Parker, L.H., Wallace, J.W. & Wildy, H. More Than Staying One Chapter Ahead of the Students: Updating Teachers' Content Knowledge. AARE Conference, November, 1993.

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Pre-Conference Draft of paper to be presented at the Annual Conference of the Australian Association for Research in Education, Fremantle, Western Australia, 22 - 25 November, 1993

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Introduction

One of the emerging paradoxes of teacher education concerns teachers' subject matter knowledge. There is general agreement that effective teaching is, amongst other things, 'knowledge-based' (see, for example, Eltis and Turney, 1993). Thus, on the one hand it is recognised that the best teachers are those who understand their subject matter well (Buchmann, 1984; Shulman, 1986, 1987; Grossman, Wilson & Shulman, 1989) and it is

emphasised that such understandings involve much more than 'staying one chapter ahead of the students' (McDiarmid, Ball & Anderson, 1989). On the other hand, however, as knowledge in all areas increases exponentially, there is a similarly increasing likelihood that both the depth and the recency of teachers' subject matter knowledge will suffer.

The two dimensions of this paradox are especially evident in science education. Recent research (Hashweh, 1987; Tobin & Garnett, 1988; Lewis & Treagust, 1991) has demonstrated the value of a sound basis in subject matter for the teaching of science subjects. However, the rapid increase in amount, complexity and specialisation of science knowledge makes it extremely difficult for science teachers to keep up-to-date. Further, in Australia, where science teachers comprise a relatively aged sector of the workforce, and are becoming more and more remote from their last experience of up-to-date scientific knowledge, the paradox is particularly problematic (Speedy, Annice, Fensham & West, 1989). In this context, the importance of research on the effectiveness of attempts to update science teachers' content knowledge is paramount.

This paper presents an analysis of one such attempt to update science teachers' knowledge. It focuses on a pilot project funded by the Australian Commonwealth government and conducted at the National Key Centre for Teaching and Research in School Science and Mathematics in Western Australia. As described in detail elsewhere (Parker, Wallace & Fraser, 1993) the project aimed to update teachers' science content knowledge through interaction with experts in their discipline area. It was based on a 'training of trainers' model (Musella, 1992) targeting initially 34 'key' teachers, each of whom then worked as the 'trainer' of a small, district-based group of science teachers. An important aspect of the model was its attempt to provide an experience which engendered ongoing participation by the teachers in their own professional development. This 'sustainable' dimension of the program was built in through links to a variety of forms of credit towards post-initial teacher qualifications, through the district networks established as part of the project and, especially for the 'key' teachers, through encouragement to take on active roles as leaders in professional development.

The purpose of the research reported here was to analyse the model of professional development utilised in the pilot project, with the aim of increasing understanding of the most effective ways of maintaining the currency of experienced teachers' scientific knowledge. The analysis is based on the participating teachers' perspectives on their own needs. It highlights the challenges faced by all involved in the project, and the practical and theoretical insights gained from the

project.

Previous Research

There is a growing body of literature reporting on and analysing inservice programs which focus on science teachers' knowledge base. Some of the programs have aims similar to the one described in this paper. Heller, Hobbie and Jones (1986) for example, describe a summer program for high school physics teachers focusing on specialised topics, while Long, Teates and Zweifel (1993) provide a detailed account of their program for revitalizing 'physics and physical science teachers whose backgrounds were in need of updating' (p. 109). Evaluation of such programs indicates improvements in a number of areas. Successful programs tend to be those which have provided teachers with an active and interactive learning experience. Clermont, Krajcik and Borko (1993) for example, demonstrated enhancement of science teachers' knowledge and skills through an intensive, short-term, skills-oriented workshop focused on chemistry demonstrations. These kinds of programs reflect what Kennedy (1993) has identified as an important basis for reform, namely a theory of the 'teacher as a learner.' As Kennedy notes, 'teachers, like other learners, interpret new content through their existing understandings and modify or interpret new ideas on the basis of what they already know or believe' (p.2).

Frequently, growth in teachers' knowledge is conceptualised in terms of the framework developed by Shulman (1986, 1987) focusing on three major domains: content knowledge , pedagogical content knowledge and pedagogical knowledge. Teachers' content knowledge is 'the amount and organization of (subject matter) knowledge per se in the mind of the teacher' (Shulman, 1986, p.9). Teachers' pedagogical content knowledge is '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). Teachers' pedagogical knowledge is 'knowledge of theories and principles of teaching and learning, knowledge of learners, and knowledge of principles and techniques of classroom behavior and management' (Wilson, Shulman & Richert, 1987, p.107). While the role of each of these three forms of teachers' knowledge is considered in the analysis of the program discussed here, the focus of the program itself was on content knowledge and pedagogical content knowledge.

The Role of Content Knowledge

Research has illustrated well the important role which science teachers' content knowledge plays in their teaching (Carlsen, 1990; Hashweh, 1987; Lewis & Treagust, 1991; Millar, 1988; Sanders, Borko & Lockard, 1993; Tobin & Garnett, 1988). It has been found, for example, that when teachers' content knowledge is strong, they are more likely to present lessons

which flow smoothly, and are well timed, appropriately sequenced and clear. They are also more likely to exploit opportunities for fruitful digression, to deal better with the variety and intensity of students' questions, and to select 'higher risk' teaching strategies, such as group discussion. Weak content knowledge, on the other hand, is associated with rapid and frequent changes during lessons, inappropriate sequencing, poor timing sometimes to the extent that lessons became bogged down, confusion, lack of consistency, difficulty in getting back on track, inability to respond adequately to students' questions, and more 'chalk and talk', lower risk teaching strategies.

The Role of Pedagogical Content Knowledge

Shulman (1987, p.8) regards pedagogical content knowledge as teachers' 'own special form of professional understanding'. While some inservice programs (e.g. Clermont et al, 1993) have targetted pedagogical content knowledge directly, other research suggests that the influence of teachers' content knowledge on their teaching actually manifests itself through changes in their pedagogical content knowledge. Sanders et al (1993) for example, highlight that when teachers are strong in their content area they demonstrate improvement in a number of areas of their pedagogical content knowledge, such as sequencing and timing of lessons, and increased recognition of the need to transform knowledge for their students, and to anticipate students' problem areas. Similarly, Long et al (1993) found that updating of teachers' physics content brought with it an increase in their confidence in their own ability to teach. They argued that this improved confidence stemmed from both the teachers' improved knowledge of physics (their content knowledge) and the expansion of their repertoire of teaching strategies appropriate to that new content (their pedagogical content knowledge). They found also that this increased confidence was associated with improvements in other areas of pedagogical content knowledge such as depth of coverage, use of everyday applications to illustrate concepts, and more logical topic sequencing.

The Role of Pedagogical Knowledge

Reports and research which take serious account of practitioners' perspectives (for example Speedy et al, 1989) demonstrate clearly the importance to teachers of pedagogical knowledge. Both for experienced teachers in an inservice setting and for preservice teachers in an initial teacher training setting, this is the form of knowledge most valued. Indeed, Sanders et al (1993, p.733) concluded from their in-depth study of science teachers, that, irrespective of whether or not teachers were well versed in their content area, 'pedagogical knowledge provided a framework for teaching that was filled in or enhanced by content knowledge and pedagogical content knowledge'. The high value placed by teachers themselves on pedagogical knowledge is a particular focus of the analysis presented here.

The Pilot Project

This paper concerns specifically the part of the pilot project which targetted teachers of high school physics. Its major focus is on the activities of 21 teachers nominated as 'key' physics teachers. This was a select group of teachers, most of whom had also volunteered to take a leadership role in the implementation of a new high school physics syllabus in Western Australia. The plan and timeline of the project were designed to provide the 21 'key' teachers with a concentrated experience with new physics knowledge, followed by periods of information sharing, reflection and, ultimately, the translation of their new learnings into a form appropriate to inservicing of other teachers, and the teaching of students in the classroom.

Following the selection of the key teachers in late 1992, the implementation of the project involved the following steps:

(a) In November 1992, each physics key teacher participated in a one-week program designed and led by physics researchers at Curtin University. The program was structured around six major, internationally recognised research projects currently underway in Curtin's Department of Applied Physics. It involved hands-on experience in physics laboratories, with each teacher working as a member of a group, on his/her chosen research project. The projects offered were:

1. An investigation of asbestiform minerals using scanning electron microscopy and elemental x-ray analysis.
2. Tracing the origin of lead in the atmosphere using mass spectrometry.
3. The global heat engine: Tracing the role of oceans in global warming.
4. The physics of interactions between x-rays and solids.
5. Sources of environmental radiation.
6. Physics from a space-based laboratory.

At the end of the week, each group produced a report on the project it had carried out. These reports were checked for scientific accuracy by the physics researchers.

(b) During the period April - June, 1993, teachers participated in the equivalent of six 3-hour sessions focusing on the skills and resources for passing on their up-to-date physics knowledge to other teachers, and on the development of resource modules for use with students.

(c) During the second half of 1993, each teacher designed and conducted a 3-day professional development program for approximately 20 physics teachers in a designated region.

Design and Procedures

The data gathering procedures used in this study were designed to elicit the teachers' perspectives on the inservice program. Questions were focused around the aims of the program,

especially the updating of teachers' physics knowledge. Participants were asked also for their views on the success of the 'training of trainers' model in disseminating knowledge and skills, and as a model for encouraging ongoing participation by teachers in inservice activities. These data gathering procedures were part of the overall evaluation of the pilot project (Wildy, 1993) which focused also on its classroom impact.

Data were obtained by means of a number of complementary methods. Field notes were taken by the three authors of this paper as participant observers during the key teachers' one-week content inservice. In addition, data were obtained from questionnaires and interviews. A detailed questionnaire was administered to the key teachers at the conclusion of their 'training'. Later, all teachers who had participated in district-based sessions led by the key teachers were surveyed, and as part of the survey, asked for their views on the sessions. There was 100 percent response to the former questionnaire, and approximately 50 percent response to the latter. Unstructured interviews were conducted with nearly all key teachers, and with a number of the other physics teachers.

Characteristics of the Participating Teachers

The population of high school physics teachers in Western Australia consists predominantly of males who have been in the teaching force for at least a decade. Both the group of 21 key physics teachers, and the group of 94 physcis teachers who responded to the State-wide questionnaire reflected these demographics. More than 80 percent had gained their highest physics qualification more than 10 years ago, and only one third of them could identify any physics content update during the past decade. Only four of the 21 key teachers, and nine of the large group of 94, were female. Thus, data on participants' preservice and inservice histories tended to confirm the urgent need for projects such as the one discussed in this paper.

Overall Reactions of the Key Teachers

The questionnaire to key teachers presented a series of statements to which participants responded on a five-point scale from strongly disagree (scored as 1) to strongly agree (scored as 5). Table 1 presents the mean response and the standard deviation for each of the 9 items.

Table 1
Key Teachers' Responses to Questionnaire Items

Statement	Mean (standard deviation) n=21
Learning about cutting edge physics is important for me	4.2 (0.7)

Engaging in research in a tertiary environment is important for me 3.8 (0.7)

The research seminars were presented in a manner suited to my level of understanding 4.0 (0.9)

Hands-on experience with state-of-the-art equipment is important for me 4.3 (0.7)

Working collaboratively with my peers is a valuable aspect of this program 4.7 (0.6)

This program will help me, as a key teacher, to teach other physics teachers 4.1 (0.8)

This program will help me, as a key teacher, to teach my students 4.5 (0.6)

This program is relevant to the new Physics Syllabus 4.4 (0.7)

The accreditation provision in the program is relevant for me 3.8 (1.1)

The most notable feature of the responses is their overwhelmingly positive nature. All participants felt that the program was "extremely worthwhile" and an "excellent program" and they made comments like these throughout the week:
"It is an excellent pilot project: there needs to be much more of this."
"I am fortunate to be involved in such a useful course."
However, although they found it "enjoyable", many also noted that it was "very hard work" and that they had "worked hard and were very tired at the end of the week". The material and its presentation were challenging and stimulating. One key teacher felt that "the equipment and research process went far beyond my level of understanding".

The key teachers were not alone in their perceptions of the level of challenge. One of the presenters felt the participants were "stretched intellectually by their research project" but it was "important for them to realise that we [the physicists] also work at the limit of our understanding." Thus, engaging in research and enhancing one's physics content knowledge was found to be challenging and hard work for key teachers and presenters alike.

The Research Experience of the Key Teachers

Engaging in research with specialists appears to have been a

powerful learning experience, one which had significant impact on key teachers' attitudes to expanding their physics content knowledge and to the research process. Teachers felt that learning about cutting edge physics and obtaining hands-on experience with state-of-the-art equipment were important for them. They also commented:

"The course added greatly to my general and professional knowledge"

"It was good working with practising physicists"

"I discovered how out-of-date the physics we teach at school is and how up-to-date the physics research in WA is"

"Exposure to actual research has given me a far greater understanding of the present state of research in physics"

However, there was confusion at the start of the week's program about its purpose and methods. The confusion arose partly because of two competing agendas; while a few teachers were initially disappointed that there would not be more research, others only came "to get more resources for teaching physics, especially the new syllabus". Some participants saw this as a conflict between what the program was offering and what they wanted to achieve. One expressed the tension in this way:

"They were talking about doing research and writing a proper research report. We only wanted to learn about physics for our Year 11 and Year 12 classes."

Like the teachers in the study by Long et al (1992) these teachers were surprised that the physicists expected them to gain an in-depth understanding of new physics content. The reaction reflects a tension between content and pedagogy, or, in Shulman's terms, between content knowledge and pedagogical knowledge. The program designers emphasised extending teachers' physics content knowledge. Teachers as practitioners, on the other hand, inclined strongly toward pedagogical issues and the production of materials for use in the classroom.

This conflict was resolved during the week in two ways. There was a gradual shift by each group to accommodate the other's point of view. For example, on the one hand, project leaders and supervisors modified the research projects to make them more accessible for school level physics; teachers, on the other hand, recognised that before they could develop classroom materials they themselves needed to become familiar with the research content, methods and equipment. Most engaged in the research projects during the week with the view to later converting their experiences and learnings into strategies suitable for use in the classroom. However, there was another way in which the conflict was addressed: one research project team divided into two separate groups each following a different agenda. This was less than satisfactory because it undermined the powerful collaborative ethos that developed during the week among each of the other five research project groups. Ultimately this group emerged as the only non-productive one in the project,

and its three members withdrew from the project altogether.

Part of the confusion, too, came from the tension between the culture and work practices of the two institutions, the school and the university. One participant described his initial experience like this:

"The first day was a shock. We came from a school where we were experienced senior science teachers to a tertiary institution where we were treated as students."

If, as is indicated by the demographic data, this was the first physics content inservice for a large proportion of the key teachers, then it was important for it to be as welcoming and non-threatening as possible. It is significant that the participants were highly professional people; they were experienced physics teachers who held positions of leadership in their respective schools, in the system and in the science teachers' professional association. Many, however, had had little personal contact with tertiary institutions since their preservice education. It was therefore important for information to be communicated and expectations clarified in ways that respected and enhanced the professional relationship between provider and clients. The development of program objectives in consultation with participants would ensure that the latter's interests were being met and that they had some ownership of the outcomes of the program. Planning time appears to be required to negotiate with participants not only the intended outcomes of the program, but also its processes and strategies. It seems likely that this more collaborative approach would also strengthen teachers' ownership of, and commitment to, their continued learning.

Collaboration with Peers: Views of the Key Teachers

For many participants one of the strongest features of the week's program was the opportunity to work closely with colleagues, and to build collaborative relationships which focused on their physics content knowledge. During the interviews participants frequently noted that one of the strengths of the program was "working with other teachers" and the "excellent collegial support". They commented:

"I was pleased to be able to develop a good working relationship with fellow physics teachers";

"Sharing learning with peers was a very valuable experience"; and

"I feel I have built contacts that I can make use of in the future".

Interaction between Key Teachers and University Staff

The week's program gave key teachers the opportunity to develop strong links with Curtin University staff particularly those in the Department of Applied Physics. Participants gave high praise for the contribution made by the presenters, and their project leaders and supervisors. They made comments like

these:
"I loved the atmosphere of the Physics Department and the helpful attitude of the staff";
"The willingness of the Physics staff to work with us, putting in many hours to help us, was most appreciated";
"The staff was extremely helpful: I really liked their friendliness and their professional approach. Everything was so well organised and carefully structured"; and
"A top effort by all presenters."
Members of the Curtin physics staff also saw benefit in the experience, as one presenter commented:
The tertiary - secondary contact has been one of the program's strengths. We're learning a lot about schools, particularly about the mind set of teachers. We're understanding that teachers are genuinely concerned about their physics teaching and are committed to change for the better. We're seeing the professionalism of teachers."
Another was less optimistic, seeing "the size of the gap between university physics and school physics" but looking for opportunities "to continue talking with teachers when they go back to school."

Linking with the Classroom: Views of the Key Teachers

As indicated earlier, the tension between the competing agendas of gaining content knowledge and preparing classroom resource packages evident early in the week appeared to have been resolved by the end of the week. Of the 21 key teachers, all but three agreed that the program was relevant to their role as a trainer of other teachers, would help them teach their students, and was relevant to the new physics syllabus. There was a small group of teachers who would have preferred to spend the week gaining wider exposure to a number of research areas rather than depth in one research area.

Most of the six research project teams found they needed all the time available during the week to complete their projects. They argued that they needed to work through the project to acquire the new understandings, knowledge and skills themselves before attempting to translate these into materials suitable for other physics teachers and their own classrooms. Again, in Shulman's terms, the teachers needed to reflect on ways of translating their new content knowledge into pedagogical content knowledge.

Accreditation: Views of the Key Teachers

One of the project's aims was to encourage ongoing participation by teachers in professional development activities, through links to credit towards further qualifications. Amongst the teachers there was a spread of views about the relevance of the accreditation offered by the program. Half of the teachers responded positively, stating that they intended taking advantage

of the offer for studies currently underway or for those planned in the near future. The rest of the group thought it was "a good idea but not necessarily useful for [them]". Although these responses need to be seen in the light of the age and seniority of the participants, they do suggest generally a somewhat lukewarm reaction from teachers towards the accreditation aspects of the project.

The Training of Trainers Model: All Teachers' Views

Teachers' perspectives on the success of the training of trainers model were generally positive. Most focused their comments on the district level meetings, indicating that they would "like to see the meetings continue", or that the meetings had been a "real help". More than two-thirds of the teachers anticipated that the model had contributed to their ongoing participation in a continuing network of physics teachers.

Overwhelmingly, however, the perspective of the larger group of teachers was dominated by their perception that inservice is only of value if it concentrates on pedagogical knowledge. None commented on the value of acquiring physics content knowledge as such. Virtually all comments related to the usefulness of the district meetings for exchanging classroom resources and ideas. Most criticisms pointed to a need for more "concrete help, such as tests, practical tests, oral assessment topics", more that was of "direct use in the classroom", and more on "classroom techniques and styles".

In Shulman's terms, pedagogical knowledge was of paramount importance to the bulk of the physics teachers. New content knowledge for these physics teachers needed to be mapped on to their existing pedagogical knowledge. Further, the translation of the new science content into resources which were immediately useful in the classroom emerged as a necessary first step in this mapping. The production of such resources also appeared to provide some impetus for teachers' continued participation in (and in some cases initiation of) professional development activities.

The Costs of Physics Content Inservice

This analysis would not be complete without some reference to the costs of the program. The costs of mounting a week's program in cutting edge physics, involving hands-on experience, with researchers of international repute, and with state-of-the-art equipment, are high. Not only are there costs associated with personnel to develop and present the program; there are also

significant costs involved in running and maintaining the highly sophisticated and expensive laboratory equipment. For example, use of the mass spectrometer and the electron microscope each requires a full-time technician. In addition, key teachers were given full access to laboratory facilities for their research projects, together with the skill and expertise of a staff member

as full-time project leader; they did not share these facilities with other students. In planning and costing future physics professional development projects of this kind all such expenses need to be considered. Without undermining the enthusiasm and commitment of the staff of the Curtin Department of Applied Physics in making available six research projects, it was evident from the number of participants and their high level of interest in all six research areas that a smaller selection of projects would have been equally appropriate and certainly less expensive.

Conclusion

This paper has identified an emerging paradox in science teacher education, namely that teachers' knowledge of science content is on the one hand essential to good teaching and on the other hand difficult to keep up-to-date. The paper has reported research on a pilot project which aimed to solve this paradox. The major finding of the research is presented in terms of Shulman's (1986, 1987) three critical domains of teachers' knowledge. It concerns the tension between teachers' own perceptions of the primacy of their pedagogical knowledge, and others' perceptions of teachers' need for more science content knowledge. This tension appears to be resolvable if teachers are given time to reflect on ways in which content knowledge can be converted to pedagogical content knowledge, in other words time to map the new content knowledge on to their existing pedagogical knowledge.

The research has provided some practical insights into effective ways of delivering teacher inservice which focuses on teachers' knowledge. First, it is clear that inservice programs should acknowledge the tension between content knowledge and pedagogical knowledge, and recognise teachers' own view that it is their pedagogical knowledge which is of paramount importance. Second, the value of the training of trainers model as a vehicle for widespread dissemination of new content knowledge per se appears to be limited. It is ineffective to focus the sessions conducted by the 'trainers' directly on new content knowledge. To be effective and to have meaning to the bulk of teachers, they need to focus on either pedagogical content knowledge or pedagogical knowledge. Indeed, to a large extent, the success of this pilot project in achieving it aims appeared to hinge on the production of resources which translated the new physics content acquired by key teachers into materials which are immediately useful in the classroom.

Third, the program provided for the trainers should target a balance between content knowledge and pedagogical content knowledge, and provide time, especially for collegial interaction, so that key teachers can link the new content knowledge to their existing pedagogical knowledge. Fourth, teacher inservice programs should be planned collaboratively, taking into account teachers' existing knowledge and skills. A fifth issue concerns the high cost of providing content inservice

in physics. While this problem is not easily solvable, this project has demonstrated that the number of content projects offered in a program does not need to be large, and the number of teachers working on each project could realistically be increased from the group size of three to five used in this project.

Additional practical insights were gained into the characteristics of sustainable models of professional development. The training of trainers model shows some promise as a model which facilitates ongoing involvement by teachers in their own professional development, providing the focus of the inservice is on pedagogical or pedagogical content knowledge. The district-based groups of teachers which provided the mechanism, in this pilot project, for trainers to pass on their knowledge to other teachers, appear likely to have a life as networks beyond the end of the project. This project also linked inservice participation to accreditation towards higher degrees. As a mechanism for generating a longer term perspective amongst teachers on their own professional development this was only moderately successful.

In conclusion, we cite Mary Kennedy's (1993, p.13) timely reminder that 'we know little about the elusive task of helping students learn subject matter and less still about how to help teachers learn it'. Further, as noted by Clermont, Krajcik and Borko (1993) much of the previous research in this area has focused on beginning teachers, and additional research focusing on experienced teachers is needed. The research reported here makes an important contribution in this regard.

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