point of liquids.
- (d) The bubbles in boiling water are air.
- (e) Water always boils at the same temperature.

Items 18 to 20 were semi-structured, requiring written responses. For example, item 18:

Given below are six diagrams (A, B, C, D, E and F), showing the atoms/molecules and their arrangements, of common substances.

Can you work out which of the substances are elements and which are compounds?

Can you also identify the state of matter of the substance in each case? Give reason/s for your answer.



## Step 2: Constructing knowledge

This step allowed students significant opportunities to interact with the structured materials in an active manner and with peers and tutors. They were encouraged to challenge their understanding of concepts by applying them to new situations and everyday-life experiences. At this stage students were constructing new knowledge and in some sense deconstructing or reconstructing previously acquired learning. Several basic conceptual-change strategies were employed during this phase which have been identified as necessary for constructivist teaching and learning (Hewson and Hewson, 1988).

## Step 3: Knowledge adaptation

Following the science-content enhancement phase, students were required to formulate ways of adapting this new learning to different grade levels (age range 6–14 years) and to explore the interrelationships with

other topics or science disciplines. This stage focused more on Shulman's (1986) pedagogical challenge to find 'ways of representing and formulating the subject that make it comprehensible to others' (p. 6). This step is seen as crucial to teaching as defined by Shulman's concept of pedagogical content knowledge.

## Step 4: Taking final 'STOCK'

Similar to step 1, this final phase consisted of administering an equivalent post-test form of the instrument to obtain an indication of the students' learning on particular topic/s. The post-test had the same format and number of items as the pre-test; however, the order of items 1–17 was changed, and the options were shuffled in an attempt to maintain a measure of equivalency between the two versions of STOCK and to minimise opportunity of success by simple recall.

For example, item 9:

- (a) Boiling occurs both at the surface of, and throughout, the liquid.
- (b) The boiling point is higher if the atmospheric pressure is lower.
- (c) Water always boils at the same temperature.
- (d) Liquids boil at 100 °C, which is called the boiling point of liquids.
- (e) The bubbles in boiling water are water vapour.

Likewise the open-ended items were also modified using the same rationale. For example, the equivalent of item 18 became:

Complete the table:

	Element/ compound	State	Draw diagram showing atoms	Reason	Example
A	Element	Gas			
B	Element	Solid			
C					Water at 20 °C
D	Compound	Gas			
E					Common salt
F	Element				Bromine

## Other modifications

These were introduced in the programme to suit the contextual and linguistic needs of the students together with several important features to promote the conceptual-change process.

These included:

- planning, preparing, collecting and making available materials, packages, equipment handouts and instructions, and appropriate articles in advance;
- the use of an interactive approach based on central principles of constructivism;
- the formulation of guidelines to facilitate students' work in the limited time allocated (i.e. one week per package). The guidelines included instructions, expectations, time allocation, additional relevant readings and activities;
- the conceptual equivalency of the two STOCK instruments (pre- and post-);
- building in appropriate instruments for both formative and summative assessment.

## Findings

For illustrative purposes, this section focuses on only one topic (matter, in terms of kinetic molecular theory) covered by the students to demonstrate the positive influence a carefully planned, focused and structured effort can have on the enhancement of the pedagogical content knowledge of the participants. Table 1 shows the performance of the nine students on the equivalent pre- and post-STOCK measures.

Each of the nine students achieved an overall positive and significant gain in pre- to post-STOCK performance. Gains ranged from 5 to 41 per cent, with an average gain of 18.7%.

In addition to the impressive quantitative gains in performance of the students, there was also strong qualitative evidence of their gain in the area of pedagogical content knowledge. For example, one student acknowledged her content knowledge limitations and the superficial nature of much of her prior science knowledge. She realised that she had to place far greater emphasis on student learning in her future teaching:

*Focusing on my learning experiences (both as a learner and as a teacher) in the first week, I can say that this programme seems to be both content- and skill-based. I am not only enhancing my scientific knowledge but I am also learning how to teach science in a real classroom situation. Why? This question 'why?' is helping me to revisit my existing notions in which I gave more importance to teaching than students' learning.*

**Table 1** Pre- and post-STOCK performance on the topic of kinetic molecular theory ( $N = 9$ ).

Student	Pre-STOCK %	Post-STOCK %	Gain %
1	58	63	+5
2	76	88	+12
3	79	95	+16
4	71	98	+27
5	86	100	+14
6	79	92	+13
7	54	95	+41
8	72	97	+25
9	66	81	+15
mean	71.2	89.9	+18.7
S.D.	10.38	11.62	10.69
t-value	- 5.24, $p < 0.01$		

The structured, yet flexible, format of the programme allowed students to openly acknowledge their alternative frameworks as shown in the following reflection:

*As we started our work on the package, it seemed to me that I was aware of all the activities and the relevant knowledge, but when I did the activities, I was so surprised to find that I also held many misconceptions. Here I just want to share about the 'no-space' filling solids. I came across this for the first time and now I know what it is. In the past, I ignored many features of the practicals and related activities, but during this week I considered some of these features microscopically. For instance, I thought that ice, being a solid, would have its particles closer together than water. However, working on the package, I found this was not the case.*

## Discussion and implications

All nine students in the programme held undergraduate science degrees before entering the MED teacher education programme. However, it became apparent on the pre-test STOCK measure that several of them lacked basic conceptual understanding of many of the topics covered in the module. This would severely limit their ability to teach these topics effectively, and hamper their future role as science teachers. The

programme was designed to enhance students' pedagogical science content knowledge so that they would be able to function effectively both as classroom science teachers and, where necessary, as science teacher educators with their colleagues.

Many of the students entered the programme with traditional ideas and beliefs of what is entailed in the teaching and learning of science. That is, they placed a heavy emphasis on the science textbook in both their planning and their approach to teaching, and relied heavily on a transmission mode of delivery. The programme was an attempt to enhance existing science learning, conceptually, to enable students to teach science from a deeper content and pedagogical base.

According to Posner *et al.* (1982), for meaningful conceptual change to take place the learner must initially be dissatisfied with the ideas currently held. In the programme, student dissatisfaction was made evident by their performance in the initial STOCK assessment. The realisation that their own understanding of basic science content and processes was lacking provided the necessary conditions for conceptual change to begin to occur. In several instances, this realisation was quite dramatic, with one student confessing that her scientific understanding of kinetic molecular theory was extremely superficial. Her inability, as evidenced in the STOCK measure, to explain adequately basic processes using kinetic molecular theory reinforced her need for greater conceptual understanding and hence set the stage for further work.

Other necessary conditions for conceptual change identified by Posner *et al.* (1982), namely the intelligibility and plausibility of further scientific knowledge, were central features in step 2 (Constructing knowledge) of the process. Here students drew heavily upon the importance of sound subject-matter knowledge, and the need to discuss openly their ideas with peers and tutors. They were quick to appreciate how much they could learn from effective teaching and how to utilise relevant resources in highly practical ways. Novel, innovative ways of making science phenomena more intelligible to the students were encouraged. Often alternative ways of approaching science concepts proved effective in making them both intelligible and plausible. The need for extensive planning and preparation outside the classroom was continually emphasised. Further, the role of personal experience in constructing knowledge emerged as a central theme during this important step in enhancing students' content knowledge.

The plausibility and feasibility of teaching central concepts dealt with in the module were often refer-

enced to relevant principles of learning theory (e.g. Piagetian notions of assimilation and accommodation, Vygotsky's Zone of Proximal Development) and served to illustrate the plausibility of teaching certain highly abstract science concepts. In general, the sessions in which students constructed new knowledge were lively and interactive as various strategies were used to convince themselves and their peers as to the plausibility and intelligibility of the concepts under investigation.

The fourth and final condition identified by Posner *et al.* (1982) for conceptual change, that of the fruitfulness of the newly acquired conceptual understanding, was largely a function of step 3 (Knowledge adaptation). Here students explored how their increased conceptual understanding could be translated into meaningful understanding for learners. That is, to be fruitful, the teacher's conceptual understanding at this stage must also be made pedagogically relevant to learners. This step, of adapting the conceptual level to different grade levels and learners' capabilities, is the very essence of Shulman's (1986) notion which encompasses all those pedagogical ways of representing science content that make it more understandable to learners. In the programme, students were challenged to devise ways in which particular concepts could be 'taught' in a defensible manner across a range of grade levels. This often required extensive analysis of the existing curriculum in terms of related or prerequisite concepts that should be covered in order for the learner to truly understand the concept in question. Following this important adaptation process in step 3, students were administered the post-STOCK measure to assess the increase in performance across the topics covered. Thus, the programme provided a platform to address all four of Posner's conceptual change conditions.

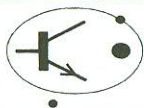
Interestingly, the four-step conceptual change model outlined here shows several consistencies with Kolb's (1984) work with adult learners. This suggested that individuals learn best if they are engaged in a cyclic process consisting of four interconnected and sequential experiences: concrete experience, reflective observation, abstract conceptualisation, and active experimentation. The congruence between the conceptual change model followed in the programme, and Kolb's earlier work with the learning cycle in science requires further investigation.

The study findings suggest that enhancement of pedagogical content knowledge is possible provided necessary conditions and support mechanisms are in place. This STOCK-taking exercise holds considerable promise for wider application in science education.

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## 2001 BRITISH PHYSICS OLYMPIAD (BPhO'2001) AND 2001 PHYSICS CHALLENGE (PC)

School physics departments throughout Britain have been circulated with information concerning BPhO'2001 for A-level students, or Scottish Students taking the Certificate of Advanced Study, together with a 90 minute Test Paper with complete solutions for teachers. The five students chosen to form the 2001 British Physics Olympiad Team will compete in the 2001 International Physics Olympiad to be held in Turkey. In addition schools will have received the competition paper Physics Challenge, for final year GCSE candidates, or Scottish students taking Highers.

### Programme of Events for School Year 2000-2001

Friday 2 <sup>nd</sup> February 2001	British Physics Olympiad Competition
Friday 2 <sup>nd</sup> March 2001	Physics Challenge Competition
Tuesday 24 <sup>th</sup> April 2001	BPhO'01 and PC Presentation at The Royal Society, London
28 <sup>th</sup> June - 6 <sup>th</sup> July 2001	2001 International Physics Olympiad, Turkey

### BPhO'01 Prizes

The National Physical Laboratory will award a prize to the highest scoring student. The fifteen highest scoring students will be invited to The Royal Society Presentation at which the five members of the BPhO'2001 team will be announced. A Scottish Prize will be awarded to the highest scoring Scottish student. In addition over 300 valuable book prizes will be awarded to students who excel in the BPhO'2001 Competition. We also offer scholarships to the 2001 British Association Festival of Science in Glasgow in September. There is also an opportunity for students to obtain vacation employment at a Government Laboratory.

### Physics Challenge Prizes

The fifteen highest scoring student and their teachers will be invited to attend The Royal Society Presentation. Over 100 book prizes will be awarded to students who excel in the competition and certificates will be presented to all those who compete in the competition and obtain marks above the 50% level.

Further information can be obtained from Dr. C. Isenberg, Secretary, BPhO'01, School of Physical Sciences, University of Kent, Canterbury Kent. CT2 7NR. Tel: 01227 823768. Fax: 01227 827558. E-mail: C.Isenberg@ukc.ac.uk