Developing pedagogical content knowledge of science teachers through action research: A case study from Pakistan

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Abstract

The aim of this study is to analyze the action research undertaken by Khan as a teacher researcher in a private school as part of the degree requirement of his M.Ed. program in Teacher Education at the Aga Khan University, Institute for Educational

Development. The purpose of this analysis undertaken by the first author and supervisor of the study in collaboration with Khan was to understand the development of Pedagogical Content Knowledge (PCK) of the teacher researcher through action research in a science classroom in the context of Pakistan. Khan taught the concepts of heat and temperature using an inquiry based pedagogy to grade 9 physics class and also examined his own practice of this innovation using action research. Using Carlsen's concept of PCK as the lens for analysis of the research report written by Khan the first author finds that transforming his understanding of the topic to teach with the indicated instructional strategy required him to transform his own understanding of science content. The findings also indicate that the requirement of cumulative testing was a barrier to the implementation of innovative pedagogy in the school context.

Keywords: Action Research, Inquiry, Pedagogical Content Knowledge, Science Teaching

Introduction

One of the ways that the role of teachers has the potential to change is the expectation or the desire for teachers to become researchers. Stenhouse persuasively argued that, "it is not enough that teachers' work should be studied: they need to study it themselves" (Stenhouse, 1975, p. 143). Since then the "teacher as researcher" movement has gained widespread support from academics as well as teachers (Elliot, 1991; Cochran & Lytle, 1993; Grundy, 1994; Kemmis & Mctaggart, 1988). Action research has been acknowledged to be one of the methods best suited to the work of practitioners such as teachers (Altrichter, Feldman, Posch & Somekh, 2008; Goswami & Stillman, 1987; Reason & Bradbury, 2001) but questions have also been raised at the efficacy of action research in the classroom (Hammersley, 2004; Radford, 2007). However, in Pakistan the teacher as researcher movement has not as yet gained currency or general acceptance. Research is considered to be a very esoteric activity that can only be undertaken by University professors or by scientists in laboratories. Hence, the concept that teachers can conduct research to improve their practice is still very new and novel. But over the last 15 years action research has been introduced in Pakistan by teacher education institutions in the private sector such as the Aga Khan University, Institute for Educational Development (AKU-IED) and Notre Dame Institute of Education (NDIE). Faculty members either from abroad or trained from outside

Pakistan introduced it in the curriculum of their Masters Degree programs and also began to write about their experiences (see for example, Halai, 2004; Retallick & Mithani, 2003). But teacher education degree programs offered by public sector universities generally do not include a research component as yet, but attempts have been made to include it in the new B.Ed. and M.Ed. curriculum (HEC, 2010).

This paper attempts to understand the development of Pedagogical Content Knowledge (PCK) as Khan a science teacher tries to both teach the topic of *heat and temperature* to grade nine female students of a private school, using inquiry approach and simultaneously understand his practice through action research as part of programmatic requirement at AKU-IED. In other words this study analyzes the role that action research plays in developing PCK in the teacher researcher. For this paper PCK is defined as, "The blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction (Shulman 1987, p.8). This implies that it encompasses both teachers' understanding and enactment.

The first author's 16-year experience of teaching science methods to graduate students at AKU-IED and guiding their action research studies is used to examine and reflect on the development of the science teacher's Pedagogical Content Knowledge (PCK). The findings in this paper are based on the analysis undertaken by the first author who is also the supervisor of the action research study undertaken by Khan (2009) for his M.Ed. program degree requirement (see abstract of thesis in Appendix A). This analysis was undertaken with permission of Khan who is also credited with being the second author as the manuscript was shared with him and his ideas incorporated into the final paper. Of the more than two dozen M.Ed. theses supervised by the first author this was selected because Khan was engaged in researching his own practice taking the stance of "teacher as a researcher" in a science classroom at the secondary level (grade 9 and 10) rather than at the lower secondary (grades 6 to 8) and primary level (grades 3 to 5) which is generally the norm at AKU-IED. Additionally, Khan has strong content knowledge and his study was not enmeshed with issues related to the need for support in science content, which would allow for a better analysis for development of PCK. Khan uses the Lewinian (1946) concept of action research characterized by "Proceeding in a spiral of steps, each of which is composed of planning, action and the evaluation of the result of the action… the cyclic nature of this model recognizes the need for action plans to be flexible" (Kemmis, McTaggart & Retllick, 2004, p. 3). Given the newness of the role of teachers as researchers in Pakistan this paper will help to understand how action research in the science classroom can be used for professional development of teachers as related to PCK in science. This is particularly of great significance in the context of Pakistan where knowledge is considered to be "out there" for human beings to discover and not something that can be created or constructed, much more so by teachers in the classroom (Halai, 2008).

Literature Review

Grossman attributes the development of PCK in teachers to a number of factors which include observation of classes, courses in teacher education and classroom teaching/learning experiences (1990). But Marks (1990) takes a much more integrated view of the development of PCK and states that the development of PCK revolves around interpretation of subject matter knowledge and general pedagogical knowledge. Others such as Cochran, DeRuiter & King (1993), Fernandex-Balboa & Stiehl (1995) have taken some elements of the original seven elements of the "knowledge base for teaching" (Shulman, 1986, p. 9) as constituting the source of PCK. It is only later that reflective practice and action research were also conceptualized as a form of professional development that contributed to the development of PCK (Appleton, 2008; Zeichner & Liston, 1987). In science education the nexus between PCK and action research has been explored from different perspectives (Goodnough, 2008, 2009; Nilsson, 2008; Gess-Newsome & Lederman, 1999; Pedretti & Hodson, 1995). However, there have been calls to move the work on PCK forward towards a deeper focus on specific topic areas in science (Bergendahl, V. C. B., 2003; Bucat, 2004; Hashweh, 2004; Mulhall, Berry & Loughran 2003). An accumulation of science topic specific development of PCK will help to remove the "professional amnesia" (Bucat, 2004, p. 225) in science teachers by carefully documenting through research the teaching strategies of competent science teachers." However, it is important to note that research on general aspects of PCK development in science has identified a number of generic features too that require careful assessment.

For example Goodnough (2008) examines six primary school teachers' learning of inquiry mode of teaching science within an action research community of practice using pedagogical content knowledge as the framework for analysis. She finds that science teachers who used very traditional and teacher-centered methods of teaching science struggled to use the inquiry approach. They found it very challenging in "'letting go' of the control of the learning environment and allowing the children to take greater responsibility of their learning" but were later "pleasantly surprised by how positively the students responded to their shifting roles" (p. 30-31). Goodnough also studied the implementation of problem-based learning in the context of science through action research conducted by five elementary teachers. She found that the, development of PCK in each science teacher developed with different knowledge bases for teaching and hence their enhancement of their PCK varied. In other words, "each teacher has a unique PCK profile and how this changes as a result of new experiences will depend on prior experiences, contextual factors and readiness to adopt new teaching approaches"(p. 239).

Ponte, Beijaard & Ax (2004) as part of large research project facilitated seven groups of teachers in six schools to undertake action research over a period of two years. The purpose was to develop professional knowledge of teachers. The findings indicate that action research program for professional development has the best chance of success if the team of teachers and teacher educators have a shared understanding and input in the program. An important aspect of PCK development of teachers has been highlighted by the same team in another paper (Ponte, Ax, Beijaard & Wubbels, 2004) They report that unless facilitators intervened the teachers tended to focus much more on the technological domain of knowledge and did not give sufficient attention to the ideological and empirical domains. The researchers concluded that despite development of professional knowledge, "we could assume that daily practice tempts teachers to seek immediate technical solutions" (p. 587).

Peters (2004) as part of the action research-based professional development project in Australia that worked with 14 institutions found that action research supports the development of the ability to reflect and understand one's own practice. The teachers participating in the study, "Felt they were more aware of their practice and of the thinking that informed the decisions they made and that this, in turn, led to some changes in thinking and practice. There was also evidence that, through the opportunities for professional discourse in the project, the teachers became more aware of their colleagues' thinking and practices" (p. 551).

Pardhan (2005) has researched the development of PCK of science teachers to promote science teaching in the context of Pakistan. Her findings support collaborative action research and critical reflection for improved development of PCK and also find that with support teachers can build a community of learners. However, the formation of community and developing trust takes time at least in the context of Pakistan where such collaborations are rare and novel and are generally not supported by school management. Ashraf and Rarieya (2008) who worked in a similar environment as Pardhan in Pakistan supported reflection in the form of reflective conversations for the development of teachers. They also presented the tensions involved in developing trust and open-mindedness. In particular open-mindedness requires an acknowledgement that there are multiple ways of viewing events and to develop this world view was a time consuming process.

Soonye & Oliver (2008) too found that PCK developed through reflection-in-action and reflection-on-action among other factors such as students' misconceptions and teacher efficacy that shaped this development process. They drawing on literature on PCK identified five components of PCK for science teaching (a) orientation to science teaching, (b) knowledge of students' understanding in science, (c) knowledge of science curriculum, (d) knowledge of instructional strategies and representations for teaching science, and (e) knowledge of assessment of science. These five concepts were used as a heuristic device to analyze and generate an understanding of Khan's PCK development while undertaking action research. The analysis showed that all of these elements supported and shaped the development of PCK for Khan, however, the data was also very clear that management of the classroom and resources contributed to the development of a special kind of knowledge that helped his teaching. Analysis of Khan's study provided an opportunity to explore the PCK development in a specific topic area of the Pakistani physics curriculum (heat and temperature). Secondary science curriculum of Pakistan includes thermal physics in the curriculum that constitutes key concepts of thermal equilibrium, flow of heat energy and the differentiation between heat and temperature (AKU-EB, 2004). Students when encountering these notions often have great difficulty in distinguishing between heat and temperature (Carlton, 2000). However, it has also been seen that when these topics are approached with hands-on inquiry based activities followed by discussions the students are able to acquire the science concepts being taught (Mustafa & Omer, 2007; Pathare & Pradhan, 2010). Hence, Khan decided to devise inquiry-based hands-on activities to teach the section of thermal physics in grade 9 textbook being used by the school to teach the students.

Context

AKU-IED was established in 1993 and now offers PhD and M.Ed. Degree programs together with Diplomas and Certificates in teacher education with the philosophy guided by three principles, teacher education should aim: (a) to be field based i.e. take place within classrooms, (b) to make teachers 'reflective practitioners', engaged in continual self-inquiry (c) to include training in classroom based research (IED, 1994; AKU-IED, 2011). AKU-IED is a postgraduate institution and does not engage with preservice teacher education hence the concept of action research was introduced in the two-year 64-credit M.Ed. program initiated in 1994. The Master's students are expected to undertake a research study over a six-month period and write a 15000-18000 word thesis which counts for 25% of the program credit (AKU-IED, 2009). A large number of students undertake action research studies in the classroom.

This kind of action research which is mandated as part of a degree program is not uncommon and has been identified in action research typologies (Somekh & Zeichner, 2009 and Robinson, 2009). Somekh and Zeichner studied how action research theories and practice have been remodeled to suit contextual needs. After an analysis of 46 publications they have characterized action research to have taken five different forms: action research in the times of political upheaval and transition; action research as state sponsored means of reforming schooling; co-option of action research by Western governments and school systems to control teachers; action research as university-led reform movement and action research as locally sponsored systemic reform sustained over time. Similarly Robinson (2009, p. 124) lists seven categories of activity within which teacher research is undertaken in South Africa: (1) Projects within pre-service teacher education programs, (2) Self-initiated communities of practice, (3) Employer-driven professional development, (4) Targeted professional development by e.g., publishers etc., (5) Research and/or action research projects supported by donor funding, (6) Professional development through formal academic programs at the masters or doctoral level for in-service teachers and (7) Postgraduate research based masters and doctoral program. Khan's study falls into the category of university-led reform movement that encourages teachers to become reflective practitioners and study their own practice as part of a formal academic program at the Master's level.

Methodology

This study was undertaken to review and analyze a M.Ed. thesis in science education based in a private high school in Karachi and present an analysis of the thesis report to understand the development of a science teacher's Pedagogical Content Knowledge. As mentioned earlier this study was undertaken by Khan a M.Ed. student and second author of this paper. He had chosen to use inquiry to teach physics in the school classroom and study his own practice using action research. Khan teaches in a private school in Gilgit-Baltistan province of Pakistan and hence chose a private high school as the site of his study. As the M.Ed. thesis is as yet not available through international databases, hence a brief abstract of the study is attached in the Appendix (see appendix A).

In this paper the major analysis was undertaken by the first author who is also the supervisor of the M.Ed. thesis written by Khan the second author. In preparation to write this paper the dissertation was read and re-read in detail to understand the development of the four elements of PCK as given by Carlsen (1999, p. 136): (a) Students' common misconceptions (b) specific science curricula (c) Topic specific instructional strategy, and (d) purposes for teaching science. Within this broad framework comments and codes in the margins were written which were later collated into categories subsumed under these four major sub-topics (Miles & Huberman, 1994). However, codes were also assigned to aspects of the study that fell outside these categories to capture idiosyncratic and indigenous understanding of PCK development.

Development of Teacher Researcher's PCK

The general view is that pedagogical content knowledge (PCK) arises from both the science content knowledge and general pedagogical knowledge (Carlsen, 1999; Grossman, 2005; Shulman, 1986). This view is supported by this analysis however boundaries between PCK, general pedagogical knowledge and science content knowledge overlapped and co-mingled. In fact a striking feature of the analysis is the time, effort and energy that Khan spent in understanding the specific instructional strategy of inquiry in the classroom and "reformatting" his content knowledge to fit the different need of the inquiry approach.

Topic-specific Instructional Strategies and PCK

Khan's action research demonstrated that using a particular instructional strategy to teach a specific topic generated opportunities to adapt the subject knowledge for pedagogical purposes which Shulman has called "transformation" (Shulman, 1986). Generally the M.Ed. students are exposed to innovative strategies for teaching science for the first time in the Science Methods course in the M.Ed. program. Khan was keen to use these new strategies in the classroom and develop a deeper understanding of both the innovation and how it can be enacted in the classroom. He selected inquiry as a number of innovations could be subsumed within this approach. He as the teacher researcher was aware that he did not fully understand the change he wanted to bring about in the classroom but realized that he would better understand the innovation once he had taught a few lessons using the new approach as a reflective practitioner undertaking action research in the classroom.

AKU-IED coursework even at the M.Ed. level includes time for practicum for inservice teachers (Halai, 2006a). Any new innovation is introduced to the inservice teachers by teacher educators themselves using that strategy in the classroom. The students are then expected to demonstrate their understanding of the new approach through practice teaching in the real world of the classroom. In some Methods courses, including science, as much as a quarter of the semester time is spent in classroom practice and related activities (Halai, 2006b). Despite this experience it is clear that teacher researchers such as Khan, though very enthusiastic, are not fully conversant with the practical aspects of the new approaches to teaching. This is to be expected as much more practice is required than can be provided within the program. The action research study spread over six months greatly helped Khan to understand inquiry approaches to teaching science but also helped him to understand the limits of the strategy in teaching all topics. Khan (2009, p. 54) writes:

> What I learnt was that this concept [heat and temperature] required explanation at microscopic level, so that the students could understand the physics behind this concept. At this stage, I realized that the issue in inquiry teaching of physics was that sometimes only relying on hands-on

> activities was not enough. I felt the severe need of a lecture, so that I could give the students conceptual understanding by teaching them the concept of heat at microscopic level, where it says heat is the sum of all kinetic energies while temperature is the average or translational kinetic energy of the molecules.

Curriculum coverage, diversity in students, time available, classroom and resource management were major challenges faced by Khan. He wrote in his thesis report, “the teaching of heat and temperature through inquiry was challenging for me throughout the study. However, it was a good experience because it provided me an opportunity to practically understand the inquiry strategy in a physics classroom and its impact on students’ learning (p. 54). But Khan also felt that he was able to sustain his teaching for seven weeks with strong support from his supervisor, but utilization of this innovative strategy might be unsustainable in his own school without the strong support and guidance and availability of resources in his own school.

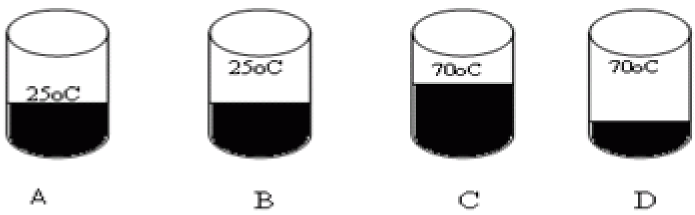
Developing PCK related to how pupils’ understand science

Khan due to his experience of teaching physics at the high school level was aware that students will have difficulty in differentiating between heat and temperature. However, he was not familiar with the nature, kind and depth of the alternate frameworks harbored by the students and nor was he familiar with the universal nature of these frameworks. On the first day of class he brought before the students two beakers of water containing different quantity of water but at the same temperature of 70 degrees Celsius. He invited the students to check the temperature of the water in the two beakers with the help of a thermometer. The students found the temperature to be the same at 70 degrees C. However, when Khan raised the question “Is the amount of heat the same in the two beakers?” there was no consensus in the class. Here a debate ensued, some felt that as the temperature was the same hence the amount of heat must be the same where some other students disagreed with this idea and said that the amount of heat was different in each beaker. Khan showed evidence of having read the literature on the subject and was prepared to deal with this alternate framework with another activity.

He demonstrated another activity (p. 32) where he let students pour different quantities of hot water at the same temperature in same amounts of cold water at the same temperature and let them note the temperature of the mixture created. The rise in temperature was more in the beaker where a larger quantity of hot water albeit at the same temperature was poured in same quantities of cold water. The students were required to respond to three questions:

1. What is the temperature in the two pairs of beakers?
2. What will happen if water is poured from C to A and D to B?
3. Will the temperature rise in the beaker A and B be the same? If not, why?

Figure1: Heat depends on amount of matter



As the rise in temperature was more in beaker A where a larger quantity of hot water from beaker C albeit at the same temperature was poured in same quantities of cold water there was some understanding developed that the larger masses have more heat. The second and third questions put the students in difficulty because the temperature in beakers C and D was the same. Some students thought that heat would also be same and hence the concomitant rise in temperature in beakers A and B would be the same. Again a debate ensued in class and to resolve it Khan asked two students to demonstrate the activity in front of the entire class. Very soon, they found that the temperature rise in the beaker ‘A’ and ‘B’ was different. The reasons ‘discovered’ by the students with support from Khan was that a greater amount of water possesses a greater amount of heat that results in higher rise in temperature. In this way, the discrepant event was resolved and according to Khan the students developed the concept that heat depends on the amount of matter while temperature does not. From this activity, Khan learnt that some abstract ideas such as the one mentioned above can be better understood if students are involved in inquiry-based hands-on, minds-on activities.

Khan was clearly aware that students do not differentiate well between heat and temperature (p. 30) and was prepared with a number of activities and resources to deal with it, but he appeared too quick in accepting that the discrepancy was resolved and that all the students had acquired the concept of "heat depends on the quantity of matter and temperature does not" (p. 32). Khan did realize that the concept that temperature depends on the kinetic motion of molecules is a very "abstract" and such ideas need a combination of strategies; a teacher cannot just depend on one strategy. Van Driel, Jong and Verloop (2002, 572) reaffirm a "growing awareness among preservice teachers concerning the need, in teaching situations, to explicitly relate the macro with the micro levels to each other." Khan had to work very hard to prepare and document the learning and lack of learning from these activities so that he could go back to the class with materials to ensure that all students had developed the same understanding of the phenomena under discussion.

Khan reflects (2009, p. 2), "A quick review of my past informs me that I was a teacher who used to place great emphasis on the definition of concepts and formulae of physics which is an endpoint, rather than considering how best to enable students to reach this endpoint which is crucial." Khan had not realized, till this point, that the ideas about heat and temperature could not be understood by textbook definitions alone. While writing this article, Khan also mentioned that relying on textbooks alone also allows students to develop alternate frameworks as it a very passive method. More important he came to the conclusion that just learning definitions of key concepts is not enough. It would not be far off the mark to suggest that students' alternate frameworks and Khan's attempts to change them shaped his pedagogical content knowledge (Park & Oliver, 2008).

Purpose of teaching science and PCK development

It became clear that when teachers undertake action research to introduce an innovative method of teaching science for understanding, they have to immediately enhance their own science content knowledge. Science teaching in the traditional classroom in Pakistan is taught in a manner that encourages rote memorization of sections of the textbook as responses to questions given at the end of chapters or units. This allows teachers to curtail student questioning and "hide" behind the textbook. However as soon as teachers decide to use innovative approaches to teaching in the classroom they need to develop not only a good understanding of the science content but also have a deeper and a more nuanced knowledge of it to be able to shape it to the needs of the new innovation. Khan, despite having strong content knowledge of the topic felt a need to broaden the base of his science content knowledge. He wanted to foster creativity in the students and that required him also to think in ways different from a traditional science teacher.

Khan reflects p. 57

> Reflecting on the lessons, I learnt that to cover the syllabus through inquiry teaching, a teacher needs to work more rigorously and needs good command on subject content. For example, to cover the given syllabus, despite being a subject specialist and having years of teaching experience, I still needed considerable time and effort to develop activities in a way that one activity could cover several concepts.

The evidence from this study indicates that innovative pedagogy in the science classroom exposed the pupils to think of science in ways that had greater consonance with views *about* science accepted by science educators (NSTA, 2000). In particular the view that scientific theories and explanations need to be internally consistent and compatible with available evidence.

Khan used a strategy as part of inquiry in “heat and temperature” where the students developed a hypothesis based on their observations, then tested the hypothesis through experimentations and finally defended their hypothesis by presenting findings based on the collection, analysis, and interpretation of the data. For the two weeks both he as the teacher and his students struggled, he to develop activities in the area of *heat and temperature* that would lend itself to this type of inquiry and the students to be able to develop the required hypothesis and plan a test for it. He writes (p. 42):

> At the end of these activities, I asked the students to develop a common hypothesis and the students successfully developed that **‘**different quantity of water exhibits different temperature rise when it is heated for same interval of tim**e’**. This time the students did not take too much time to finalize the common hypothesis. I think it was because the students concentrated more on the activities and they learnt that hypothesis is actually the tentative explanation of a phenomenon.

As soon as teachers and students use new and different and ways of teaching science the view that they get about science is also altered. In this case the studies reflect this change of perception but do not delve into it deeply.

Assessment through Cumulative Testing a Barrier to Innovative Pedagogy

Novak (1993) stated, “every educational event has a learner, a teacher, a subject matter and a social environment. I would like to suggest a fifth element – evaluation” (p. 54). While this is true for all teaching learning situations but it has special importance in Pakistan. Most of the action research studies that are undertaken as part of the AKU-IED M.Ed. program requirement take place in either primary or middle grades. Grade 9 and 10 pupils in Pakistan have to give a major summative external examination conducted by the Board of Examination. Khan was doing his action research in grade 9 whose pupils were expected to appear for the Board examination. However, what was different in this case was that the school had accepted to have their pupils examined by a private examination board. This Board though examined pupils on the National curriculum of Pakistan but encouraged critical thinking skills in the manner in which the questions are written and evaluated (AKU-EB, 2004).

In the beginning these students were not appreciative of inquiry method for teaching science. They were aware that success with high grades in these examinations is very important for them. Admission to professional colleges for careers in engineering, medicine or business depends on these grades and competition is very intense. Hence, for these students as well as parents and teachers a major concern was how would the innovation in teaching help them to score high in the board examinations? For the school management an additional concern was how would the curriculum for the board examinations be completed within the stipulated time while Khan used inquiry method in the classroom? Undertaking this study for Khan (2009) was challenging until he convinced the students and the school management that the pupils would not only learn hands-on, minds-on science but also master the concepts in a way that they would be able to respond to better respond to the new ways of evaluation being introduced by the Board. Hence, the assessment would be supported by the pedagogy.

Conducting action research in such an environment was a challenge for Khan for he had to teach for understanding through inquiry and develop his own repertoire of skills to ensure that the students would be able to succeed in the private Board examination.

Classroom and resource management

One of the major challenges that science teachers have to grapple with is classroom and resource management while conducting an activity in the science classroom. They have to deal with multiple issues such as safety, availability of multiple sets of apparatus for group work, and distribution of materials to all students at the same time. The main reason that teacher-centered methods of teaching have managed to hold sway over schools for more than hundred years is that it makes it easy to manage a class of 40 or more pupils in the class. As soon as more innovative teaching strategies such as inquiry are used in the science classroom, they put the student at the centre-stage and that create a host of class management problems. Dealing with these issues took practice and experience. The first few lessons taught by Khan were fraught with challenges and problems- he was overwhelmed with multiple issues which included classroom and resource management. He resolved these issues slowly as the study progressed and learnt from his experiences as both a teacher and researcher in the classroom. By the end of their research period he realized that these management issues were part of teaching with approaches that are more student-centered. His strong content knowledge gave him the confidence to cope with these challenges. He also developed PCK to deal with the specific and special task of teaching in an environment where he had to make a special effort to manage and generate resources.

A major challenge Khan faced was to plan ahead for all teaching contingencies, decide what and how to engage the pupils in the classroom and also observe his own teaching and most important engage with all the students to ensure that learning was taking place even though for the action research study they he was focusing on a small sub-group of students. This was also a huge opportunity for him to learn to manage these problems. At the end of each session he had to reflect on the lesson, write fieldnotes and plan their next lesson as a part of their cyclical process of action research. That allowed him the space to find ways to overcome the classroom management issues which in the normal pressures of teaching does not necessarily get done.

Khan in his first cycle where he was engaged in teaching students the "differentiation between heat and temperature" used the demonstration method to undertake three activities. He set up the apparatus in front of the class, invited two volunteers from the class to come to the front and demonstrate the activity. On reflection at the end of the cycle he realized that the students were frustrated. He found that the most important reason was that the all the students could not see the activity (Khan, 2009, p. 34).

> During the informal discussion with the critical friend, I explored that one of reasons of the students' frustration was because of large class size. As a result, some of the students could not properly observe the activities because the activities were conducted through demonstration rather than doing in groups. The students were not seated in groups either, they were working individually or discussing with the students next to them which did not work effectively and resulted in students' failure to develop a common hypothesis (Field notes, 26th Jan, 2009).

However, the bigger issue related to classroom management was that the new approaches to teaching science demanded a new approach to the management of the classroom - for instance almost all of the teacher researchers had been exposed to cooperative learning and the benefits of talk in their classroom. Hence Khan encouraged the pupils to sit in groups and interact with each other. This pedagogy expected that each member of the group would contribute to the learning of the group and that all the groups would more or less proceed at a similar pace. However, this often was not the case. Hence, he had to devise ways to ensure that norms of group learning were followed in the class which was an additional but necessary burden for him.

As far as classroom and resource management was concerned he realized that most materials/activities for the science he wanted to teach in the classroom had to be devised or used in a particular way that suited his needs. Most of the items he required were simple such as a beaker and a thermometer but the way he used them was different. Some of the activities appeared simple but the logistics of doing them in the classroom were very difficult. Khan used hot water and ice in simple experiments in the classroom but to get hot water, maintain the temperature at whatever degree he needed and procure ice cubes of the same size at the right time in the classroom proved to be a major challenge for him which he had not thought through in the beginning. Khan required that his students work with boiling water; he not only had to take care of safety issues but also use strategies to see that the water did reach boiling point quickly in class during the limited time of a class period.

Classroom and resource management required Khan as the teacher researcher to understand the basic practical aspects of science teaching- collecting materials and practicing the activity ahead of time, using time effectively in class. His role also required him to reflect on the more theoretical aspects of his teaching- why does he want to teach in this way, what are the demands of the particular pedagogy as per classroom and resource management, etc.

Time in more than one way was a major constraint for teacher researcher such as Khan. He had to teach a specific content area in a given time otherwise the students of that section of the class that was a part of the study would be left behind other sections that were not a part of the study. Time was also a major factor as far as time to plan the science lessons using the innovation and preparing the materials for use in the classroom.

Discussion and Implications

As a teacher educator I have taught M.Ed. students how to use innovative approaches of teaching science and also tried to document the process (Halai, 2006b). However, after this analysis it is clear that the science teachers who undertake action research have a far deeper, reflective and reflexive understanding of their teaching as compared to science teachers who do a practicum after observing their methods tutors and planning a lesson with their support. In fact teacher researchers discounted some of their key accomplishments. Khan is a product of the Pakistani system of education where his science knowledge was based on rote memorization. Yet he was able to convert that knowledge into a "different format" to help him to use the innovative pedagogy. This science knowledge did not remain compartmentalized into the three major subject areas (physics, chemistry and biology) and in fact crossed boundaries into mathematics, social studies and humanities. His own reflections remained focused on the technical aspects of the teaching science and conducting research. AKU-IED and other teaching institutions which in future will have to teach teachers to research their own practice should seriously consider offering support to schools for their teachers such as Khan and others like him who are back in schools to continue this process of researching their practice both individually and collaboratively.

Any reform effort in teaching science (or any other subject) has to be harmonized with modes of assessment. Khan initially faced resistance to inquiry methods of teaching particularly in higher grades from pupils who were aware that in the final analysis their scores in the final external assessment were more important than the critical and analytical thinking skills and an understanding of science that these pedagogies inculcate. All effort to change the archaic system of assessment and the corruption in the system of conducting and scoring answer scripts needs to be made before the reform efforts can take root.

Khan's experience demonstrate that the hierarchy between the three major domains of teacher knowledge undergo some change; the teachers learnt much more within the domain of pedagogical content knowledge but it appears that the domains of general pedagogical knowledge and subject knowledge also undergoes development and change. In other words the hierarchy visible in the models presented by Grossman (1990) and Carlsen (1999) was only partially visible in this case.

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Appendix A

Abstract

This study reports an action research conducted in a private school in Karachi. The purpose of the study was to understand the implementation of inquiry approach to teaching physics in a classroom at the secondary level. The research was guided by the main question 'How can I implement inquiry teaching strategies in a physics classroom at secondary level in a private school in Karachi?' For this purpose Wenning's (2005) 'hypothetical inquiry strategy' was adapted. To understand the inquiry process, Kemmis and McTaggart's spiral model of action research was employed. I used the qualitative approach to collect the data. The main tools for data collection included personal reflections, semi-structured interviews, observations and document analysis as well as informal talks with a critical friend.

In this study, I played a dual role; as a researcher as well as a classroom teacher. During the study the physics teacher in the classroom helped to observe my teaching and to monitor some of the groups at different stages during inquiry teaching. There were thirty students in grade IX who participated in the study. Their major role was to learn physics concepts through inquiry strategy, where they performed and observed hands-on activities, developed hypothesis, created and conducted experimented to give empirical evidence to their hypothesis and defended it by presenting their findings to the classmates.

The study was conducted by implementing three action cycles (a total of nine lessons) where each learning cycle consisted of three lessons. The main finding of the study reveals that teaching physics through inquiry strategy in a Pakistani secondary school context was challenging but possible. Besides some facilitating factors, there were challenges and constraints ranging from content specific issues such as teaching and learning abstract ideas in physics to problems and challenges of general classroom management and the motivation of students towards inquiry. Implications for different stakeholders are discussed followed by recommendations for further study.