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A Holistic Professional Development model for South African physical science teachers

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The state of mathematics and science education in South Africa is a cause for concern. This situation can be attributed, in part, to many mathematics and science teachers' limited content knowledge, ineffective teaching approaches, and unprofessional attitudes. To address these three problem areas simultaneously, a holistic model for the development of Grades 10 to 12 Physical Science teachers was constructed and evaluated against national and international benchmarks. The effects of the model were assessed over a period of four years with 75 teachers. The model was developed in a distance education context, with no face-to-face contact required. It comprises the following elements: a study guide which integrates the development of teachers' content knowledge, pedagogical content knowledge, cognitive skills and experimental skills; reflective journals; assignments; workshops; peer support and science kits. We briefly describe the research that culminated in the Holistic Professional Development (HPD) model, followed by an account of each element of the model. We then present evidence that suggests that the model is effective in helping teachers develop along three desired dimensions, namely, content knowledge, teaching approaches, and professional attitudes.

Introduction

Mathematics, Science and Technology (MST) education has been a national priority in South Africa for several years, as evidenced, for example, by the National Strategy for Mathematics, Science and Technology Education devised by the Department of Education in 2001(Department of Education (DoE), 2001a). However, the number of Grade 12 learners who pass Physical Science and Mathematics on Higher Grade, a requirement to enter into science-based studies at university, remains very low. Statistics for 2002 and 2003 (DoE, 2004) and for 2004, 2005, 2006 and 2007 (Pandor, 2005; 2006; 2007) are shown in Table 1.

Table 1 Number of learners who passed HG Physical Science 2002–2007

2002	2003	2004	2005	2006	2007
24,888	26,067	26,975	29,965	29,781	28,122

International measures also indicate that South African learners are performing poorly in science. For example, of the 38 and 50 countries that participated in the Trends in Mathematics and Science Study (TIMSS) in 2001 and 2003, respectively, some of which are developing countries, South African learners came last in Mathematics and Science (Howie, 2001; 2003:1-20).

Reddy (2004), who co-ordinated the study in South Africa, explained that there are multiple, complex problems that contribute to learners' poor performance. These include poverty, resources, learning cultures, infrastructure of schools and low teacher qualifications.

Many groups and organisations, from NGOs to businesses to provincial education officials to student volunteers, have tried to improve the state of school mathematics and science through a variety of interventions. Unfortunately, most interventions are short-term, often only one-off, and have no theoretical foundation. Many initiatives, such as Saturday schools, focus on helping learners pass the senior certificate examinations. While these initiatives may help some individuals, they do not improve the education system. According to Kahle (1999:2), "Schools are only as good as their teachers, regardless of how high their standards, how up-to-date their technology, or how innovative their programs". Long-term, sustainable improvement of mathematics and science education must therefore focus on strengthening teachers.

Professional development of teachers is not new, but in recent years the way in which it is structured and delivered is being reconceptualised. Dass (1999:2) reports that traditional 'one-shot' approaches to professional development have been inadequate and inappropriate in the context of current educational reform efforts. They are also out of step with current research about teacher learning (Kyle, 1995; Lieberman, 1995). Ball & Cohen (1999:5) indicated that professional development of teachers is "intellectually superficial, disconnected from deep issues of curriculum and learning, fragmented and non-cumulative". Although it is widely acknowledged that changes are needed, only limited information is available about the factors that contribute to effective mathematics and science professional development, as well as examples of programmes that lead to effective practice (Kyle, 1995; Sparks & Loucks-Horsley, 1990).

In the South African context, the need for several specific components has been identified. In synthesising 38 research projects conducted as part of the President's Education Initiative Research Project, Taylor and Vinjevold (1999: 139) state, "Teachers' poor grasp of the knowledge structure of mathematics, science and geography acts as a major inhibition to teaching and learning these subjects". Strengthening science teachers' content knowledge should therefore be an essential component of any professional development programme. However, content knowledge is not enough, as indicated by Adler and Reed (2002:25), who write, "The issue is how to integrate further learning of the subject with learning about how students in school acquire subject knowledge". They suggest that teachers need to learn "subject knowledge for teaching", echoing the sentiments of veteran educator, Shulman (1986), who coined the term "pedagogical content knowledge". The need for an additional component of professional development, namely, professional attitudes, was identified in a study in which 1 200 South African mathematics and science teachers were surveyed (Grayson, Ono, Ngoepe & Kita, 2001). Results from this study showed that various unprofessional attitudes were widespread, such as coming late to class, not preparing for class and omitting sections of the syllabus that teachers did not understand.

Our aim was to design and evaluate a holistic professional development model for FET (Further Education and Training) physical science teachers in South Africa. Various professional development models have been devised in South Africa. For example: Project UNIVEMALASHI a district-level systemic reform initiative for teacher development improving content knowledge, skills and attitudes of foundation phase teachers (Onwu & Mogari, 2004); Mpumalanga Secondary Science Initiative (MSSI) a school-based system of professional development to improve the teaching of mathematics and science at the junior secondary level (Rogan, Grayson, Van den Akker, Ndlalane, Dlamini & Aldous, 2002); the spiral model to support implementers of outcomes-based education through professional development by means of cascading (Du Toit & Sguazzin, 2000). What makes our model different from other models is that it explicitly integrates the development of teachers along the three dimensions identified earlier, namely, content knowledge, teaching approaches, and professional attitudes. Teacher professionalism is about the "quality of practice" that a teacher demonstrates (Sockett, 1993:9). It is because of the integration of these three dimensions of professional development that we say our model is holistic.

In creating our model, in addition to looking at South African models, we also studied existing programmes and models from several different countries. These programmes are PEEL (Australia), Discovery (USA), Cognitively Guided Instruction (USA) and the Japanese approach to professional development. These programmes were selected because they have been sustainable over a long period. Two models for professional development were also studied, namely, the models of Bell and Gilbert (New Zealand) and Loucks-Horsley, Hewson, Love and Stiles (USA).

After studying these programmes and models, the following common features were identified: reflection on teachers' own practice, development of teachers' content knowledge, provision of infrastructure to support teachers, collaboration with fellow teachers and researchers, provision of opportunities to try out and discuss new teaching strategies, development of teachers as lifelong learners and recognition and development of teachers' beliefs.

A further seven principles for effective professional development have been identified by the Professional Development Project of the National Institute for Science Education in the USA (Loucks-Horsley, Stiles & Hewson, 1996). These principles are: have a clear image of effective classroom learning and teaching; develop teachers' knowledge and skills to broaden teaching approaches; use instructional methods that mirror the methods to be used with students; build or strengthen the learning community of science and mathematics teachers; prepare and support teachers to serve in leadership roles; provide links with other parts of the educational system; and continuous assessment. All of these recommendations informed the development of the HPD model.

In this article we give a brief overview of the process of developing the Holistic Professional Development (HPD) model. We then describe the elements of the final version of the model and present evidence for its effectiveness. Finally, we discuss implications and possible applications of the HPD model.

Research framework

The design framework for professional development for mathematics and science education of Loucks-Horsley, Hewson, Love and Stiles (1998) was selected as an appropriate guide for the development of the HPD model. The model was developed in three phases. Phase I comprised a baseline study, phase II comprised the creation of an initial version of the model and phase III comprised modification of the model.

The framework is presented in Figure 1. At the centre of the framework is a generic planning sequence consisting of four elements — goal setting, planning, doing, and reflecting. This is referred to as the implementation process and was applied in each of the three phases of the development of the HPD model. The implementation process is informed and constrained by the implementation strategies that are available and feasible, critical issues that need to be addressed in the context of interest and the researchers' knowledge

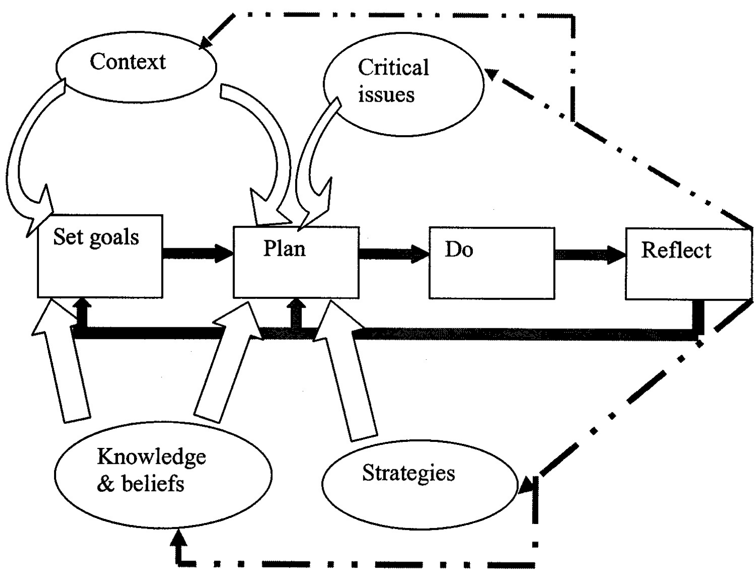

Figure 1 Framework for designing professional development (Loucks-Horsley *et al.*, 1998:17)

and beliefs about teachers, teaching, learners and the school context. Figure 1 indicates multiple feedback loops from the "reflect" stage to illustrate how design continues to evolve as we learn from doing.

In our intervention, the main strategy used was to develop a year-long Physics course that was offered via distance learning. The context for the intervention was teachers from disadvantaged schools where there were limited resources, no laboratories or libraries and insufficient textbooks and desks. The teachers were underqualified, particularly in the area of content knowledge. Two critical issues that were central to the model from the beginning were equity considerations and capacity building to strengthen teachers' effectiveness. A third critical issue, namely, the development of a professional community, was addressed after phase II. In terms of beliefs, the researchers subscribe to a constructivist view of learning (Von Glasersfeld, 1992). As far as teachers and teaching are concerned, we see the primary role of a teacher as facilitating learning. We concur with Loucks-Horsley *et al.* (1998:30) that all learners are capable of understanding and doing science.

Grounded theory was used to arrive at the specific elements within each phase, which were appropriate for developing the HPD model. Grounded theory, as described by Glaser and Strauss, is "the generation of theory, rather than theory testing or mere description". According to this view, theory is not a "perfect product" but an "ever-developing entity" or process (1967:32).

Method and data collection

Phase I involved constructing a baseline of teachers' content knowledge, teaching approaches and professional attitudes. Case studies were constructed with a convenience sample of 3 of the 25 teachers from urban Gauteng schools who were enrolled for a year-long professional development programme sponsored by the Gauteng Department of Education. Various forms of data were triangulated to create an in-depth profile of these teachers. The data that were collected include observation notes taken during visits to the teachers' classrooms, assignments, questionnaires, and pre- and post-tests. The pre- and post-test were aimed at assessing the teachers' content knowledge before and after the professional development programme. The same test was used and was designed by the Human Sciences Research Council (HSRC) to test the knowledge and insight of potential physical science educators and comprises questions on mechanics and electrostatics. The baseline study revealed that development was needed along all three of the identified dimensions. The results of the baseline study, together with information obtained about other professional development programmes and models (PEEL, 2004; Discovery, 1996; Carpenter, Fennema, Franke, Levi & Empson, 2000; Lewis & Tsuchida, 1997; Bell & Gilbert, 1996) were used to construct an initial version of the HPD model.

In phase II, the initial version of the model was trialled. A one-year distance education course was designed for Grade 10–12 Physical Science teachers, called Physics for Teachers I. Twelve teachers enrolled for this course. The elements of the initial version of the model were a study guide, workshops, assignments and reflective journals in which teachers were required to reflect on both their experience as students in the course and their classroom practice. The impact of the model was evaluated using data obtained from assignments, journal entries, pre- and post-tests, examination scripts, workshop evaluation forms, classroom observations and interviews with 12 teachers from rural schools in Limpopo (Kriek & Grayson, 2003). The assignments and the pre- and post-tests were aimed at assessing the teachers' content knowledge. The pre-test was written before the workshop started and the post-test after the workshop. Similar questions were asked in the examination six months after the workshop. Classroom observations by one of us (JK) verified the assessment of teachers' content knowledge and changes in teaching approaches. The journals, workshop evaluation forms and interviews were used to determine if more elements needed to be added, as well as evaluating the effectiveness of the elements in terms of the three dimensions of interest, content knowledge, teaching approaches and professional attitudes. From the data collected, the model was modified and two new elements were added, namely, peer support and a science kit.

In phase III, the modified model was implemented and trialled again with a new group of teachers. In total, 75 teachers participated from urban and rural schools in Limpopo, Gauteng and KwaZulu-Natal. As before, the elements and impact of the model were evaluated using data obtained from assignments, journal entries, pre- and post-tests, examination scripts, workshop evaluation forms and interviews. The pre-and post-tests were similar to the ones used in phase II. Additional information was obtained from forms filled out by teachers and their selected peers as part of the peer support element that was added to the model. Analysis of the data collected did not suggest a need to add more elements to the model. More details about the research process are available (Kriek, 2005).

The final HPD model was evaluated against several international benchmarks (Buchanan, 2002; Desimone, Porter, Garret, Yoon, & Birman, 2002; and the National Science Education Standards, 1996) containing 41 criteria. The model was found to meet 37 of these criteria. It is also in line with the vision of the South African Department of Education (DoE, 2001a) for teacher development.

Features of the final HPD model

One of us (JK) is employed at a distance education university, so the starting point for the HPD model was a distance mode course. As a tool for professional development, such a course has several advantages: teachers do not need to leave their own classes or attend lectures during vacations and weekends, and the structure requires teachers to work on the course continuously over a whole year. It is therefore not short-term, which is one of the weaknesses of many professional development programmes (Buchanan, 2002). The specific design of both the study guide and assignments, which are standard components of the courses offered by the university, were unusual in that the focus was not only on content knowledge but also on pedagogical content knowledge and a variety of skills. Reflective journals were included based on other research (Desimone *et al.*, 2002) that examined the importance of developing teachers' capacity to be reflective practitioners. Workshops were offered on a voluntary basis to allow for some face-to-face contact between the lecturer and the students. (Workshops were only organised in areas where teachers indicated they would attend.) In addition, peer support and science kits were added to the model as a result of the findings in phase II of the study. Each element of the HPD model is described below.

Study guide

The study guide was designed to integrate the development of teachers' physics content knowledge and pedagogical content knowledge (PCK). According to Shulman (1986:10), pedagogical content knowledge (PCK) "goes beyond knowledge of subject matter *per se* to the dimension of subject matter knowledge for teaching".

Furthermore, in order to develop a deep understanding of physics, teachers need to not only acquire knowledge of central concepts and principles, but also to develop various thinking and reasoning skills (Arons, 1979; 1984; 1990), problem-solving skills (Schultz & Lochhead, 1991) and experimental skills (Grayson, 1996). They also need to develop metacognitive skills (Nickerson, Perkins & Smith, 1985) in order to monitor and manage their own learning processes, enabling them to continue to learn new physics after the end of the course. The study guide was designed to integrate the development of all of these skills together with a sound understanding of physics concepts and principles.

The general approach taken in the study guide is to present the teachers with a situation that would promote cognitive conflict in order to expose alternative conceptions that may be present. This is followed by a discussion of both the alternative conception and the scientific explanation, together with a discussion of ideas on how to teach the particular topic so that learners will develop a solid understanding. The study guide also includes experiments and exercises. The complete guide is 350 pages long for the first module and 238 pages for the second module, and each was designed to take 10 months to work through.

Assignments

In the HPD model, the students are enrolled in a one-year programme. To help the students pace themselves and make sure they stay on task throughout the year, they were required to submit four assignments spaced out over the year. These assignments were compulsory and included Grade 12 examination type questions, both multiple-choice and longer problems. To integrate the assessment of content knowledge and pedagogical content knowledge and to improve their teaching practice, the teachers were required to provide detailed solutions, as well as outlining how they would explain their reasoning to learners. They were also asked to explain what they thought their learners' difficulties would be and how they would address them. In addition, they were asked to perform a related experiment, which included taking measurements, analysing results and drawing conclusions and compiling and completing a worksheet for the experiment.

Workshops

Voluntary, face-to-face workshops during the year were used to assist teachers with sections of the work they found difficult. These workshops involved addressing both conceptual and cognitive difficulties and developing experimental skills. In addition, the workshops were used to allow the teachers to experience co-operative learning (Johnson, Johnson, Roy & Zaidman, 1986; Johnson, Johnson & Holubec, 1994), which is regarded as important, given the emphasis on learner-centeredness in the new school curriculum (DoE, 2001b). The workshops also gave the teachers the opportunity to meet their fellow students, something that often does not happen in distance education. Students studying through distance education mode can often feel isolated from their fellow students.

Reflective journals

All professionals need to reflect on their practice and experiences if they are to grow and develop constantly. Teachers are no exception. Research has shown that structured activities that encourage teachers to reflect are a useful tool in professional development (Desimone *et al.*, 2002). Therefore one of the elements of the HPD model is the use of reflective journals. To encourage teachers to be reflective, as part of the course they were required to write about their learning experiences on a weekly basis in a journal which was submitted four times a year, together with the other assignments. When teachers record what they have learnt, what they are still unsure of, how they are implementing different teaching strategies and how they can change their teaching practices in order to be more effective, their reflections become a tool for their own professional development, and their metacognitive skills are enhanced.

Peer support

When teachers are distributed across the country and time and money are limited, the location and frequency of workshops that can be offered are also limited. To offer teachers some support and a means of overcoming their sense of isolation within these constraints, a peer support element was included in the HPD model. The peer support component is a hybrid of a Japanese practice known as lesson study (Collison & Ono, 2001) and a practice promoted in the USA called peer coaching (Lewis, 2002). In the HPD model, each teacher enrolled in the course was asked to select another science or mathematics teacher at the same school or a neighbouring school to act as a peer. Both the teacher and the peer were asked to attend one another's classes and discuss the lessons together afterwards. Teachers in the course then submitted their comments about both their own and their peer's lessons, together with the peer's comments about the teacher's lessons. The purpose of this exercise was not so much for one teacher to coach the other in the content as for the teachers to reflect together on what went well in the lessons and what could be improved.

Science kit

A science kit is provided to enable teachers to carry out some of the experiments that are part of the course. Although not intended primarily for this purpose, teachers also used the kit to perform demonstrations in their class. The kit was designed to fit into an average-sized lunchbox, since teachers in rural areas seldom have a laboratory and very often do not have specific classrooms assigned to them. The 'lunchbox' packaging makes it easy to carry the kit from class to class. The kit contains basic physics equipment, such as bulbs, batteries, magnets, iron filings, a spring and a tuning fork. When the teachers use the kit to perform experiments, both their conceptual understanding and experimental skills are developed. In addition, when the science kit is used in their classrooms to demonstrate phenomena and explain concepts to their learners, both their teaching skills and the learners' understanding are improved.

Effects of the HPD model

Qualitative data from the classroom observations, assignments, journal entries, pre- and post-tests, examination scripts, workshop evaluation forms, interviews and peer observation forms were coded in terms of the three dimensions of interest: Content Knowledge (CK), Teaching approach (TA) and Professional Attitudes (PA) (see Table 2.)

Table 2 Data sources used to obtain information about each of the three dimensions of professional development

	CK	TA	PA
Classroom observation	√	√	
Assignments	√	√	
Journal entries		√	√
Pre- post-tests	√		
Examination scripts	√		
Workshop evaluation forms	√	√	
Interview		√	√
Peer observation forms		√	√

During analysis of the data, an interrelationship among these dimensions emerged. The influences of the various elements of the HPD model, namely, the study guide, reflective journals, workshops, science kits and peer support, on these three dimensions are summarised in Table 3 and illustrated in the following section.

Table 3 Influence of the elements of the HPD model on the three dimensions of professional development and sources of data

Elements	Dimensions		
	CK	TA	PA
Study guide	Interviews; examination scripts; journal entries; classroom observation	Interviews; classroom observation	Interviews; journal entries
Reflective journals		Journal entries	Journal entries
Workshops	Pre-and post tests; examination scripts; interviews; journal entries	Interviews; evaluation forms; journal entries	Interviews; journal entries
Science kit	Interviews; journal entries; pre-and post tests	Interviews; journal entries; workshop evaluation forms	Interviews; journal entries
Peer support	Journal entries; peer support evaluation forms	Journal entries; peer support evaluation forms	Journal entries; peer support evaluation forms

Teachers' content knowledge

Sixty percent (45/75) of the teachers indicated that the study guide contributed to the development of their conceptual understanding. This is illustrated by the following quote that was taken from a teacher's journal:

> *I have developed an understanding of the following concepts magnetic field, magnetic poles and I'm able to explain the difference between magnetic force and electric force. I have learned the hints when writing out an experiment … I used to omit this section when teaching because I had not enough knowledge and understanding of it. Now I will treat it with confidence.*

In the latter part of the quote, this teacher admitted to leaving out this section of the work in the past as she did not understand it. We considered this an unprofessional practice. Another teacher indicated a similar practice. During a classroom visit by the first author, the teacher explained a relatively difficult section to the learners and afterwards came and said that he had omitted this section in the past. These changes in practice are important, particularly given that in the professional attitudes study (Grayson *et al.*, 2001) it was found that only 75% of mathematics and science teachers surveyed felt it was their responsibility to study and learn a section of the syllabus on their own if they did not understand it. These and other results (Kriek, 2005) indicate that the teachers enrolled in the programme are now able to teach sections that they did not understand previously. A relationship between improved content knowledge, teaching and professional attitudes is apparent.

One of the difficulties in learning physics is that while students experience physical phenomena in their daily lives, many of the physics explanations of these phenomena are counter-intuitive, leading to misconceptions. These misconceptions are resistant to change and can interfere with the acquisition of scientific concepts (McDermott, 1991). The study guide helped teachers to identify both their own and their learners' misconceptions and to acquire strategies for addressing them, as illustrated by the journal extract below. This teacher's improved understanding also resulted in a more positive attitude towards the subject.

> *Your study materials are just like walking Physics lecturers, they are excellent, they explain the concepts clearly. They correct our misconceptions in Physics. They also correct the misconceptions our learners have. The way you explained the concepts, and the misconceptions I had before are now clarified therefore my attitude is completely changed, it is positive I was negative before.*

Fifty-two percent (39/75) of the teachers indicated that as their content knowledge improved, so did their confidence. This is illustrated by the following extract from an interview:

> *I discovered that something what* [sic] *was missing in me which I was not confident about so I started to study and going through those books* [*study guides*] *I started to have much more confidence and even the assignment you give us — make me to work harder than I used to do.*

Increased confidence also increased the teachers' willingness to make further efforts in improving their own content knowledge.

Improvement of the teachers' content knowledge was also evident in the workshops. For example, one of the workshops focused on drawing several types of kinematics graphs (such as position, velocity and acceleration versus time) and translating between the different types of graphs. The marks of the teachers attending the workshop improved from an average of 20% on the pre-test to an average mark of 95% on the post-test. On similar questions in the examination the average mark was 60%. Increased ability to reason, using graphs, also led to greater confidence in teaching the topic, as illustrated by the following journal entry.

> *I got more knowledge as far as graphs is concerned since from that day. This brought to me a confidence and I feel I can handle the section very well now. The workshop also installed* [sic] *the spirit of peer tutoring and also afforded the educators opportunity to discuss their problems in physics teaching.*

Not all of the teachers attended the voluntary workshops. However, 60% (18/30) of those who did attend indicated that the workshops addressed their conceptual and cognitive difficulties and developed their experimental skills. The following extract from an interview shows that this teacher was able to use what he learnt in the workshop to present the concepts better to his learners:

> ... *I even use those materials ... if they see an object thrown upwards then you are given 5 different graphs. If you draw a distance-time graph — What is the shape? ... It helped me, even in explaining to the learners better using those graphs.*

The peer support element (added in phase II) also assisted in the strengthening of teachers' content knowledge. Fifty percent (10/20) of the teachers indicated an improvement in their content knowledge. In the feedback forms teachers submitted after the peer teaching activity, one teacher wrote, "*He* [my peer] *taught me many things which I was not familiar to* [sic]," while another wrote that it helped her to have a peer "*for enriching my knowledge*".

Teachers' teaching approaches

Changing teaching practices is no easy process (Hand, 1996). However, indications of a change in some of the teachers' teaching practice were noticed. The following journal entry illustrates the positive effects participation in the programme had on this teacher's ability to manage classroom discussions. From a one-way, teacher-dominated "chalk and talk" teaching approach, observed during classroom visits and so common in South African classrooms (Taylor & Vinjevold, 1999), the approach was transformed into animated teacher-learner and learner-learner interaction.

> *They* [the learners] *argued about concepts such as distance and displacement, speed and velocity. At the end of it, I tried to explain to them how these quantities differ. And as I was explaining to them I found that I started to understand it even more.*

This teacher realised that by changing his teaching approach, his own and his learners' content knowledge improved. In an interview with this teacher, he indicated that the pass rate of his Grade 12 Physical Science Higher Grade learners increased from 43.2% in 2001 (before he took the course) to 61.1% in 2002 (after taking the first course) and 84.4% in 2003 (after taking the second course). Fifty-seven percent (43/75) of the teachers indicated that trying out new teaching approaches had a positive influence on their learners' learning.

Comments in teachers' journal entries were made regarding the influence of the science kit on their classroom practice. The science kit was only added in phase II. Fifty-six percent (14/25) indicated that they used the science kit in their classroom. The science kit was provided primarily for the development of the teachers' own conceptual understanding and experimental skills. However, use of the kit by the teachers in class added an additional teaching strategy to their repertoire and appeared to enhance the learners' conceptual understanding, as illustrated by the journal extract below.

> *I was not aware that the tuning fork was going to help me with a lot of work when it comes to sound waves. In the past, I taught sound as an abstract concept but now I am able to teach it using the apparatus. The tuning fork helps me a lot to demonstrate the propagation of sound.*

However, not all of the teachers were comfortable in carrying out experiments.

One teacher commented, "*It was difficult to perform the experiments* (*nobody to help*)". Another said, "*When experiments are carried out, they must be clearly shown. Some of us teachers are not good performers of experiments because we were disadvantaged during our time*". There is a limit to what can be achieved by distance education in this area. The development of experimental skills is best done during contact sessions, but alternatives such as the use of video clips can be considered and investigated.

The following journal entries from a different teacher show that successful application of a teaching strategy described in the study guide, namely, controlled confusion, boosted both the teacher's confidence and the learners' performance.

> *I intend applying the teaching strategy in Unit 1 page 17, i.e. confusion first, then solving the problem, tomorrow on Monday. I have positive feeling that my learners are to be helped — through this. So, I prepare my lesson in accordance with this teaching strategy.*

Next day:

> *It is after school hours. I just finished marking the class work I gave to my learners. No one can believe how well they have performed. It is because of the strategy I used.*

Peer support also influenced teaching practices. This was identified when the feedback forms from both the teacher and his/her peer were compared. Sixty-five percent (13/20) indicated that peer support had an effect on their teaching practices. For example, one teacher wrote as follows about the positive effect that peer support had on her teaching practice:

> *So the effect of this part of team teaching will make my classroom teaching to be successful for it helped to be observed by my peer. I have already improved my teaching at where is good to me. I am so proud about it.*

However, a problem raised was that in some schools it was not possible to have another science teacher act as a peer. Nonetheless, peer support can be of value even if the peer teaches another subject, as illustrated by the following comment on the feedback form:

> *It was difficult to find someone to observe my lessons as I am the only science teacher at our school and neither myself nor the maths teacher has any free lessons. The teacher* [Biology teacher] *that came gave some useful tips and shared some interesting info on Isaac Newton with the kids.*

Teachers' professional attitudes

The professional attitudes study (Grayson *et al.*, 2001) showed that teachers were often reluctant to do more than the bare minimum in terms of time spent on school-related tasks. After intervention, 40% (30/75) of the teachers indicated that they are working harder. The low percentage could be due to the fact that it is no easy process to change behaviour through professional development; teachers need months and sometimes years to change (Loucks-Horsley & Stiegelbauer, 1991:15-36; McCarty, 1993).

However, the journal entry below from one of the teachers indicates that some had a radical change of heart: she is now studying every day.

The material in our guide moves one from confusion to clarity. The subject matter is very interesting and thought provoking in such a way that ***one could hardly skip a day without studying****. Theory could immediately be put into practice and awareness of natural science is sharpened. The enquiring mind is also awakened. One also becomes considerate to the environment* (Bold font inserted by authors for emphasis).

Bearing in mind the general reluctance to "walk the extra mile" among many teachers, the following extract from an interview with another teacher is a very pleasing indication of a good professional attitude:

A teacher must work harder and harder and harder. Because if one relaxes, the learners also relaxes [sic].

Another teacher indicated that as a result of the programme, he regards himself as a leader in his community of teachers. He has gained confidence as a result of building his capacity. Building capacity was identified as one of the critical issues when designing the framework for the HPD model. He is even confident enough to express his willingness to help those colleagues who are experiencing teaching problems, as indicated in the interview extract below:

I was referring to the confidence now I am having. It is that I don't ever have a problem if I may be asked in another school. One teacher can ask me to come and help him. Even himself with some of the problems he is having. I feel great. Yah I feel great about it.

In addition, 8% of the teachers expressed their gratitude telephonically for the difference the model had made to their content knowledge and classroom practice. One teacher indicated that she had been promoted to Head of the Department of Mathematics and Science at her school and attributed it to her change in professional attitude.

Evaluation of HPD model

In order to evaluate the final HPD model against other international benchmarks, it was compared with the six factors identified by the American Institute for Research (Buchanan, 2002) as critical in making professional development effective. These factors are duration, content, form, active learning, collective participation, and coherence. Desimone *et al.* (2002:83) found similar factors in their research. All these factors have been addressed in the HPD model. Examples of how these factors were addressed are given below.

The factor of *duration* is addressed in the design of the programme, which runs for an entire academic year and includes face-to-face workshops, four assignments and reflective journals that need to be maintained on a weekly basis. A longer, sustained and intensive professional development programme is more likely to have an impact than a half-day event or a few after-school sessions spread throughout the school year. *Content* was addressed in the study material, which focused on both content and how to teach it. The professional development programme took several *forms*, including independent study, workshops and peer interaction. *Active learning* was fostered through teachers observing and being observed, as well as through workshops and reflective journals. *Collective participation* has been addressed through the peer support element of the HPD model, combining peer coaching and research lessons. The programme was *coherent* in that all the elements were designed according to the same underlying philosophy and were aimed at achieving similar outcomes. Teachers reflected that because of the improvement in their content knowledge, they had more confidence in their teaching, which led them to act more professionally. This empowered them to assist teachers from other schools who needed help in their subject matter and teaching.

The National Research Council of the USA determines standards for professional development (National Science Education Standards, 1996) for the Science and Education faculties of colleges and universities. There are four standards with 22 substandards. Of these 22 substandards, the only ones not achieved by the HPD model were the introduction of media and technological resources, provision of locations where effective science teaching can be illustrated and modelled, and the inclusion of ways to address the explicit teaching of research skills. Future research could consider how to address these standards.

As part of the National Strategy for Mathematics, Science and Technology (MST), the South African Department of Education spelt out its expectations for MST teacher development:

> [Higher education institutions] should develop rigorous new programmes for educator preparation, strengthening both subject matter expertise and pedagogical mastery. The quality and relevance of the training programmes should be reviewed to ensure that when trainees complete, they are competent in both subject content knowledge and teaching skills and strategies (pedagogic content knowledge) — that is, knowing how to teach specific scientific, mathematical and technological concepts and principles to young people at different stages of development (DoE, 2001a:19).

The HPD model has been designed to meet all of the expectations indicated in the above quotation.

Conclusion

For South Africa to produce the number and quality of scientists and technologists it needs to compete internationally and develop domestically, the number and quality of passes in Physical Science must increase. Teacher development lies at the heart of long-term, sustainable improvement. In the South African context, we propose that teachers need development along three dimensions simultaneously: content knowledge, teaching approaches and professional attitudes. The Holistic Professional Development (HPD) model was designed to facilitate such development. Using the design framework for professional development for mathematics and science education of Loucks-Horsley, Hewson, Love and Stiles (1998) a model was developed with several important features. A study guide and assignments ensure that teachers engage with the course throughout the year, while providing them with new insights and teaching strategies that they can apply in their own classrooms. The journals afford teachers an opportunity to reflect on their own professional growth, generating ideas for their own further development in the process. Peer support helps to overcome the sense of isolation teachers often experience, while providing a starting point for the creation of a supportive, professional community, one of the critical issues. The science kit enables teachers to carry out practical work even when there are no science laboratories. An advantage of the HPD is that it uses distance mode teaching, which allows teachers to work in their own time, without having to leave their classroom or attend lectures during their holidays.

Evidence from a variety of sources suggests that application of the HPD model with practising physical science teachers does indeed support their development along the three desired dimensions. Furthermore, these dimensions are interrelated. For example, it was found that improvement of teachers' content knowledge increases teachers' confidence, which, in turn, makes them more prepared to use a variety of teaching strategies, in particular, more learner-centred and activity-based approaches. While not tested in the study, anecdotal evidence suggests that the use of more innovative teaching approaches makes science classes more interesting and leads to better understanding and a more positive attitude towards science among learners. This, in turn, increases teachers' willingness to spend more time on task and increases their own sense of professionalism. It can also lead to increased learner enrolment and confidence, as illustrated by the following quotes from the teacher we interviewed at a rural school:

> *... I can say the enrolment of the science classes. We used to have a few per grade but now the science classes are overcrowded.*
>
> *... But then if you teach them with confidence they also refer them to teaching that ... And they start to have confidence.*

Our results have shown that the application of the HPD model has the potential to extricate teachers from a vicious cycle where poor content knowledge leads to lack of confidence and enjoyment of teaching, resulting in an unwillingness to spend time on task and use innovative teaching approaches. Instead, teachers can become part of a virtuous circle where improved content knowledge leads to increased confidence, enjoyment and a willingness to spend more time on task and use more learner-centred teaching approaches. Moreover, the HPD is sound when judged according to external standards for professional development and is aligned with the South African government's intentions for MST teacher development.

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References

Adler J & Reed Y (eds) 2002. *Challenges of Teacher Development. An Investigation of Take-up in South Africa*. Pretoria: Van Schaik Publishers.

Arons AB 1979. Some Thoughts on Reasoning Capacities Implicitly Expected of College Students. In: Lochhead J & Clement J (eds). *Cognitive Process Instruction: Research on Teaching and Thinking Skills*. Philadelphia: Franklin

Institute Press.
Arons AB 1984. Student Patterns of Thinking and Reasoning: Part 3. *The Physics Teacher*, 21:3-88.
Arons AB 1990. *A Guide to Introductory Physics Teaching*. New York: Wiley.
Ball DL & Cohen DK 1999. Developing Practice, Developing Practitioners: Toward a Practice-based Theory of Professional Development. In: Darling-Hammond L & Sykes G (eds). *Teaching as the Learning Profession*. San Francisco: Jossey-Bass.
Bell B & Gilbert J 1996. *Teacher Development: A Model from Science Education*. Washington, DC: Falmer Press.
Buchanan M 2002. *Making Mathematics Professional Development Helpful for Teachers*. Available at http://www.nrich.maths.org.uk/mathsf/journalf/jul02/amarticle/. Accessed 11 November 2003.
Carpenter TB, Fennema E, Franke ML, Levi L & Empson SB 2000. Cognitively Guided Instruction: A Research-based Teacher Professional *Development Program for Elementary School Mathematics. Report No. 0003*. Madison, WI: University of Wisconsin-Madison.
Collinson Y & Ono Y 2001. The Professional Development of Teachers in the United States and Japan. *European Journal of Teacher Education*, 24:223-248.
Dass PM 1999. Evaluation of a District-wide In-service Professional Development Program for Teaching Science: Challenges Faced and Lessons Learned. *Electronic Journal of Science Education*, 4:1-19.
Department of Education (DoE) 2001a. *National Strategy for Mathematics, Science and Technology Education in General and Further Education and Training*. Pretoria: Department of Education.
Department of Education 2001b. *Physical Science National Curriculum Statement Grades 10–12 (General) Policy*. Pretoria: Department of Education.
Department of Education 2004. *Table 6: Subject Statistics for the 2002 and 2003 Senior Certificate Examinations (Part 1) All Provinces*. Available at http://education.pwv.gov.za/DoE_Sites/DoE_sites.htm . Accessed 20 September 2004.
Desimone LM, Porter AC, Garret MS, Yoon KS & Birman BF 2002. Effects of Professional Development on Teachers' Instruction: Results from a Three-year Longitudinal Study. *Educational Evaluation and Policy Analysis*, 24:81-112.
Discovery 1996. Available at http://www.discovery.k12.oh.us/ landscapestudies/PP96/pp96toc.htmlx. Accessed 12 December 2004.
Du Toit D & Sguazzin T 2000. *The Spirals Model: New Options for Supporting Professional Development of Implementers of Outcomes-based Education*. Pretoria: Department of Education.
Glaser BG & Strauss AL 1967. *The Discovery of Grounded Theory*. Chicago, IL: Aldine Publishing Company.
Grayson DJ 1996. A holistic approach to preparing disadvantaged students to succeed in tertiary science studies. Part 1: Design of the Science Foundation Programme (SFP). *International Journal of Science Education*, 18:993.
Grayson DJ, Ono Y, Ngoepe G & Kita M 2001. Professional attitudes of mathematics and science teachers in South Africa and Japan. Paper presented at the *9th conference of the South African Association for Research in Maths, Science and Technology Education*. Mozambique, 11-15 January.
Hand B 1996. Diagnosis of Teachers' Knowledge Bases and Teaching Roles When Implementing Constructivist Teacher/Learning Approaches. In: Treagust DF *et al.* (eds). *Improving Teaching and Learning in Science and Mathematics*. New

York: Teachers College Press.
Howie SJ 2001. *Mathematics and Science Performance in Grade 8 in South Africa 1998/1999. TIMSS-R 1999 South Africa*. Pretoria: Human Sciences Research Council.
Howie SJ 2003. Language and Other Background Factors Affecting Secondary Pupils' Performance in Mathematics in South Africa. *African Journal of Research in Mathematics, Science and Technology Education*, 7:1-20.
Johnson DW, Johnson RT & Holubec EJ 1994. *The New Circles of Learning. Cooperative Learning in the Classroom*. Edina, MN: Interaction book Company.
Johnson DW, Johnson RT, Roy P & Zaidman B 1986. Oral Interaction in Cooperative Learning Groups: Speaking, Listening, and the Nature of Statements Made by High-, Medium-, and Low-achieving Students. *Journal of Psychology*, 119:303.
Kahle JB 1999. Teacher Professional Development. Available at http://gos.sbc.edu/k/kahle.html. Accessed 30 October 2005.
Kriek J 2005. Construction and evaluation of a holistic model for the professional development of physics teachers via distance education. PhD thesis. Pretoria: University of South Africa.
Kriek J & Grayson DJ 2003. Initial Development of a holistic model for Physical Science teacher development. Paper Presented at the *3rd Conference on Science, Mathematics and Technology Education*. East London, South Africa, 11-14 January.
Kyle Jr WC 1995. Professional Development: The Growth and Learning of Teachers as Professionals over Time. *Journal of Research in Science Teaching*, 32:679-691.
Lewis C 2002. Journal of Staff Development. Available at http://www.nsdc.org/library/jsd/lweis233.html. Accessed 20 September 2004.
Lewis C & Tsuchida I 1997. Planned Educational Change in Japan: the Case of Elementary Science Instruction. *Journal of Education Policy*, 12:313-331.
Lieberman A 1995. Practices that Support Teacher Development: Transforming Conceptions of Professional Learning. *Phi Delta Kappan*, 76:591-596.
Loucks-Horsley S, Hewson PW, Love N & Stiles KE 1998. *Designing Professional Development for Teachers of Science and Mathematics*. California: Corwin Press, Inc.
Loucks-Horsley S, Stiles KE & Hewson PW 1996. *Principles of Effective Professional Development for Mathematics and Science Education: A Synthesis of Standards*. NISE Brief. 1(1). Available at http://www.wcer.wisc.edu/nise/Publications/Briefs/NISE_brief_Vol_1_No_1.pd Accessed 20 September 2003.
Loucks-Horsley S & Stiegelbauer S 1991. Using Knowledge of Change to Guide Staff Development. In: Lieberman A & Miller L (eds). *Staff Development for Education in the 90s*. New York: Teachers College Press
McCarty H 1993. From Deadwood to Greenwood: Working with Burned Out Staff. *Journal of Staff Development*, 14:142-46.
McDermott LC 1991. What We Teach and What is Learned — Closing the Gap. *American Journal of Physics*, 59:301-315.
National Science Education Standards 1996. *Centre for Science, Mathematics, and Engineering Education (CSMEE), National Academy of Sciences*. Washington, DC. Available at http://books.nap.edu/html/nses/pdf/chap8.pdf. Accessed 1 August 2003.
Nickerson RS, Perkins DN & Smith EE 1985. *The Teaching of Thinking*. Hillsdale, NJ: Laurence Erlbaum.
Onwu GOM & Mogwari D 2004. Professional Development for Outcomes-based Education Curriculum Implementation: the Case of UNIVEMALASHI. *South*

African Journal of Education for Teaching, 30:160-177.

Pandor N 2005. Results of the 2005 Senior Certificate Examination. Media release. Available at www.nwpg.gov.za/education/gr12/2005/press_release/Grade_12_Results_National_DoE_291205.pdf. Accessed 7 September 2007.

Pandor N 2006. *Not There Where We Want To Be. Release of the 2006 Senior Certificate Examination Results, Parliament*. Available at http://www.info.gov.za/speeches/2006/06122814451003.htm. Accessed 10 September 2007.

Pandor N 2007. *The 2007 senior certificate examination results: the numbers. Media release*. Available at http://www.search.gov.za/info/previewDocument.jsp?dk=%2Fdata%2Fstatic%2Finfo%2Fspeeches%2F2007%2F07122808451001.htm%40Gov&q=(+((pandor)%3CIN%3ETitle)+)%3CAND%3E(category%3Ccontains%3Es)&t=N+Pandor+on+release+of+2007+matric+exam+results. Accessed 26 November 2008.

PEEL 2004. *Project for Enhancing Effective Learning*. Monash University. Available at http://www.peelweb.org/pd.html. Accessed 13 December 2004.

Reddy V 2004. *Performance Scores in International Maths and Science Study Reflective of South African Inequalities*. Available at http://www.hsrc.ac.za/Media_Release-232.phtml. Accessed 14 September 2005.

Rogan JM, Grayson DJ, Van den Akker J, Ndlalane T, Dlamini S & Aldous C 2002. The Implementation of C2005 in Mpumalanga: Towards a Theory of Implementation. Paper Presented at the *10th Conference of the South African Association for Research in Maths, Science and Technology Education*, Durban, 10-14 January.

Schultz K & Lochhead J 1991. A View from Physics. In: Smith MU (ed). *Toward a Unified Theory of Problem Solving. Views from the Content Domains*. New Jersey: Associates Hillsdale.

Shulman LS 1986. Those Who Understood: Knowledge Growth in Teaching. *Educational Researcher*, 15:4-14.

Sparks D & Loucks-Horsley S 1990. Models on Staff Development. In: Houston WR (ed). *Handbook of Research on Teacher Education*. New York: MacMillan.

Taylor N & Vinjevold P (eds) 1999. *Getting Learning Right: Report of the President's Education Initiative Research Project*. Johannesburg: The Joint Education Trust.

Von Glasersfeld, E 1992. A Constructivist View of Learning and Teaching. In: Duit R, Goldberg E & Niedderer H (eds). *Research in Physics Learning: Theoretical Issues and Empirical Studies*. Kiel: IPN Institute for Science Education.

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