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TEACHING SCIENCE AND MATHEMATICS FOR CONCEPTUAL UNDERSTANDING? A RISING ISSUE

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ABSTRACT. Working with in service science/mathematics teachers at the Aga Khan University Institute of Educational Development, Karachi, Pakistan we find that even though the teachers take aboard innovative ideas, they find it challenging to implement the newly acquired ideas primarily because of their inadequate subject matter knowledge. In this paper we will describe and discuss select case studies from Pakistan to provide evidence regarding this issue and support it with literature from other parts of the world. We will finally share some implications and possible alternatives to address this issue.

KEYWORDS. Conceptual understanding; Pedagogical content knowledge; Pedagogical knowledge; Rising issues; Subject matter (content) knowledge; Teaching science and mathematics.

INTRODUCTION

In recent years there have been signs of conceptual shift in the practice of teachers from traditional to innovative methods. Teacher educators at the Institute for Educational Development, Aga Khan University (AKU-IED), Karachi, Pakistan view a teacher as a facilitator in supporting and developing students' thinking capabilities in general and science and math in particular. This is to enable the students to become responsible and informed individuals within the society and also to assume responsibility for their own learning. Therefore, the notion of teacher's new role in the context of teacher education at AKU-IED has been interpreted from the constructivist philosophy that suggests characteristics for teaching in accordance to a child's psychological and social perspectives of learning in the classroom. The teacher educators thus view a teacher as a facilitator in supporting and developing students' thinking. In theory, then, a teacher is expected to set tasks for the students and analyse outcomes of the tasks in order to understand how students construct meanings, listen to the other students, understand their level of thinking, and help them to achieve a common agreement of a concept (Cobb, et al., 1991; Jaworski, 1994).

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The teachers' engagement and experiences in the teacher educational programmes at AKU-IED generally lead to a change in their teaching perspectives on what mathematics and science teaching could or should be and what could be the limitations of the traditional mode of teaching for students' learning of the school subjects e.g. mathematics, science, and social studies. Findings from our experiences of working with teachers indicate that even though innovative teaching has been considered by the teachers to be desirable, the teachers in most cases can not successfully implement innovative methods for reasons that stem primarily from their own content (subject matter) knowledge.

Our findings concur with studies from other parts of the world that teachers need a good, basic conceptual understanding of content, in addition to pedagogy in order to shift their practice towards the promotion of student thinking. The discussion in this paper will focus on mathematics / science teachers' knowledge base needs particularly subject matter in planning and implementing innovations for conceptual understanding in their classrooms. The data (anecdotes/examples) that will be used in this paper for discussion and arguments is from our doctoral study field work and reflections of our own practice of working with teachers.

THEORETICAL FRAMEWORK

Shulman (1986; 1987) and Borko and Putnam (1995) suggest that a good knowledge of the subject is needed by teachers when designing curricula, lesson plans, and related instructional strategies which address the learning needs of students. In this regard Shulman has introduced a knowledge-base of teachers that;

> *Identifies the distinctive bodies of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction (1986 P. 8).*

This special knowledge of the teacher Shulman (1986) called pedagogical content knowledge (PCK). According to Shulman, (1986) pedagogical content knowledge includes an awareness of ways of conceptualising subject matter for teaching. The author has elaborated (PCK) as follows:

> *Understanding the central topics in each subject as it is generally taught to children of a particular grade level and being able to ask the following kinds of questions about each topic: what are the core concepts, skills and attitudes which this topic has the potential of conveying to students? What are the aspects of this topic that are most difficult to understand for students? What is the greatest intrinsic interest? What analogies, metaphors, examples, similes, demonstrations, simulations, manipulations, or the like, are most effective in communicating the appropriate*

> *understandings or attitudes of this topic to students of particular backgrounds and prerequisites? What students' preconceptions are likely to get in the way of learning? (1986 P. 9)*

This means that teachers need to ask questions to increase their own special form of professional understanding of teaching, for example, what are the aspects of this topic that are most difficult for students to understand? What students' preconceptions are likely to get in the way of learning? Swafford (1995) further goes on to suggest that teachers do not need to know only general aspects of classroom teaching and techniques of teaching but also need to know methods that are specific to the subjects. Thus, it is important that pedagogical knowledge of mathematics / science develops alongside knowledge of mathematical / science representations and of students' thinking. Pedagogical knowledge, thus, must include knowledge of mathematical / science representations. This in turn means for teachers to have a deeper perspective of the subject both from content as well as pedagogy point of view.

Since the introduction of the concept of pedagogical content knowledge by Shulman in 1986 other components like students' misconceptions Grossman, (1989), and learning environment (Cochran and Jones, 1998) have been added for students' meaningful learning. Ball (1990) emphasized that teachers themselves also need a deeper understanding of mathematical processes in order to understand students' thinking. Magnusson, Krajcik and Borko (1999) further presented nine orientations as part of pedagogical content knowledge for teaching of science (could be equally applicable to mathematics) process, academic rigor, didactics, conceptual change, activity-driven, discovery, inquiry, project-based science, and guided inquiry. In light of the nine orientations pedagogical content knowledge can be considered as, "an important construct for describing the role of teachers' knowledge in facilitating the students' knowledge development, particularly for complex subject matter such as mathematics/science" (Magnusson, Krajcik and Borko, 1999 : 4-5). Pedagogical content knowledge, then, is the knowledge base of a teacher that enables him/her to transform the subject matter knowledge and curricular activities into classroom.

Undoubtedly, to transform the personal subject matter knowledge into meaningful, purposeful way to promote students thinking means that teachers first and foremost need a good, basic conceptual understanding of the subject matter knowledge. A number of research findings also reveal this. Research - based theories outlined by Grossman (1992) of teachers learning to teach also favour teachers' growth in their understanding of subject matter as a starting point with the belief that "thinking about the teaching of a subject matter can influence what teachers will later learn from classroom practice" (p. 176). Fennema and Franke's (1992) Cognitively Guided Instruction (CGI) project in the area of mathematics education considered the question of whether teachers can better facilitate student learning when they are knowledgeable about how students learn mathematics. They endorsed the idea that children's ideas / thinking, when appropriately integrated in sound manner and made part of the curriculum, can influence the teaching and learning of mathematics. This model implies that the teacher's conceptual understanding and cognition of the subject matter knowledge is crucial to student learning. This can be said of science teaching as well. Smith and Neale (1989), conducted a summer program for 10 primary science teachers to understand, facilitate, and document conceptual change in teachers content knowledge and the teaching and learning primary science. They reported that as the participating teachers changed their understanding of the subject content and how to teach it using effective strategies, they also taught differently. From Shulman's (1987) perspective of 'pedagogical content knowledge' teachers' ability to teach was enhanced. The authors further go on to write:

> *Teachers' knowledge of the content (emphasis is ours), their translation of that content into appropriate and flexible usage in lessons, their knowledge of children's likely preconceptions to be encountered in lessons and the effective teaching strategies for addressing them, and especially their beliefs about the nature of science teaching, all proved to be critical components in the changes they were able to make in their teaching. (Smith and Neale, 1989, p. 17)*

The authors' work informs us that teachers' own content (subject matter) knowledge understanding is one of the critical components of teachers' knowledge base to teach effectively through innovative approaches. Nilssen (1995) and Borko et al. (1992) have cited examples from knowledge domain of mathematics about student teachers that after several attempts in trying to rectify a situation while implementing innovative ideas lost control and reverted to convential methods. This was also observed by Pardhan (2002) who worked with a group of in-service teachers at AKU-IED, Karachi, Pakistan. Furthermore, even some of the course participants of the institute who had become reflective practitioners shared their experiences to this effect. An anecdotal evidence being:

At times during a lesson when confronted with a question I would get stuck and would not know how to answer the question or give a satisfactory explanation. Once, while students were discussing the particle being the smallest 'unit' of matter, one student argued"… but I have read that particle (atom) consists of electrons, protons and neutrons. So how can a particle itself be the smallest part of the matter?" At that moment I felt myself blank and did not know how to respond to the student. I knew a lot about the individual concepts but I could not link them to help my students to understand what 'unit' meant. As a student I learnt science mainly through traditional approach: this is why I think I am facing problems. My lack of content knowledge is also affecting my pedagogical skills. (Journal entry of student teacher, 1999. Emphasis ours. Used with permission.)

Fennema and Franke (1992) had also revealed that mathematics teachers need a good basic conceptual understanding of the subject matter (mathematics) and the pedagogical knowledge (mathematics knowledge) to shift their practice from "telling" to promoting student thinking. As the anecdote above suggests the authors' findings hold true even for science teachers. A number of other research findings also support the argument that content (subject matter) knowledge of the teachers is a critical component of teachers' special knowledge (PCK) from teaching perspective. The examples of studies that follow are from mathematics field, however, these can be applicable to the science field as well. The anecdote above from a science lesson support this.

Research findings of Lampert, (1988), Clarke, (1995) and Spence, (1996) revealed an unfamiliarity of new teachers in the secondary schools with the content of mathematics and the processes of concept building that affected students' mathematics education. The authors thus suggest that an important development should include improvement in the quality of these teachers' knowledge of school-level mathematics. Clarke (1995) reported that the teachers had personally, as students, studied a mathematical topic in isolation from other topics, which was not enough for them to promote conceptual understanding amongst students. Lampert (1988) questioned limited mathematical knowledge of a teacher in relation to achieving his or her new aim, of promoting students' mathematical thinking, in a classroom, "how can a teacher who lacks a 'network of big ideas' and the relationship among those ideas and between ideas, facts and procedures develop these things?" (p. 163 - 164)

Eisenhart et al (1993), in their description of a teacher's attempt to teach the division of fractions revealed a gap in the primary teachers' knowledge of the underlying structure of mathematics in terms of relationships and interconnections of ideas and their meaning to mathematical procedures. In their research, the teacher, himself, was unable to explain what it meant to divide, or to use different forms of representations, or to link the division of fractions with whole numbers. The teacher's incomplete knowledge-base hindered his decision to implement innovative teaching methods in the classroom. The authors research besides the teacher's lack of conceptual understanding of fractions, also identified a number of other factors (such as pressure of syllabus, workload) that inhibited him from teaching topics conceptually.

Ma, (1999) found that a limited knowledge of mathematics restricted a secondary school teacher's capacity to promote conceptual understanding among students. Ma's research revealed that the teachers, in her research, knew about new methods of teaching but their limited subject matter knowledge did not let them achieve their new aims of teaching for conceptual understanding. The author reasoned this to be because of teachers' own experiences of learning of mathematics without understanding conceptually. Ma illustrated this by describing problems with the mathematical knowledge of several experienced teachers, that lead to difficulties in teachers' trying out new ideas in their own teaching. The teachers as a result of their engagement in a teacher development programme had come to believe that there was a need for, both, to remember and also to understand procedures. However during their classroom practice while teaching topics like multidigit number multiplication their approach was still predominately based on memory of procedures rather than on understandings. Spence (1996) examined issues surrounding the mathematical knowledge of two teachers in their beginning attempts to teach mathematics. The author noted that the teachers' limited understanding of mathematics as a subject blocked their understanding of the students' learning processes and did not allow the teachers to analyse their own teaching practice. The author also found that one of the teachers was not even able to recognise her own lack of understanding of mathematics. Hutchinson (1996) reports that beginning teachers' problems with mathematical knowledge can frustrate them to a point that they find it safer to revert to traditional approach:

> *Even though Kate [the teacher] had a strong background in mathematics, she became frustrated when activities challenged that knowledge and appeared to revert to traditional method as the "one right way". Her previous learning in the domain did not appear to be conceptually developed to allow for new challenges to that knowledge. (p. 182).*

The above discussions, literature review and research findings suggest that the subject matter knowledge of science/mathematics teachers is crucial for shaping or reshaping their practice. This has also been our experience of working with mathematics and science teachers in Pakistan. In this paper we will share our similar experiences, learnings and their discussion and implications.

FINDINGS

The subject matter (science/mathematics) understanding of the teachers who graduate from the in service teacher development programme from AKU-IED, gets challenged as they teach mathematics or science with reasoning. Teachers' limited conceptual understanding of the content and heavy reliance on the prescribed textbook methods and particular answers becomes evident when they express their respective subject matter point of views while planning, teaching and analysing their lessons beyond the textbook. Teachers' limited understanding of the subject matter hinders their attempts to incorporate their new learnings in the planning of lessons making connections of their innovative/new ideas with the textbook methods and designing alternative assessment. Teachers perceive all this as a barrier to their own mathematical/science assumptions and their students' examination. In this paper we will use specific examples or anecdotes from our field based experiences of working with the participant teachers of our doctoral studies (Pardhan, 2002; Mohammad, 2002) to discuss further the above stated problems.

Teachers' Planning Processes

The examples from our wider set of experiences and their analysis revealed that problems with subject knowledge presented a barrier to the teachers in unpacking the conceptual underpinning of the subject specific procedures when they made effort to plan lessons according to their new vision of teaching. Most of the teachers at times were unable to review, clarify and rationalize the subject matter related assumptions behind the textbook exercises or while trying to teach beyond the textbook. For example in a pre-observation conference with a teacher educator, a teacher (Naeem) expressed his desire to plan a lesson on percentages for students' conceptual understanding. He shared that prior to AKU-IED experiences he had mostly used the textbook method with his students (he became silent and looked at the teacher educator). In order to pursue the talk the teacher educator asked Naeem to share his understanding of the topic. In response Naeem just restated the textbook given method 'multiplying a fraction by hundred converts it to percentage. He could not provide further explanation although the teacher educator tried to probe and prompt him. To initial Naeems' thinking beyond textbook the teacher educator suggested some real life examples on percentages e.g. exam grades, discounts, and tax and also discussed what they meant. This helped Naeem to recall the textbook definition of percentages as a part out of hundred. Discussion enabled Naeem to recollect his AKU-IED experiences, basically, what resources the programme facilitators used and he shared this with the teacher educator. He then thought of using some of those ideas e.g. making some posters of daily life commercials such as '20% extra toothpaste', '50% of the cost'. The rationale to use these posters he stated would be to initiate students discussion on percentages to enable them to explore the meaning themselves. However, in the middle of the discussion Naeem started raising concerns about accessibility of resources and arrangement for displaying the posters by saying "there is no material available in school and no arrangement of hanging charts in the classroom" [1](field notes January 6, 2000). In response to this the teacher educator tried to encourage Naeem to think of other alternatives which could work in his situation e.g. using chalkboard and oral discussion, Naeem's position in this regard is reflected in his words:

> *The writing could take more than 10 minutes, and in a 30 minute period, I do not think it is possible to teach a complete lesson. I do not think that verbal examples could motivate children to participate in the discussion. Children need stimulus; this is the beginning [to apply different methods]* [2]*(6 Jan, 2000).*

As the dialogue above reveals, for Naeem to plan a lesson beyond the textbook for percentages proved to be a demanding task. The teacher educator felt, perhaps, an equivalent fraction approach would enable Naeem to come up with a plan. The teacher educator thus suggested to Naeem to review equivalent fractions and building on it to help students to develop the meaning of percentages; Naeem liked the idea and wanted to give it a try. However, it did not take him long to turn back to the teacher educator saying "how can I teach fractions and their relation to percentage, at the same time complete the textbook exercise in limited time in one

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[1] Similar concerns have been raised by a number of science graduates as well. Some examples are "materials are not available…no space to store materials, models and charts…" (personal notes)

[2] Time is constraint…I had to achieve all the objectives…I could not… reading process for the students is problem…discussion in some things becomes long…and planning could not be completed on time… (Immediately after lesson self-reflection Saira September 27, 2000)

lesson (field notes Jan 6, 2000)[3]. Naeem found it difficult to plan a lesson beyond the textbook approach and explanations.

The example given above reveals the teacher's limited mathematical knowledge hindered him to explore alternate method of teaching. The teacher wanted to plan a lesson on percentages, but he was unable to discuss the meaning of percentages, their relation to fractions, the assumptions underlying the relevant formula, and the application of the formula in other new situations. Teachers' subject matter knowledge was solely restricted to the textbook and it was also found to influence their handling of students' responses or answers.

Handling students' responses

During the study it was found that limited subject matter knowledge was problematic for teachers to handle student responses or answers effectively. Teachers were unable to analyse content related assumptions behind students' responses or to use student answers to further enhance students' content understanding. The teachers struggled to attempt to reconcile a new method of teaching with their limited subject matter knowledge. This lead to the teachers recognizing their inadequate conceptual understanding. The effects of this on teachers' behaviours were; rephrasing the students verbal expressions; ignoring students' answers; and imposing own or textbook knowledge on students without understanding. The above conclusions are based on a number of lessons observed of the teachers. A selected sample anecdote is shared as evidence.

In a lesson on 'equations' a teacher [Sahib] ignored students responses in which either the student explanations were different from the one in the textbook or [Sahib] was unsure of the correctness of the response. Sahib had some of the students to come up to the chalkboard and solve equations. He encouraged them to provide reasons and explanations for their method. He started them off by using simple (e.g. $x + 7 = 9$) equations and then he moved the students to more difficult ones ($2x - 3 = 1$). This is when [Sahib] faced problems as the teacher [Sahib] - student talk in the box below reveals.

The teacher invited a student to the chalkboard to solve the equation $2x - 3 = 1$

1 T What will we 'cancel' first?

2 S1 Three

3 T Good

4 T What is the sign with three?

5 S1 Minus

6 T What does minus three mean?

The student without speaking….. on the chalkboard writes $2x = 4$.

3 Syllabus is a problem…some discussions become long and we rush to complete the syllabus. (Immediately after lesson self-reflection Saira September 27, 2000)

7 T Think again

The student (S1) did not respond….moving away from S1 and addressing the other students the teacher asked,

8 T Who will tell the meaning of minus three?

9 T Good. Yes, who will tell hmm…?

10 T We add three to one side and do the same operation on the other side…(no response from students…they looked confused).

The teacher moved to the student (S1) again,

11 T What next?

The student (S1) wrote, x = 2

So far student (S1) has responded well to the teacher's mostly recall type questions; however teacher [Sahib] hardly acknowledges. It appears Sahib wants explanations along the lines of the textbook.

12 T Why is x equal to 2? Sahib is attempting to probe student's (S1) understanding

The student without speaking wrote on the chalkboard x + 2 = 4

13 T (Sahib without responding to student's (S1) response turns to other students)

Anyone in the class, tell me the meaning of 2x?

14 S2 (Another student who raised his hand) x plus x

The teacher ignores S2's response and invites another student to answer the question

15 S3 x multiplied by 2

16 T Good (as if teacher expected only correct textbook knowledge and hence acknowledges it but incorrect ones he ignored), if there is no sign between x and a number it means that there is a sign of multiplication.

The teacher wrote on the chalkboard in one of the corner, x * x = x2 and x + x = 2x

17 T In multiplication powers are added and in addition coefficients are added.

A similar segment of a science lesson is given in appendix 1.

From this point onwards the students remained silent, looking at each other…. looking confused… teacher went on talking…. 'telling' textbook explanations and imposing his own ideas onto the students without a single attempt to find out why students (S1, S2) responses were different from his expected (textbook) ones.

The teacher's inappropriate explanations, inadequate acknowledgement of students' responses and practically no attempt to seek for student explanations for their correct or incorrect responses had a negative impact on the students. Students became silent listeners and confused. As lines 16 and 17 reveal teacher himself had limited content knowledge that too was textbook knowledge. It was in the post-conference that the teacher realized that his knowledge was insufficient to understand the students' mathematical thinking processes and to analyze students' mathematical assumptions. The teacher was unable to extend students' ideas beyond textbook, to help them to formalize their intuitive thinking and challenge their incorrect notions to promote shared meaning of mathematical procedures. More importantly to make connections and meanings of own and new ideas with the textbook content. Not only Sahib but several other teachers we have worked with have revealed this concern.

Connection between new ideas and textbook content

The lack of teachers' mathematical understanding hindered them to make connections of new ideas with mathematical assumptions in the textbook procedures. These problems with mathematical knowledge acted as a barrier to teachers in linking their students' prior / former learning to the new concepts in the context of a lesson. The teachers often attempted to organise practical activities to teach for conceptual understanding but they could rarely incorporate any adequate explanations with reasoning within that chosen practical demonstration. Next we offer a case from our classroom observation that exemplifies this issue of teachers' inappropriate explanations.

The teacher [Sahib] introduced 'circles' through a practical demonstration. Sahib asked one student (Kamran: students sat on the floor, there were no student benches or chairs in the class) to stand up and stretch his arm, then the other students were asked to stand at a distance of Kamran's arm length; in this way he had the students to form a circle themselves with one student (Kamran) at the centre. Next he drew a circle on the chalkboard. He then asked students to imagine and identify their positions in the diagram on the chalkboard. From this moment onwards the teacher-students talk that followed is given below in the box.

1 T Now look at the board.

2 T What is the distance between Kamran and each student?

3 S (A voice from the class) about an arm.

4 T Where is Kamran[4]? (Kamran Kahaan hai ?)

5 S In the middle (Beech main).

6 T In 'English' [language] we call it [pointing at the centre] 'centre', and the distance between Kamran and each student is called 'radius'.

[4] Kamran was the student who was standing at the centre in the practical demonstration; therefore, the teacher asked them to imagine the position of Kamran.

The teacher next asked the students 'what will we call the distance between Kamran and each of you…'(repeated it three times). Students (in chorus each time) radius. He then joined two points on the circumference of the circle to form a chord and asked:

7 T When we join two points on a circle what do we call this distance?

8 S2 'radius',

9 S3 (Another voice) 'diameter'

10 T The line or distance that joins two points of a circle is called a 'chord'.

The teacher then drew another line segment this time passing through the centre of the circle and' told' the students this is the diameter that also joines two points on the circle. He then asked:

11 T What difference do you see between these two lines? (pointing to the chord and then the diameter: chord and diameter were free-hand drawings)

12 S4 One is straight and the other is slanting.

13 S5 One passes through the centre while the other does not.

14 T How many radii are in a diameter?

(no response from the students.)

15 T What is the difference between a diameter and a radius?

16 T If diameter is two then the radius is one.

17 T If diameter is 10, what will be the radius?

18 S6 Five.

19 T A diameter has always two radii.

The teacher then asked the students to draw circles and identify diameter, chord and radial [5] ***segment.***

The above example shows that the teacher did not use appropriate mathematical language in introducing the circle; for example, he seemed to be confused between the geometrical concepts of 'line segment' and the physical quantity 'distance' (e.g., line 10). He did not provide clear definitions of the terms that he used namely radius, radial segment, chord, and diameter. Neither did he explain clearly that he used the radius interchangeably to mean 'half length' of diameter as well as a 'line joining the centre to any point on the circumference'. The teacher found it difficult to integrate practical activities with the appropriate and mathematically accepted textbook explanations. We believe this was either because the teacher did not have

[5] According to the textbook a radial segment is a line which joins the centre to circumference and radius is the distance between the centre and circumference.

adequate mathematical knowledge to provide the students with a clear explanation about these terms or the teacher had inadequate competency in using practical activities.

DISCUSSION

The above examples uncover an issue of the teachers' inability to integrate informal and formal subject matter assumptions, ideas and procedures and the students' former learning experiences in order to promote students' concept building in the subject. The teachers' knowledge was based on textbook knowledge for which they did not have much conceptual understanding. The teachers' own lack of subject matter understanding did not allow them to promote a child-centred learning environment. They, primarily sustained their authority in the classroom and used traditional teaching methods contrary to what they intended to achieve.

A gap existed between the teachers' personal subject matter knowledge and what they expected of students' learning with reasoning to be. The teachers' beliefs and aims of teaching were updated by AKU-IED's influence but their inadequate subject matter understanding obstructed them to achieve their aims of the lessons. The teachers' new expectations of their teaching exacerbated the problem of their limited subject matter knowledge. The teachers seemed to be unable to re-conceptualise their teaching in the real classroom conditions in the context of their improvement in practice. All three teachers taught the lessons in fragments without establishing explicit connections or incorporating students' responses.

The issue of how teachers can develop new roles with their inadequate mathematics or science background needs to be addressed. How can teachers teach differently, if they have only memorized rules themselves? If the teachers' own experience of doing mathematics/science means following the teachers' rules or memorizing what teacher or textbook says, then how can they provide the experience of mathematics/science with reasoning without them knowing the reasoning themselves? Do the teachers have resources and support to advance their knowledge at the school level? What would be the consequences of the teacher's limited knowledge for the children's learning?

We suspect that the limitation of mathematics/science is a big threat to the teachers' confidence and desire for developing innovative teaching. In the context of a Pakistan school, mistakes are not accepted due to an expectation that focuses on the product and 'the what' instead of the process and 'the why'. For example, when a parent asked for clarification of the teacher's explanation (that was different from the textbook's explanation), the teacher felt threatened. The teacher reverted to the textbook and blamed the student's carelessness in listening to the teacher, because s/he wanted to avoid further complications and misjudgments. The teacher did not want to be dishonest but for his/her it had implications for his/her appraisal and his/her position at the school. The teacher's behavior reflects the context of Pakistan schools, where mistakes are not expected and accepted, particularly from professionals and elders. Our own background experience of living and teaching in Pakistan confirms that it is a matter of shame and threat to admit a lack in knowledge; it is highly embedded in the cultural norms of our context. As teachers make efforts to improve their teaching, they are likely to run a risk of being negatively viewed because it exposes their lack of knowledge and this will be seen as having a negative effect on students' learning outcomes.

Our analysis uncovers the issue that teachers cannot grow further professionally with their limited subject matter and pedagogical knowledge. The teachers need to enhance their mathematics/science understanding in order to understand what constitutes teaching of mathematics/science with reasoning. The teacher educators (in this case at AKU-IED) need to have a greater sensitivity to, and understanding of, the consequences of teachers' limited knowledge on students' learning as well as implementing the learning from a Visiting Teacher (currently called Education in Certificate: Mathematics or Science) programme. Should educators (in this case at AKU-IED) suggest that teaching directly from textbooks is more appropriate in the circumstances of limited understanding of mathematics and pedagogy? What implication has this for a future VT programme?

Our earlier discussion of the underlying philosophy of the teacher educators in Pakistan addresses[6] important issues in relation to development of teachers' mathematics/science teaching that supports school children's development of thinking capabilities. A traditional mode of teaching reduces children's cognitive and intelligent thinking and sustains the shortcomings in developing innovative teaching. However, the teachers appeared to be aware of the usefulness of the new methods of teaching and were motivated to improve their teaching. They also believed that to involve students in learning with reasoning is beneficial for students' development of thinking.

However, a transition from routine practice to a new perspective of teaching is not an easy task for the teachers in Pakistan. The teachers' own conceptual limitations restricted them in conceptualising the underlying assumptions of the philosophy of AKU-IED in the practicality of their new roles as teachers (Mohammad, 2005). The teachers were unable to explain the assumptions of their proposed new practice designed to help students develop conceptual thinking from a mathematics/science activity when they tried to implement their AKU-IED learning into the classroom. They had difficulties in engaging students in any problem solving method to enable students to generate their own ideas. The teachers were able to collect and include in their plans interesting activities, invite students' answers, organise group work, but they were unable to align such activities to the objectives of the lessons for conceptual understanding.

There are indicators in this study for AKU-IED that point to teachers' needs with which the teacher educators must be concerned. The teacher educators at AKU-IED (including

[6] Based on concepts such as learning with reasoning, encouraging students' participation in activity and thinking and organising the classroom for cooperative learning

ourselves) need to; review what teaching means in Pakistan schools; consider the people who will teach and their mathematics/science comprehension, and to improve the design and the delivery of the programmes.

Teachers cannot go further on their own with their limited understanding of mathematics /science subjects and mathematics/science teaching. They need to develop their own conceptual understanding first before they can make sense of students' thinking, handle their answers effectively and promote conceptual understanding (Mohammad, 2004).

Two major and crucial areas for the educators at AKU-IED to consider we feel are:

(a) Mathematics/Science Knowledge - teachers have very limited mathematics/science subject matter knowledge; they need to be taught mathematics/science. The Aga Khan University-Institute for Educational Development needs to address how, where, and when would teachers learn mathematics/science? What would be the consequences of teachers' limited mathematics/science in understanding of new ideology of learning presented at the AKU-IED?

(b) Mathematics/science Pedagogy - teachers do not appear to understand the values of teaching concepts such as negotiating, encouraging, participation. They do it, if at all; because AKU-IED said it was good. Where/when/how do they come to understand its value and need? Of course, (b) can be related to (a) but with regards to 'where/when/how' it needs to be addressed.

CONCLUSION

In this paper we have argued, with supporting evidences from Pakistan, for the need of sound subject matter knowledge of mathematics/science teachers to empower them to be more successful in implementing innovative teaching rather than in the struggle to revert to old practice. This, as the above literature review also suggests, resonates with the findings of other countries e.g. UK and USA. The issue, thus, is local as well as global. Currently, we feel the mathematics/science teacher education courses offered at the teacher education institutes predominantly address subject matter knowledge as a part of the over all discourse of the programme/course to deliver the new instructional theories, philosophies and pedagogy. As such the course time is always insufficient to cover all necessary content adequately. We feel there is urgent need for the teacher development institutes to provide alternate pathways to enhance teachers' (mathematics/science) subject matter knowledge. Possible alternatives can be: introduction of subject specialization courses that can allow teachers to study one or more subjects in depth. Another pathway can be establishment of University-School partnerships that can eventually lead to teachers' networking for on-going learning through 'communities of learners' (Pardhan and Rowell, 2005). In order to resolve teachers' issues related to subject matter knowledge, there is a need for 'communities of learners' at professional level among teachers who are committed to change their practices. Furthermore, teacher educators or teacher education reforms should not focus solely on strategies for the development of individuals but also promote ways and means where the individuals can work with colleagues and organisational leaders to impact learning outcomes.

REFERENCES

Ball, D. (1990). The Mathematical Understanding that Prospective Teachers Bring to Teacher Education. The Elementary School Journal, pp. 449-466.

Borko, H., & Putnam, R. T. (1995). Expanding a teacher's knowledge base: A cognitive psychological perspective on professional development. In T. R. Guskey & M. Huberman (Eds.), Professional development in education: New paradigms and Practices. (pp. 35-66). New York: Teachers College Press.

Borko, H., Eisenhart, M., Brown, C. A., Underhill, R. G., Jones, D., & Agard, P. C. (1992). Learning to teach hard mathematics: Do novice teachers and their instructors give up easily? Journal for Research in Mathematics Education, 23(3), 194-222.

Clarke, B. (1995). Expecting the Unexpected: Critical Incidents in the Mathematics Classrooms. Unpublished Doctoral Dissertation, University of Wisconsin-Madison.

Cobb, P. et al. (1991). Assessment of a Problem Centred Second Grade Mathematics Project. Journal For Research in Mathematics Education, 22(1), pp. 3-29

Cochran, K. F., & Jones, L. L. (1998). The subject matter knowledge of presservice science teacher. In B. J. Fraser, & K. G. Tobin (Eds.), International handbook of education (pp. 707 - 718). London: Kluwer Academic Publisher.

Eisenhart, M., Borko, H., Underhill, R., Brown, A., Jones, D. and Agard, P. (1993). Conceptual Knowledge falls Through the Cracks: Complexities of Learning to Teach Mathematics for Understanding. Journal for Research in Mathematics Education, March, pp. 107-114

Fennema, E., & Franke, M. L. (1992). Teacher's knowledge and its impact. In Douglas A. Grouws (Ed.), Handbook of Research on Mathematics Teaching and Learning. New York: Simon and Schuster Macmillan, 147-164).

Grossman, P.L. (1992). Why models matter: An alternative view on professional growth in teaching. Review of Educational Research, 62, 2, 171-179.

Grossman, P. L. (1989). Learning to teach without teacher education. Teachers college record, 91, 191-208.

Hitchinson, E. (1996). Pre-service Teachers Knowledge: A Contrast of Beliefs and Knowledge of Ratio and Proportion. Doctoral Thesis, University of Wisconsin - Madison.

Jaworski, B. (1994). Investigating Mathematics Teaching: Constructivist Inquiry. London: Falmer Press.

Lampert, M. (1988). The Teacher's Role in Reinventing the Meaning of Mathematical Knowing in the Classroom. In Behr, M. J. et al. (ED) Proceedings of the 10th Conference of the North American Chapter of the International Group for the Psychology of Mathematics Education, pp. 433-480

Magnussan, S., Krajcik, J., & Borko, H. (1999). Nature, source, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome, & N. G. Lederman (Eds.) Examining pedagogical content knowledge. (pp. 95-132). London: Kluwer academic publisher.

Ma, L. (1999) Knowing and Teaching Elementary Mathematics, London: Lawrence Erlbaum Associates.

Nilssen, V. (1995). Unexpected answers: Case study of a student teacher derailing in a math lesson. Revised version of a paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, April 18-22).

Pardhan, H., & Rowell, P. (2005). Science Teacher Development in Pakistan: A Learning Community Approach. In Retallick, J., & Farah, I. (Eds), Transforming Schools in Pakistan towards the Learning Community. Oxford. (In press: to be published in April, 2005)

Pardhan, H. (2002). Collaborative Action Research for Science Teachers' Pedagogical Content Knowledge Enhancement. An Unpublished PhD Dissertation. Canada, Alberta: University of Alberta.

Mohammad, F. R. (2002). From theory to Practice: An Understanding of the Implementation of IN-service Mathematics Teachers' Learning from University in to the Classroom in Pakistan. Unpublished PhD Dissertation. UK, Oxford: University of Oxford.

Mohammad, F. R. (2005). 'Problems of teachers' re-entry in schools after in-service education', in I. Farah and B. Jaworski (Eds), Partnerships in educational development Karachi, Pakistan, Oxford University Press. (In press)

Mohammad, F. R. (2004). Practical Constraints upon Teacher Development in Pakistan, Journal of In-service Education, Vol. 30, Number 1.

Shulman, L.S. (1987). Knowledge and teaching: Foundations of the New Reform. Harvard Educational Review, 57, 1-22.

Shulman, L. S. (1986). Those who understand: knowledge growth in teaching. Educational Researcher, 15, 4-14.

Smith, D. C., & Neale, D. C. (1989). The construction of subject matter knowledge in primary science teaching. Teaching and Teacher Education, 5 (1), 1-20.

Spence, M. (1996). Psychologizing Algebra: Case studies of Knowing in the Moment. Doctoral Dissertation in preparation, University of Wisconsin-Madison.

Swafford, J. (1995). 'Teacher Preparation' in Prospects for School Mathematics. In

Carl, M. I. (Ed), Mathematics Education Trust of the National Council of Teachers of Mathematics.

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APPENDIX 1

The lesson began with recall of text-book definition of matter 'matter has mass and occupies space': (Key: S1, S2,…. Represents individual student; SS represent all students and PT represents the teacher)

PT Tell me what is matter?

S1 There are three states of matter

PT I have not asked about states…

S2 Miss, anything that is like stone.

PT (no response to the student S2's answer) Anything that has…. (expecting students to respond … students quiet or some talking) What it has … Sara, what it has… (no response from Sara) …Anything which has mass and occupies space … now say together…

PT and SS (in chorus) Anything that has mass and occupies space (repeat a couple of times).What are three states of matter?

SS (almost all in chorus) Solid, liquid and gas

PT (repeats) Solid, liquid and gas…can you give me example? (lesson transcript)

PT is at the chalk board, most of the time facing the chalkboard. Many voices … hard to hear anything distinctly, students at the back of the class near me [R] seen doing their own things…busy talking…PT writes on chalkboard: Solid Liquid Gas…walks to a student in front close by…(field observations and notes)

S3 Sui Gas (local name for methane gas used as energy source by most house holds)

PT Very good (goes back to chalkboard writes 'Sui Gas' under 'Gas' and writes some own examples under 'Solid' and 'Liquids' and then erases everything). (lesson transcript)

It is five minutes into the lesson… mostly teacher talks and that too fast and expects quick standard answers. Mostly students closer to teacher's table just in front of the classroom seen paying some attention rest doing own things… looking around, fidgeting, or just sitting idle…In similar manner, for the next seven minutes students are asked 'what' and 'when' questions about shopping apples and milk and teacher manages few students to say apples 'we buy in kilo' and 'milk in liters'. Simultaneously keeps writing and erasing on board. Finally makes two columns: kilogram/gram/milligram/pau and liter/milliliter as headings. Note 'pau' is a local unit for 100 grams. And then suddenly turns to the class and 'now I will give …you (students) will have to be careful…' leans over a table by the chalkboard, picks up plastic bags with stuff in … co-teacher who had been standing in the front left corner of the class all this time helps to pass the bags …teacher randomly gives away items (including sheets of paper to rite on) tied in plastic bags or loosely… students start talking, reaching for items or almost snatching items… some girls hold onto items for themselves…noise level goes up…teacher mostly stays in front of the class with one group in particular, facing away from the rest of the class …for the next fifteen to twenty minutes there is commotion in the class… most of the time students are unsure as to what to do or perhaps just seem to seek teachers consent. Students are heard asking questions but mostly low level 'what is this … thing? what to write? where to write this?' or reporting what the other student has written. Teacher responds now and then and that too by 'telling' rather than stimulating discussion. Teacher's questions are mostly low level 'what' 'where' type, though 'why' were heard at times, but these were inadequately capitalized upon for purposes of making students to think or get a satisfactory answer... (field observations and notes)

Students seemed to have difficulty in a) knowing what to do b) reading and writing words and c) understanding concepts. The student-teacher talk most of time was more like a guessing game as this transcript segment suggests: [Key: PT for teacher; S1, S2, ... for students]

PT (pointing at a student's work) this one here write 'coca cola' …what is this that you have written…(picks up a coca cola can)

S3 (pointing at a writing on the can) This here is its name

PT Read it

S3 Ko…kaa… ko…ka

S4 Teacher this (meaning the word coka cola) should come up here

(unlike most of the other students, this student had divided the page into two columns by drawing a straight line right across the middle of the page widthwise. 'Up' meant top have of the page …see appendix 6)

PT Why should it go up there?

PT (mixed voices of students…can only pick up some words …) ko…ka…teacher…ko… teacher…will go up (meaning top half of the page) …

PT Why would it be up?

S4 Teacher it has air… air is in it…

PT What comes in it?

S4 Yes, liquid comes in it.

PT Yes,

S3 Teacher solid…solid…Yes

S4 Gee…ram

PT Yes, it will come under 'gram'. Very good. (lesson transcript/ field notes: for sample transcript see Appendix 2)

Students' not knowing what to do lead to confusion and restlessness in class. The last ten minutes were mostly spent in teacher trying to manage class and in the process getting frustrated: Ten minutes to go for students' snack break to be followed by school recess… noise level has risen …materials are still on the tables or some on the floor…teacher is trying to get students' attention…it is not working… suddenly …(field observations/notes)

PT (almost shouting) Now girls…now girls…what have you written? Say your answers… (turns around faces the chalk board and the students sitting on her right in front…) under the column 'Kilogram/gram' ... (the students in front get all the attention and they contribute five items... rest of the students either moving around, talking or fighting … for the Litre/millilitre column teacher hurriedly entered five items herself without saying a word… it is only four minutes left for the lesson… in an angry loud voice) I want you all to stop…please bring all the things (only some students from the two groups in front responded and walked up to hand some items… co-teacher and teacher move around to collect items…trying to make students quieter and stay in their seats… students were getting restless…impatiently waiting for the bell to ring…). (lesson transcript/field notes)

Source: Pardhan, 2002: 62-65