The change of science teachers' personal knowledge about teaching models and modelling in the context of science education reform

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Abstract

In order to enhance teachers' professional awareness, it is necessary to understand and value their subjective or personal knowledge and beliefs. This study investigated the change of science teachers' personal knowledge about teaching models and modelling in science within the context of educational reform in the Netherlands. The study followed nine experienced science teachers during the first years of the implementation of a new syllabus, which emphasises models and modelling. Data collection consisted of the repeated administration of a Repertory Grid instrument. From the results, three different types of personal knowledge concerning teaching models and modelling in science were identified, each of which showed significant change over time. Type 1 combined modelling as an activity undertaken by students with the learning of specific model content. In Type 2 the learning of model content was combined with critical reflection on the role and nature of models in science. Finally, in Type 3, the learning of model content involved both students' production and revision of models, and a critical examination of the nature of scientific models in general. Implications for the teachers' professional development are discussed.

Introduction

Science teachers in Dutch upper secondary education have recently begun teaching the syllabus of a new course entitled 'Public Understanding of Science' (PUSc.). A distinctive element in this new syllabus is the critical reflection on scientific knowledge and procedures (De Vos & Reiding, 1999). In this respect, the introduction of PUSc. bears similarities to the vision of science education reform in many other countries, such as Canada (Aikenhead & Ryan, 1992), the USA (AAAS, 1994), and the UK (NEAB, 1998), which requires students to become knowledgeable in various aspects of scientific inquiry and the nature of science. The implementation of PUSc. coincides with a broad revision of secondary education in the Netherlands. Among other matters, the purpose of this innovation is to stimulate self-regulated learning and to decrease the emphasis on teacher-directed education. Science teachers, therefore, are not only confronted with a new syllabus and new content, but are also expected to adopt new pedagogical approaches, such as guiding and supervising students' learning processes rather than lecturing, as well as the use of new media. These ideas correspond closely to current international educational innovations which are designed, among other things, to help students develop a rich understanding of important content, think critically, synthesise information, and to leave school equipped to be responsible citizens and lifelong learners (Putnam & Borko, 1997).

Aim of the study

Much contemporary educational research strives for an explanation and understanding of teaching processes and the teacher's subjective experience. The current focus on making visible the "formerly hidden world of teaching" (Clark, 1995, p. 56) is based on the assumption that it is the teachers' subjective and personal knowledge of learning, teaching, students, curricula, and so on, which has an impact on how they teach and respond to educational innovation (Clark & Peterson, 1986; Duffee & Aikenhead, 1992; Verloop, 1992). It is the teachers' knowledge and beliefs or cognitive structures, also referred to as the 'theoretical framework' (Posner, Strike, Hewson, & Gerzog, 1982), the 'personal construct system' (Kelly, 1955), and 'interior images of the world' (Senge, 1990), that give coherence to experiences, thoughts, feelings and actions, in a specific context. Teachers, like other people, do not simply respond to the environment, they are "meaning makers – continually appraising and reappraising the events they encounter in life" (Walker, 1996, p.7). In order to enhance their professional capability, it is necessary to understand and value the personal knowledge and beliefs that teachers develop over the years.

In this paper, we report on the method and results of a qualitative study of a small group of science teachers, examining the first years in which they taught the new PUSc. syllabus. The study investigated the change in the teachers' comprehension concerning the teaching of one of the elements most characteristic of the new syllabus, that is, reflection on the nature of science. Previous research (e.g., Gallagher, 1991) has led to the general conclusion that science teachers possess limited knowledge of the history and philosophy of science. Consequently, their understanding of the nature of science is unsatisfactory. Furthermore, the relationship of this understanding to classroom practice has been found to be complex (Abd-El-Khalik & BouJouade, 1997; Lederman, 1992). As the role of models and modelling in science is widely recognised as central in understanding the nature of science, this study specifically focused on the change of teachers' personal knowledge of teaching models and modelling in the context of the new syllabus. To this end, we focused on the personal knowledge of individual participants and, as people share similarities as well as differences (Kelly, 1955), we also looked for parallels in the knowledge of different teachers in the study (see Meijer, Verloop, & Beijaard, 1999).

Teachers' knowledge as a personal construction

In the literature about teachers' knowledge, various labels have been used, each indicating a relevant aspect of this knowledge. Together, these labels give an overview of the ways in which teachers' knowledge has been investigated to date (Verloop, Van Driel, & Meijer, 2001). Here we focus on the label 'personal knowledge' (Connelly & Clandinin, 1985), emphasizing the individual and contextual nature of teachers' knowledge. We adopt the epistemological position that considers knowledge to evolve as a personal construction of reality. In this study, we follow George Kelly's (1955) views on human beings as pro-active agents, and his phenomenological emphasis on how people make sense of their experience.

The philosophy that underpins Kelly's personal construct psychology is congruous with many current approaches in educational research, particularly with what is regarded as qualitative or interpretative investigation (Pope & Denicolo, 2004). For example, in order to understand the individual culture of teachers, so-called 'narrative' research methods are applied in which personal material such as a 'life story', 'conversation' and 'personal writing' are used (Connely & Clandinin, 1990; Gergen, 1988). Based on his theory of personal constructs, Kelly (1955) derived the 'repertory grid' technique as a method for exploring personal construct systems. As he was a psychotherapist, the application of his method has for a long time been restricted to clinical psychology. However, since the 1980s, there has been an increasing number of publications in educational research that mention the use of the repertory grid to inquire into the process of learning and teaching, primarily from the perspective of the students and teachers directly involved (for example, Bezzi, 1996; Castejon & Martinez, 2001, Corporaal, 1991; Pope & Denicolo, 2004; Solas 1992; Verloop 1989).

Teachers' personal knowledge can originate from a range of experiences including both practical experiences, such as everyday activities, as well as past formal schooling, which includes initial teacher education or continued professional training (Calderhead, 1996). The development of this knowledge has been seen as a gradual process of tinkering and experimenting with classroom strategies, trying out new ideas, refining old ideas, problem setting and problem solving" (Wallace, 2003, p.8). This process has been found to be highly implicit and reactive, and can be understood as 'workplace learning', or 'professional development' (Eraut', 2000; Kwakman, 2000; Schön, 1987). The development of teachers' personal knowledge is highly influenced by subjective factors on the one hand, and by perceptions of task factors and work environment factors on the other (Kwakman, 2003; Klaassen, Beijaard, & Kelchtermans, 1999).

Context of the study

'Public Understanding of Science' as a new distinct science subject

Public Understanding of Science (PUSc.) has recently been introduced alongside the traditional science subjects, such as physics, chemistry, and biology, for all students aged 16 to 18 in non-vocational senior secondary education in the Netherlands. This new subject is aimed at developing an understanding of the general significance of science – 'science for all' – rather than preparing and qualifying a student for the further study of science in higher education. Without aiming at a thorough command of subject matter, PUSc. intends to provide every student with a vision of what science and technology are, and what role they play in modern society. A distinctive new element in this syllabus is the attempt to develop the student's capacity to reflect critically on scientific knowledge and procedures. The main idea underlying the implementation of a completely new subject, rather than adapting the existing science subjects, was the fact that PUSc. was to be compulsory for all students, whereas the 'traditional' science subjects are optional as from Grade 10. In addition, it was also expected that PUSc. as a new subject would more easily allow for new teaching strategies, and new topics to be developed and implemented, as compared to the existing subjects with their long-established teaching traditions. Therefore, PUSc. was not meant to be integrated into the existing science subjects (De Vos & Reiding, 1999).

The educational goals of PUSc. are divided into six interrelated Domains, A to F (see Figure 1; SLO, 1996, p. 10). The learning of general skills (Domain A), such as communication skills, computer skills, and research skills, should take place in combination with the learning of specific subject matter content (Domains C to F). In addition, the reflection on scientific knowledge and procedures (Domain B) should be linked to specific science topics, for example, 'genetic engineering' (Domain C) and the 'greenhouse effect' (Domain D). Since the PUSc.

curriculum places particular importance on the students' awareness of the ways in which scientific knowledge is produced and developed (Domain B), in contrast to the course content of physics, chemistry and biology, reflection on the nature of science, in terms of history, philosophy, and scientific methodology, should be emphasised (SLO, 1996).

[insert Figure 1 about here]

Dutch senior secondary education includes two streams: general senior secondary education (Grades 10 and 11), and pre-university education (Grades 10, 11, and 12). These streams have somewhat different emphases in their examination programmes. The programme for general senior secondary education (HAVO) places more emphasis on practical and concrete applications of the subject matter, whereas pre-university education (VWO) has more abstract and complex goals: pre-university students, for instance, should be capable of using their knowledge and skills in new situations or contexts. As PUSc. does not have a centralised, nation-wide, final examination, schools have some freedom of choice in developing a curriculum which reflects the interests of both teachers and students. For example, teachers may combine topics from the various domains according to their preferences. In addition, they have the freedom to decide in which grades, from 10 to 12, PUSc. will be taught.

Models and modelling in 'Public Understanding of Science'

Aiming to improve the comprehensive nature of students' understanding of the main processes and products of science, Hodson (1992) proposed three purposes for science education: (i) to *learn science*, that is, to understand the ideas produced by science, that is, concepts, models, and theories; (ii) to *learn about science*, that is, to understand important issues in the philosophy, history, and methodology of science; and (iii) to *learn how to do science*, that is, to be able to take part in those activities that lead to the acquisition of scientific knowledge.
In the natural sciences, models are developed, used and revised extensively by scientists (Van Driel & Verloop, 2002). Moreover, modelling is seen as the essence of the dynamic and non-linear processes involved in the development of scientific knowledge. Therefore the achievement of Hodson's goals of a comprehensive understanding of science by the student entails a central role for models and modelling in science education (Justi & Gilbert, 2002). This is why, as it is expressed in Table 1, PUSc. offers an appropriate framework to help students gain a rich understanding of scientific knowledge and procedures. To this end, the learning of scientific models (Domains C to F) and the act of modelling, that is, the production and revision of models (Domain A), should go hand in hand with the development of the capacity to make informed judgements on the role and nature of models in science (Domain B).

[insert Table 1 about here]

The above analysis implies, for example, that in the PUSc. domain titled the 'Solar System and Universe' (Domain F), students could be asked to compare and discuss several models for the 'solar system' from the history of science (Domain B). In addition, in the domain titled 'Life' (Domain C), students could be asked to design models (Domain A) for the 'human immune system'. Reflecting on this assignment, students could be encouraged to discuss the functions and characteristics of models in general (Domain B).

In order to achieve these aims, it is necessary for teachers to have an adequate understanding of the nature of models and modelling in science. Unfortunately, there is little evidence to suggest that the majority of science teachers have an in-depth knowledge of the importance of modelling in science, and about the manner in which scientists use models (Justi & Gilbert, 2002; Van Driel & Verloop, 1999). With regard to science teachers' knowledge of and attitudes towards the use of models and modelling in learning science, Justi and Gilbert (2002) concluded from a study of Brazilian science teachers that the teachers generally showed an awareness of the value of models in the learning *of* science, but not of their value in learning *about* science. Furthermore, modelling as an activity by students would not seem to be widely practised.

Results of Van Driel and Verloop's (2002) study of Dutch science teachers' knowledge about teaching models, *before* the introduction of PUSc., indicated that the teachers could be divided into two subgroups. One subgroup appeared to focus on the content of specific models, implementing mostly teacher-directed learning activities. The other subgroup paid more attention to the nature of models, and to the design and development of models. These teachers appeared to use relatively more student-directed learning activities. The use of teaching strategies focusing on models and modelling, however, seemed only loosely related to the teachers' personal knowledge of their students, particularly of their students' views about models, and their modelling abilities.

The introduction of PUSc. in combination with a move towards constructivist teaching strategies in Dutch secondary education has introduced science teachers to new experiences which may influence their personal knowledge about teaching models and modelling. With this in mind, we formulated the following two research questions:

1.What is the content of science teachers' personal knowledge about teaching models and modelling, at a time when they still have little experience of teaching the new syllabus?

2.Which changes occurred in these teachers' knowledge as they become more experienced in teaching the new syllabus?

Method and procedure

In this section, we will start with a description of the participants in the study and how they were selected. Following this, because of our focus on George Kelly's ideas on how people make sense of their world (Kelly 1955) and the use of his repertory grid technique in this study, some attention is paid to the meaning and the use of the original repertory grid method, before turning to the description of the actual research instrument and the research procedure followed.

Participants in the study

This study was conducted among nine PUSc. teachers working at five different schools. All were using a teaching method called '*ANtWoord*' ('Answer') which we selected for our study because of its emphasis on the role and nature of scientific models. It should be noted that in the Netherlands, schoolbooks are published by private publishing companies that operate outside the control of government institutions. Although books normally comply with the goals set by The Ministry of Education, the actual content of the books is not prescribed and there is considerable variation among authors. In other PUSc. teaching methods, in contrast to *ANtWoord*, scientific models and the act of modelling do not receive as much attention.

The nine teachers replied to a written invitation which we sent to the users of *ANtWoord*. After meetings at their schools, organised to explain the purposes and conditions of the study, they agreed to take part in the study. The teachers, all male, varied with regard to their disciplinary backgrounds, and years of teaching experience (Table 2).

Before they actually started to teach PUSc., the teachers took part in an in-service programme to become qualified for the new science subject. This course consisted of a total of 60 hours of workshops and conferences as well as self-regulated study activities, which also amounted to approximately 60 hours. In this course, new teaching strategies and new science content with regard to the various domains of PUSc. (A to F) were discussed. In addition, much attention was paid to organizational aspects of the implementation of the new subject at the school.

[insert Table 2 about here]

The repertory grid technique

George Kelly developed a method, originally designed as a highly structured clinical interview procedure, which enables individuals to articulate and interrogate their system of personal constructs. The 'rep grid' is essentially a matrix comprising a set of 'elements' and a set of 'constructs'. The elements comprise people, situations, or events, which are comparable and should span the area of the problem under investigation (for instance: all trips abroad in the last five years). The way that we make sense of these elements is represented by our personal constructs. The constructs may be thought of as bipolar, that is, they may be defined in terms of polar adjectives (good-bad) or polar phrases (makes me feel happy-makes me feel sad). As such, Kelly maintained that our discrimination of the world unavoidably involves contrast. When we characterise something in some particular manner, we are also indicating what it is *not* (for example, fat is only meaningful in relation to thin, large relative to small, or acid to alkali). These meaningful constructions of elements are working hypotheses which are put to the test of experience, rather than being facts of nature.

Since Kelly's original account of what he called 'The Role Construct Repertory Grid Test', several variations of rep grid have been developed and used (Cohen, Manion, & Morrison, 2001). In the original clinical version, elements and constructs were elicited from the participants. In current educational research, elements and constructs are elicited, negotiated or provided, depending on the purpose of the investigation.

The research instrument

The instrument developed for the present study can be characterised as a 'standardised' rep grid, consisting of *provided* elements and constructs (Corporaal, 1991). This allowed us to compare the teachers at two different moments in time, both as a group and individually. To study the teachers' personal knowledge of teaching models and modelling, twelve concrete educational activities focusing on models and modelling in PUSc. were supplied as elements to be compared (see Table 3). So as to be recognised by the teachers, these activities were taken, almost literally, from the *ANtWoord* method. The activities corresponded to our interpretation of the three aims of PUSc. (Table 1), that is, to learn the major models (Domains C to F), learn about the nature of models (Domain B), and learn to produce and revise models (Domain A). A number of construct dichotomies, or bipolar constructs, were developed by the first and second authors, based on statements selected from an earlier interview with each teacher, conducted by the first author. This interview included questions about the teachers' personal knowledge about teaching models and modelling in PUSc. Three PUSc. teachers, who were *not* among the nine participants in the study, were asked to give their comments on the developed dichotomies. As a result, a list of fifteen constructs was designed (Table 4). These constructs could be placed in three categories: (1) **Activity** constructs referring to the nature of the activities, for example, (O): '*Teacher-centred*' versus '*Student-centred*'; (2) **Teacher** constructs which reflected the teachers' ideas on their competency for, and their affinities with these activities, for example, (N): '*This activity works well*' versus '*I don't have a good grasp of this activity*', or (I): '*This is one of my favourite activities*' versus '*I do not look forward to this activity*'; (3) **Student** constructs referring to student characteristics with regard to the educational activities, for example, (E): '*Suitable for 16-year-olds*' versus '*Suitable for older students*'.

[insert Table 3 about here]
[insert Table 4 about here]

Procedure

The repertory grid method has a twofold use (Alban-Metcalf, 1997). In its static form, it elicits perceptions held by people at a specific point in time, while in its dynamic form, repeated applications of the method indicate changes in perception over time.

To chart the change of science teachers' personal knowledge about teaching models and modelling, the designed rep grid instrument was applied twice: firstly in April 2002 and secondly in May 2004. Between these two moments in time, the teachers have taught six to nine PUSc. lessons per week, mostly to Grade 10. Particular interventions aimed at teachers' knowledge or competences, however, have not been conducted in the context of the present study. According to the teacher instruction (see Appendix), the teachers were asked to rate twelve educational activities in terms of fifteen bipolar constructs which should be regarded as representing extremes in a five-point scale or construct dimension running left to right from a value of 1 to a value of 5. By rating, teachers were able to indicate the comparative degree to which elements fit comfortably at or between the construct poles in relation to the other elements (Pope & Denicolo, 1993). The rating of the elements took place individually, at a location chosen by the teachers. This was usually their classroom or a small office at the school. The whole process, including instruction by the first author and the completion of the grid by the participant, took about forty-five minutes.

The procedure was tested beforehand using two PUSc. teachers *not* participating in the study and *not* involved in the development of the instrument. The test required that the teachers, after a short instruction, read the guidelines and completed the grid in the presence of the first author. It was found that the procedure worked well. This implied that the guidelines were clear, that the elements were understood by the teachers, and that the names of the constructs were meaningful, that is, they could be applied to the elements.

Analysis

Because the elements were rated according to the constructs, it was possible to apply statistical methods of analysis to the teachers' raw grids. To analyse the data in this study, we used the computer program Rep IV (Research Version 1.00; Gaines & Shaw, 2004). Rep IV is a set of tools for analysing and comparing rep grids and producing graphic representations or plots of construct networks. Here, we confined ourselves to a description of the method and results of the data analyses with FOCUS and COMPARE.

FOCUS sorting and hierarchical clustering

The FOCUS program reorders the information in the raw grid by placing closely matching elements (elements that are rated similarly) together, and also placing closely matching constructs (constructs that are used in the same way) together. The major criterion for forming groups or clusters is that the linear reordering of the rows of constructs and the columns of elements, respectively, will result in a final grid that displays a minimum total difference between all adjacent pairs of rows and columns (Shaw, 1980). The patterns resulting from the similarities that one attributes to both constructs and elements reflect coherent domains of meanings that are used to explain certain issues (Bezzi, 1996) at a particular point in time. Repeated rep grid administration and analysis may indicate the changes over time in these personal meanings.

The first and second grids (completed in 2002, and 2004) of the nine teachers in the study were subjected to FOCUS cluster analysis. Next, each analysed grid was examined by the first author with respect to the way FOCUS grouped the elements (i.e., educational activities concerned with models and modelling) together, and grouped the constructs (i.e., the teachers' perspectives on these activities) together, allowing to give a description of a teacher's personal knowledge about teaching models and modelling in the years 2002 and 2004, respectively.

COMPARE

The COMPARE program evaluates the ratings in two different grids and shows the absolute differences between these ratings. We used this program to compare each teacher's second grid (2004) with his first one (2002). A plot produced by comparing the two grids showed those constructs and elements, which had changed most, over time, on the basis of which the first author could describe the change in a teacher's personal knowledge.

The outcomes obtained with the techniques described above resulted, for every individual teacher, in a description of elements and constructs which were related, and the most important changes in these elements and constructs between 2004 and 2002. In the next step, the first author compared these outcomes for all the nine teachers in the sample. By looking for similarities and differences in the teachers' clustering of elements and constructs, she was able to identify three qualitatively different types of teachers' personal knowledge. Following this, the first and the second author discussed the outcomes for each individual teacher in relation to the characteristics of these three types, to explore whether they could associate each teacher with one of these types. It was discussed whether certain teachers did not 'fit' one of the types, or whether additional types were needed. This discussion did not lead to the identification of new types. Eventually, consensus was reached that all teachers could be related one of the three types exclusively (i.e., two teachers were considered representative of personal knowledge Type 1, three of Type 2 and four of Type 3; see the section Conclusions).

In the next section, we will discuss the analyses of the data of three teachers, each of whom is a clear exponent of each one of the three types of personal knowledge. We show the results of two teachers, we called David and Harry, who were colleagues at School C (Table 1). In addition, we will describe the results of another teacher, who we called Robert, from School E. In each case, we will start with a short description of the teacher's work environment. Only in the first case, David, we will present the grids to illustrate the results. In the cases of Robert and Harry we will present a verbal report only.

Results

The personal knowledge of David (School C)

Context.

David was a biology teacher with 15 years of teaching experience in the discipline, at the start of our study. He taught PUSc. to pre-university students in Grade 10, since the year 2000. Because David was a departmental manager of pre-university students of Grades 10 to 12, he spent a lot of time in his own office, when not teaching. This office was not closely situated to the science classrooms, so he operated rather isolated from the other science teachers. He was selected by the school board to become a teacher of PUSc. He taught six PUSc. lessons per week (two groups of students, three lessons per group).

Rep grid analyses.

David rated twelve educational activities in terms of fifteen bipolar constructs: score 1 means 'agree with the left pole of the construct' (i.e., on the left side of the grid); score 5 means 'agree with the right pole of the construct' (i.e., on the right side of the grid). FOCUS clustered together elements (I to XII) that are rated similarly, and constructs (A to O) that are used in the same way. Groups or clusters are indicated by the curved lines on the right side of the grid, which connect certain constructs, or elements. The percentages, ranging between 60% and 100%, on the upper right side of the grid, indicate how much is shared between certain constructs, or elements. The software programme prints the scores in different shades ('1': white; '3': grey, and '5': dark) to visually help the reader to get an overview of the outcomes, and to facilitate the interpretation of the outcomes represented in the grids. In addition, we have inserted frames in the grids to make it easier for the reader to see which elements and constructs are clustered.

In 2002, the FOCUS cluster analysis of David's raw grid (Figure 2) showed two large groups or clusters of closely matching elements (rows in the grid), as can be seen in the lower part of Figure 2 (one group above the dotted line, and the other one below).

[insert Figure 2 about here]

Such a grouping can be understood as representing a combination of educational activities David rated similarly on the constructs (columns in the grid). The first group, the one *above* the dotted line, is comprised of eight activities. Six of these activities correspond to the PUSc. Domain A (learn to produce and revise models). Two activities correspond to the Domains C to F (learn the major models). The second group, the one *below* the dotted line, combines the other four activities. Three of these activities are associated with Domain B (learn the nature of models), and one activity is corresponding to the Domains C to F. The presence of two groups of activities in David's analysed grid shows that David perceived the activities of Domain A and the activities of Domain B - each combined with different activities of the Domains C to F - to be quite different with respect to each other.
To understand the grounds on which David discriminated between these two groups of activities, we examined his ratings of these activities on the various constructs. It was found that David saw Domain A activities primarily as '*active*' and '*student-centred'* (as illustrated by his scores on the constructs F and O: David scored Domain A activities on these constructs with a 4 or a 5, which indicated that he agreed, or partly agreed, with the expressions placed on the right side of the grid). Domain B activities, on the other hand, were considered as '*passive*' and '*teacher-centred'* (also illustrated by his scores of these activities on the constructs F and O: Domain B activities were scored on these constructs with a 1 or a 2).
In addition, David identified four out of six Domain A activities (i.e., IX, XI, VIII, and X) as '*traditional science activities'*, '*developing research skills'*, and activities for which '*pre knowledge is required*'. He also considered these activities as '*concrete*' and activities of which he had '*no good grasp*' (as can be concluded from his ratings on, respectively, the constructs C, B, D, J, and N).

[insert Figure 3 about here]

In 2004, David completed a grid for the second time. His analysed raw grid (Figure 3) then showed those three activities corresponding to Domain B (IV, V, and VI) no longer being clustered, but separated from each other and isolated from the rest of the activities. A strong cluster of two Domain A activities of 'make a scale model' (X) and 'create a simple model'

(XI), showed up. Together with activities of 'discussing the historical development of models' (Domain B; VI) and 'discussing own models' (Domain A; XII), these activities were seen by David as activities on which he had '*no good grasp*' (as can be concluded from his scores on construct N) and which '*cost a lot of preparation*' (as illustrated by his scores on construct K). A majority of these four activities were also seen as '*student-centred*', '*concrete*', '*developing research skills*', '*suitable for 16-year-olds*', activities to which he did not '*look forward to*', and '*PUSc.*' activities (as illustrated by David's scores on the constructs O, J, B, E, I, and C).
Eight activities were now appraised as '*working quite well*' (as illustrated by David's scores on construct N). Six activities were considered as '*fairly basic*', too (as illustrated by his scores on construct K). In 2004, most of the well working and basic activities (V, IX, VIII, VII, II, III, I, and IV) were more or less considered to be '*teacher-centred*', '*abstract*', '*developing science knowledge*', '*suitable for older students*', *'favourite',* and belonging to the '*traditional science subjects*' (constructs O, J, B, E, I, and C).

[insert Figure 4 about here]

David's knowledge change is illustrated in Figure 4. This figure shows the plot produced by comparing his two grids. It shows the absolute differences between the ratings in the two grids with the constructs and elements sorted so that those most similar in the two grids are on top and on the right respectively and, consequently, those most changed at the bottom and on the left. The two graphs on the right side of Figure 4 represent the percentage similarity between the two grids, for the constructs and the elements, respectively.
It is apparent that the most changed constructs, that is, constructs with less than 75% similarity in the two grids (i.e. constructs I, L, E, G, K, and L) were categorised as **Teacher** constructs and **Student** constructs (cf. Table 4). As an illustration, we will discuss David's ratings on Teacher construct G: '*For this activity I have sufficient knowledge / For this activity my knowledge is not sufficient*', and how they changed. In 2002, David considered his knowledge for only two of all activities (i.e., IV and XII) to be rather '*sufficient*' (as can be concluded from his scores on construct G, Figure 2). It is apparent that, on this specific construct, he changed his rating of no less than ten activities (as illustrated in Figure 4). In 2004, as a consequence, he perceived to have sufficient knowledge for all but one activity (i.e., VI, as can be concluded from his scores on construct G, Figure 3).
It was found that David's most changed elements, that is, elements with less than 75% similarity in his two grids (i.e. elements V, II, XII, IV, and XI), represented activities of all different Domains A, B, and C to F. As an illustration, we will discuss the changes in David's rating of element II representing the educational activity of 'play with a model to gain more insight into it' (Domains C to F). In 2002, David considered this activity, amongst others, as '*student-centred*', '*suitable for 16-year-olds*', and as an activity to which he '*did not look forward*' (as can be concluded from his scores on constructs O, E, and I, Figure 2). He changed his rating of the activity of 'play with a model to gain more insight' on each of the constructs mentioned above with three points (as illustrated in Figure 4). In 2004, as a consequence, he scored the same activity on the opposite poles, that is, as '*teacher-centred*', '*suitable for older students*', and '*favourite*' (constructs O, E, and I, Figure 3). As David also changed his rating of

'let play with a model to gain more insight' on another seven constructs, this activity ranks among his most changed elements.

Final statements.
We conclude that from 2002 to 2004, for David a set of activities focusing on models and modelling had become 'working well' and to some extent 'basic'. In particular, he combined a series of model content activities (Domains C - F), with the educational activities of 'discussing the functions and characteristics of models in science' and 'discussing the similarities and differences between a model and its phenomenon' (Domain B, IV and V). Therefore, we conclude that, in teaching models and modelling, David had learned to combine the learning of model content with a reflection on the nature of models.
On the other hand, David had come to consider activities dealing with model production (X and XI), and the 'historical development of models' (VI) as *'concrete'*, *'student-centred'*, *'developing research skills'*, and *'suitable for 16-year-olds'*. These educational activities were also increasingly seen by him as *'costing a lot of preparation'*, of which he *'had no good grasp'*, and to which he *'did not look forward'*. As such, it is questionable whether, within his PUSc. lessons, David had paid much attention to these activities.

The Personal knowledge of Harry (School C)

Context.
Harry was a chemistry teacher with eight years of teaching experience in his own discipline, at the start of the study. He taught PUSc. to general secondary education students (not pre-university students) in Grade 10. As the school board had selected him to be the 'driving force', he organised the implementation of the new syllabus at the school, and felt responsible for its success. He was motivated to teach PUSc. He taught nine PUSc. lessons per week (three groups of students, three lessons per group).

Rep grid analyses.
In 2002, Harry's analysed grid showed two groups of closely matching elements (educational activities).

The first group represented seven educational activities, six of which correspond to Domain A (learn to produce and revise models), and one to the Domains C to F (learn the major models). The second group was comprised of five elements representing all three Domain B activities (learn the nature of models), and two activities of the Domains C to F. This finding makes clear that, in 2002, Harry, like David, perceived the activities of Domain A and the activities of Domain B - each combined with different activities of the Domains C to F - to be quite different with respect to each other.
To understand on which grounds Harry made this distinction, we examined his ratings of the activities of Domain A and Domain B on the different constructs. It was found that he considered four Domain A activities and one activity of the Domains C to F to be '*active*' and '*motivating for students*' He also perceived these activities to be '*favourite*' and activities of

which he had '*sufficient knowledge*' On the contrary, Harry appraised the group of Domain B activities and the two remaining activities of the Domains C to F as, to some extent, '*passive*', '*not motivating for students*', and as activities to which he *'did not look forward'* and for which he '*had not sufficient knowledge*'.
When completing the grid in the presence of the first author, Harry commented with regard to the construct of *This activity is teacher-centred / This activity is student-centred* (O), that it was impossible for him to rate the Domain A activities of 'discuss own models', 'make a scale model', and 'create a simple model' on this specific construct because he: "had not practised these activities in classroom, actually" It is remarkable that Harry had no problems in rating these specific activities on the other constructs.
Only two activities were appraised as more or less *working well.* These two activities were dealing with 'make an abstract model concrete' and 'let play with models to gain more insight' (Domains C-F). In addition, Harry considered only two other activities to be '*basic*'

In 2004, examination of Harry's analysed grid showed that the contrast between the group of Domain A activities and the group of Domain B activities - both in combination with different activities of the Domains C to F - had become sharper (as can be concluded from the increased use of extreme score values, that is, 1 and 5). In 2004, Harry still saw a specific group of four Domain A activities (in combination with one activity of the Domains C to F) as '*active*' and '*motivating for students*'. In addition, it was clear that he identified these activities as '*student-centred*', and '*developing research skills*'. On top of that, Harry considered these activities to be '*concrete*', '*favourite*', and activities for which '*no pre knowledge is required*'. Harry also appraised these activities as '*working well'* and some of them as '*basic*', which is remarkable because in 2002, as we discussed earlier, three of the four Domain A activities mentioned above were not even applied in his classroom. Finally, it was obvious that Harry still, and even stronger, perceived the three Domain B activities, combined with the activity of 'give concrete form to abstract or difficult models' (Domains C to F), to be *'passive*', '*not motivating for students*', '*teacher-centred*', and '*developing science knowledge*'.

It is apparent from the plot resulting from the comparison of his two grids (i.e., COMPARE, see above), that the most changed constructs in Harry's knowledge were three **Activity** constructs, and one **Teacher** construct whereas the most changed elements were three activities of Domain A. This implies, among other things, that Harry's knowledge developed in such a way that he had come to identify these Domain A activities more clearly and stronger as '*active*', '*student-centred*', and '*developing research skills*'. Besides, these Domain A activities had now become appraised as '*working well*', and '*basic*'.

Final statements.
We conclude that between 2002 and 2004, for Harry a set of activities focusing on models and modelling had become 'working well' and to some extent 'basic'. This concerned a combination of four Domain A activities, that is, 'discuss own models', 'make a scale model, 'create a simple model', and 'observe phenomena and test the usefulness of a specific model to explain the observations', and one activity of the Domains C to F, that is, 'play with a model in

order to gain more insight into it'. Harry had developed a robust view of these activities, which he increasingly perceived to be *'active'*, *'concrete'*, *'student-centred'*, *'motivating for students'*, *'developing research skills'*, activities for which *'no pre knowledge is required'*, and which are *'favourite'* to him. Therefore, we conclude that, in teaching models and modelling in PUSc, Harry had combined students' model production with the learning of model content.

It is unlikely that, within the PUSc. lessons of Harry, much attention was paid to Domain A activities 'making predictions based upon a model', and 'debating on alternative models'. Just as activities dealing with reflection on the nature of models (Domain B), Harry saw these activities (amongst others) as *'abstract'*, activities for which *'pre knowledge is required'* and which are *'suitable for pre-university students'*.

The personal knowledge of Robert (School E)

Context.

Robert was a teacher in physics with 26 years of experience in teaching this discipline, at the start of the study. He had taught PUSc. to students of Grades 10 and 11 (15 to 17-year-olds), since three years, due to its earlier implementation at his school E. Robert is one of three PUSc. teachers, working closely together, at this school. The teachers at this school designed their own specific course, which they called 'PUSc.-plus', aimed at Grade 12 pre-university students. The syllabus of this course included activities dealing with Domain B (learn the nature of models), such as lectures in philosophy of science, and debating sessions with university professors and university students, who had been invited over to the school for this purpose.

Rep grid analyses.

In 2002, Robert's analysed grid showed that he, like David and Harry, perceived the activities of Domain A (learn to produce and revise models) and the activities of Domain B (learn the nature of models) - both combined with different activities of the Domains C to F – to be different with respect to each other.

He generally distinguished Domain A activities from Domain B activities on one specific construct *This activity is teacher-centred / This activity is student-centred* (O), the former activities being seen as *'active',* whereas the latter were rated as '*passive'*. In addition, most Domain A activities were seen by Robert as '*time consuming*', '*student- centred*', and more '*suitable for other (not pre-university) students*'. Domain B activities, on the contrary, were perceived as: '*not time consuming*', '*teacher-centred*', and more '*suitable for pre-university students*'. Robert rated the Domain B activity of 'discussing the historical development of a model' somewhat different from the other activities on a group of four constructs. It is clear that Robert saw this activity as more '*suitable for non-science students*', '*costing a lot of preparation*', and as an activity to which he '*did not look forward*', and of which he '*had no good grasp*' Already in 2002, a majority of the twelve activities were perceived by Robert as '*working well*' (eight activities) and '*basic*' (seven activities). Robert perceived his knowledge for all twelve activities as '*sufficient*'.

In 2004, inspection of Robert's analysed grid showed that the three Domain B activities, that is, 'discuss the functions and characteristics of models in science', 'discuss the similarities and differences between a model and its phenomenon', and 'discuss the historical development of a specific model', were grouped together with the activity of 'make an abstract model concrete' (Domains C to F). Robert identified all these activities as '*passive*', '*not time consuming*', '*teacher-centred*', and '*developing science knowledge*'. Another strong cluster that emerged consisted of Domain A activities concerned with 'discussing own models', 'make predictions based upon a model and test them', and 'debate on alternative models'. Robert considered these three activities as '*suitable for older students*', and activities for which '*pre knowledge is required*'.
In addition, Robert saw the cluster of Domain A activities 'create a simple model' and 'make a scale model' in combination with 'let play with a model to gain more insight into it' (Domains C to F as '*concrete*', '*suitable for other students*' (*not pre-university students*), and as activities to which he '*did not look forward*'.
Finally, Robert considered two Domain A activities together with one activity about the Domains C to F as '*concrete*' and '*attractive to non-science students*'.
In 2004, Robert had come to perceive all activities as '*working (quite) well'*, and most activities as '(*fairly) basic*', too.

The plot produced by comparing the two grids of Robert showed that his most changed constructs were three **Activity** constructs and one **Student** construct. The most changed educational activities were concerned with various domains, for example, Domain B activity 'discussing the historical development of a model', and Domain A activity 'make an abstract model concrete'.

Final statements.
We conclude that in teaching the actual PUSc. syllabus Robert had emphasised the learning of model content and the learning of model production. To this end, he had combined the activities concerned with the PUSc. Domains A and C to F. Apparently, with regard to these activities, Robert had come to discriminate more clearly between older and younger students, between pre-university students and other students, and between science and non-science students. All these activities Robert had continued to identify as *'active'*. In addition, for the syllabus of the 'PUSc.-Plus' course (Grade 12, pre-university students), Robert probably combined these activities with activities from Domain B (learn the nature of models).

Conclusions

In order to answer our first research question (What is the content of science teachers' personal knowledge about teaching models and modelling, at a time when they still have little experience of teaching the new syllabus?), we compared the descriptions of the teachers' personal knowledge as described from the analyses of their grids completed in 2002. Comparing the analysed rep grids of all nine teachers in 2002, it appeared, in general, that all made a distinction between activities from the Domains A and B. Teachers seemed to score these activities very similarly on the **Activity** constructs (i.e, Domain A activities being scored as *'active',* whereas Domain B activities were rated '*passive')*, and on the **Student** constructs (i.e, Domain A activities being scored as *'motivating for students',* whereas Domain B activities were rated '*not-motivating'*). On the other hand, activities from the Domains A and B were scored very differently on the **Teacher** constructs (i.e., *'I have (not) sufficient knowledge for this activity'*).

In an attempt to typify the personal knowlegde of the nine teachers about teaching activities focusing on models and modelling, we investigated which combinations of activities were rated as, more or less, '*working well*' and '*basic*' (Teacher constructs N and K, see Table 4). Next, we compared the combination of activities we found for each individual teacher, *across* the nine teachers, and, as a result, three types of combinations were identified. These were interpreted as three types of personal knowledge, which will be described below. Comparing the results of the nine teachers with these three types, we considered the personal knowledge of two teachers more or less indicative of Type 1, the knowledge of three teachers indicative of Type 2, while the personal knowledge of four teachers could be qualified as representative of Type 3. In the section 'Results', we already described the knowledge of "David" (representing Type 1), "Harry" (representing Type 2), and "Robert" (representing Type 3). The personal knowledge of each of these teachers was considered to be the most pronounced examples of the three respective types.

Three types of personal knowledge about teaching models and modelling

Personal knowledge Type 1.

In Type 1, the learning of model content is combined with a critical reflection on the role and nature of models in science. To this end, the two teachers holding this type of personal knowledge, such as David, tend to connect the learning of particular subject matter (Domains C to F) with a discussion of the similarities and differences between models and phenomena, and a discussion of the functions and characteristics of scientific models in general (Domain B). These activities are generally appraised as aimed at developing science knowledge, and therefore more suitable for pre-university and older students.

Personal knowledge Type 2.

In Type 2, students' production of models is combined with the learning of model content. To this end, the three teachers holding this type of personal knowledge, such as Harry, aim to connect students' observation of phenomena, and students' creation and discussion of simple models (Domain A), with letting them 'play' with physical models to enhance their understanding of specific subject matter (Domains C to F). These activities are generally appraised as active, concrete, student-centred, developing skills, more suitable and motivating for younger students and students of general secondary education (not pre-university students).

Personal knowledge Type 3.

In Type 3, students' model production and revision (Domain A) is combined with the learning of specific model content (Domains C to F). In addition, reflection on the nature of models in science (Domain B) is also combined with the learning of specific subject matter (Domains C to F). The majority of all activities is considered to be working well and basic. The four teachers representing this type of personal knowledge, such as Robert, generally perceive activities about the reflection on the nature of models in science (Domain B) as abstract and, therefore, in combination with the learning of particular subject matter (Domains C to F), as more suitable for pre-university students and for older students, and more attractive to science students.

Students' model testing and model revision (Domain A) are, in general, perceived as activities for which a certain amount of pre-knowledge is required and, therefore, in combination with the learning of particular subject matter (Domains C to F) are considered as more suitable for older students (Grade 11, pre-university and general secondary students as well).

Finally, students' production and discussion of simple models are considered as concrete activities and, therefore, in combination with the learning of particular subject matter (Domains C to F) are considered to be more suitable for other students (not pre-university students) and for younger students in general (Grade 10), and particularly attractive to non-science students.

In order to answer our second research question (How does this knowledge change when those teachers become more experienced in teaching the new syllabus?) we inspected and compared the descriptions of each teacher's knowledge change between 2002 and 2004, based upon their most changed elements and constructs. First, we explored whether patterns could be found in the combinations of elements from the various PUSc. domains, and constructs (i.e. Teacher, Student, and Activity) which had changed most significantly, or most often. This exploration, however, did not reveal specific patterns, indicating a certain type of change.

At a more general level of speaking, the change of the teachers' personal knowledge of teaching models and modelling can be characterised by either an expansion, or an endorsement of initial ideas and perceptions. For example, educational activities from the different PUSc. domains were increasingly (that is, more often and stronger) appraised to be passive or active, motivating or not motivating, and so on. Moreover, based on the observation that particular educational activities were increasingly appraised as working well and basic, it may be hypothesised that the teachers' ideas about these educational activities were manifested more clearly in their teaching practice over time.

Discussion

On the basis of our results with respect to the first research question, it can be argued that our study contrasts with previous research on science teachers' knowledge about the use of models and modelling in learning science (Justi & Gilbert, 2000; Van Driel & Verloop, 1999). Possibly as a consequence of the specific context of our study (i.e., the implementation of PUSc. which demands teachers to focus on models), we found that modelling as a learning activity for students (PUSc. Domain A), and activities with regard to reflection on the nature of models (PUSc. Domain B) were not unusual in the teaching practice of the participants in our study.

Generally speaking, it appeared that some teachers (i.e., knowledge Types 1 and 3) aimed at students' learning to produce and revise models (Domain A), in combination with learning particular model content (Domains C to F). Other teachers (i.e., knowledge Types 2 and 3) combined reflection on the role and nature of models in science (Domain B) with the learning of specific science topics (Domains C to F). Since all participants rated activities from the Domains A and B quite differently, it is questionable whether within their PUSc. lessons, the act of modelling (Domain A) involved explicit reflection upon the role and the nature of models in science (Domain B).

In line with conclusions from previous research (e.g., Gallagher, 1991), some of the teachers in our study appeared to have little knowledge of learning activities associated with the history and philosophy of science, at least in 2002. In particular, those teachers representing knowledge Type 2, who focused on model production in combination with model content, seemed to lack knowledge of educational activities dealing with the 'historical development of scientific models', 'functions and characteristics of models in science', and 'differences and similarities between models and phenomena'. In addition, some teachers, especially those representing knowledge Type 1, combining model content with reflection on models, were identified as lacking knowledge concerning educational activities focusing on model production and revision. These (in-) sufficiency's within the teachers' personal knowledge of models and modelling probably influenced the content and course of the change of their personal knowledge about teaching models and modelling, over time.

There is some indication in the present study that the change of the teachers' personal knowledge over time was not only related to their initial knowledge, or lack thereof, concerning models and modelling, but was also connected to their students' background and age. That is, it is apparent that teachers who generally represented knowledge Type 1 taught the new syllabus to pre-university students, Grades 10 and/or 11, while teachers representing Type 2 taught the PUSc. syllabus to students in general senior secondary education (Grades 10 and/or 11). Finally, it was noted that some of the teachers who represented knowledge Type 3 taught a course entitled 'PUSc.- plus' to pre-university students, Grade 12, in addition to teaching the regular PUSc. syllabus to students of Grades 10/11.

Implications

The development of teachers' personal knowledge is often seen as a gradual process of picking up techniques, activities and materials. Since we found in the present study that there is a need to extend teachers' knowledge about the use of models and modelling in teaching PUSc., especially those representing Types 1 and 2, teachers could be provided with additional teaching materials in which educational activities from the various domains of PUSc. are already integrated, and which can be easily adapted to students of different levels, and ages. This approach is consistent with what has been referred to as 'tinkering' (Wallace, 2003) and 'bricolage' (Hubermann, 1993), referring to teachers' tendency to experiment with classroom strategies, trying out new ideas and refining old ideas, which may lead to changes in their personal knowledge.

In addition, since we found in the present study that teachers' skills in producing and revising models (Domain A) was often limited, as was their knowledge about the history and philosophy of science (Domain B), professional training can be designed to improve these skills and knowledge. For instance, this can be done by engaging teachers in building and testing dynamic computer models, and comparing their models with the results of empirical investigations. This approach was studied by Crawford and Cullin (2002) who found that it promoted (preservice) science teachers' modelling skills and views of the purposes of using models.

From a more general constructivist view on the development of professional knowledge, and the idea of teachers being 'reflective practitioners' (Schön, 1983; Fullan & Hargreaves, 1992; Calderhead & Gates, 1993), it is deemed important that teachers are provided with opportunities and facilities to reflect on teaching experiences in order to articulate and share their personal knowledge and beliefs. In the present study, we found that working with the repertory grid instrument stimulated the teachers to reflect on their teaching practice concerning the use of models and modelling activities. Therefore we suggest using this instrument as a reflective tool in the context of teachers' professional development of their personal knowledge about models and modelling (cf. Christie & Menmuir, 1997).

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Appendix

The Rep Grid procedure

Step 1: Read the statements [listed in Table 4]; these are dichotomies which right poles and left poles are regarded as extremes on a continuum or dimension.

Step 2: Read the educational activities [listed in Table 3] and think of them as activities in your PUSc. curriculum; you could check the list of examples from your teaching method [see Table 3]. Each of the twelve activities has to be characterised with help of the dimensions A to O, listed in Table 4.

Step 3: To start the characterizing, you should read activity I (*You give, for students, concrete form to abstract or difficult models*), and dichotomy A (*Time consuming* versus *Not time consuming*). Activity I has to be rated then on or between both poles of dichotomy A. This rating is graded in five points according the following equivalence: (1) Agree with (left pole); (2) Partly agree with (left pole); (3) Neutral; (4) Partly agree with (right pole); (5) Agree with (right pole). In the case the construct does not apply to activity I, you should rate a zero. You should fill in your score on the proper spot (coordinate) in the grid. Next, you should read activity II, and rate this activity on dichotomy A, on a five-point scale and put your score into the grid.

Step 4: Repeat the procedure to rate the other activities, one by one, on dichotomy A.

Step 5: Repeat the whole procedure to rate the activities on all dichotomies B to O. Your grid has been completed now.

Table 1. PUSc. as framework to improve students' understanding of science

PUSc. Domains	A	C-F	B
Hodson (1992)	Learn how to do science	Learn science	Learn about science
Justi & Gilbert (2002)	Learn to produce and revise models	Learn the major models	Learn the nature of models

Table 2. Features of the participants

School	Number of teachers in the study	Disciplinary background	Years of teaching experience*	Years of teaching experience**
A	1	physics	11	2
B	1	biology	25	3
C	2	1 chemistry	8	2
		1 biology	15	2
D	2	1 physics	23	2
		1 chemistry	22	2
E	3	1 physics	26	3
		1 chemistry	9	3
		1 biology	11	3

* in the teachers' own discipline, at the start of the study

** in PUSc., at the start of the study

Table 3. Rep grid elements (educational activities)

	Educational activity	PUSc. Domain	Examples in the ANtWoord Method	Aim for teaching science
I	you give, for students, concrete form to abstract or difficult models	C to F	Models of the Solar System; Exercises; Computer programs; Workbook Chapt.3; Chapt.8	Learn science (Learn major models)
II	you let students 'play' (in structured assignments) with a model, in order to gain more insight into it.	C to F	Exercises about the topics 'Sun', 'Moon', and 'Planets' with regard to Models of the Solar System; Workbook Chapt.3;	Learn science (Learn major models)
III	you have students to make knowledge and application assignments with regard to a specific model	C to F	Tools and exercises; Workbook Chapts. 3, 5, and 6	Learn science (Learn major models)
IV	you discuss the function and characteristics of models in science	B	ANtWoord book Chapt.1 par.4 Workbook Chapt.3 par.2	Learn about science (Learn the nature of models)
V	you discuss the similarities and differences between a model and its phenomenon	B	Workbook Chapt.3 par.2	Learn about science (Learn the nature of models)
VI	you discuss the historical development of a specific model	B	Models of the Solar System, Human Immune System, Origin of Life; Workbook Chapt.3 par.2; Chapt.5 par.6; Chapt.6 par.1; 2, 3, 5, and 6.	Learn about science (Learn the nature of models)
VII	you have students to observe phenomena and test the usefulness of a specific model to explain their observations	A	Observations of the Sun and the Moon; Testing of the Heliocentric and Geocentric models Workbook Chapt.3 par.2	Learn to do science (Learn to produce and revise models)
VIII	you have students to determine and debate on which points, a certain model works better (making the understanding or predicting of a phenomenon better) than another model	A	Models of the Universe; Models of the Origin of Life; Workbook Chapt.3 par.3 Workbook Chapt.6	Learn to do science (Learn to produce and revise models)
IX	you have students to make predictions based upon a model, and test them	A	Use of computer simulations with regard to: the greenhouse effect, weather predictions; Workbook Chapt.6 par.1 Workbook Chapt.8	Learn to do science (Learn to produce and revise models)
X	you have students to make a scale model, and compare it with the original object	A	Scale model of the Solar System; Workbook Chapt.3 par.2	Learn to do science (Learn to produce and revise models)
XI	you have students to create a simple model	A	Models of the Solar System; Workbook Chapt.3 par.2;	Learn to do science (Learn to produce and revise models)
XII	you have students to discuss their models	A	Models of the Solar System; Workbook Chapt.3 par.2;	Learn to do science (Learn to produce and

revise models)

Table 4. Rep grid constructs (perceptions of educational activities) to be scored according to:

	Left pole of the construct	Right pole of the construct	Category of the construct
A	This activity is *time consuming*	This activity is *not time consuming*	**Activity**
B	Here by students mainly develop *scientific knowledge*	Here by students mainly develop *research skills*	**Activity**
C	This is an activity *typical for PUSc.*	This activity belongs more to the *traditional science subjects*	**Activity**
D	For this activity *little pre-knowledge* is acquired	For this activity a *lot of pre knowledge* is necessary	**Activity**
E	This activity is more suitable for *16- year-old students*	This activity is more suitable for *older students*	**Student**
F	With this activity, students are *actively working*	With this activity, students tend to be *passive*	**Activity**
G	For this activity *I have sufficient knowledge*	For this activity *my knowledge is not sufficient*	**Teacher**
H	This activity is more attractive to *science students*	This activity particularly attracts *non-science students*	**Student**
I	This is one of *my favourite* activities in the PUSc. syllabus	I don't look forward to this activity	**Teacher**
J	This activity is rather *abstract*	This is a *concrete* activity	**Activity**
K	This is fairly much a *basic activity for me*	This activity costs me a great deal of preparation	**Teacher**
L	This is a motivating activity for students	This activity is not motivating for students	**Student**
M	This is more suitable for pre-university students	This is more suitable for general students	**Student**
N	This activity *works well*	I don't have a good grasp of this activity	**Teacher**
O	This activity is *teacher centred*	This activity is *student centred*	**Activity**

1.Agree with left pole;
2.Partly agree with left pole;
3.Neutral;
4.Partly agree with right pole;
5.Agree with right pole.

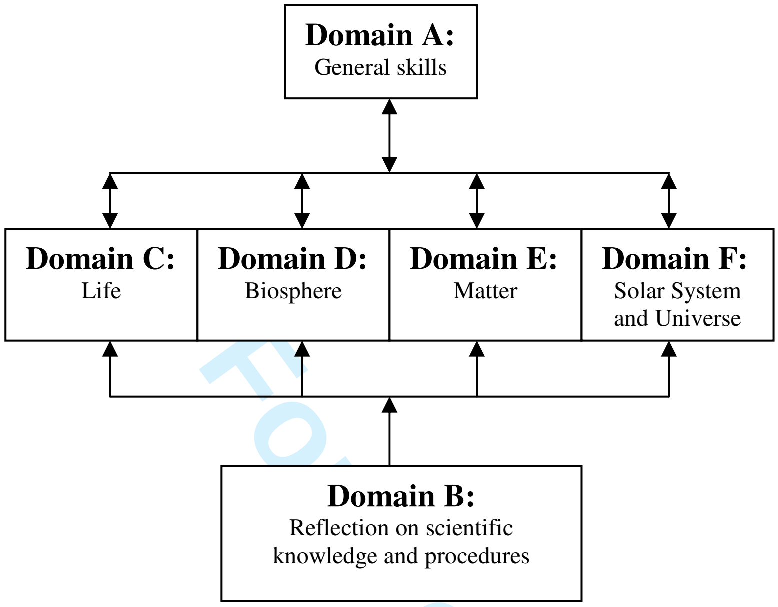

Figure 1: Relations between Programme Domains in PUSc.

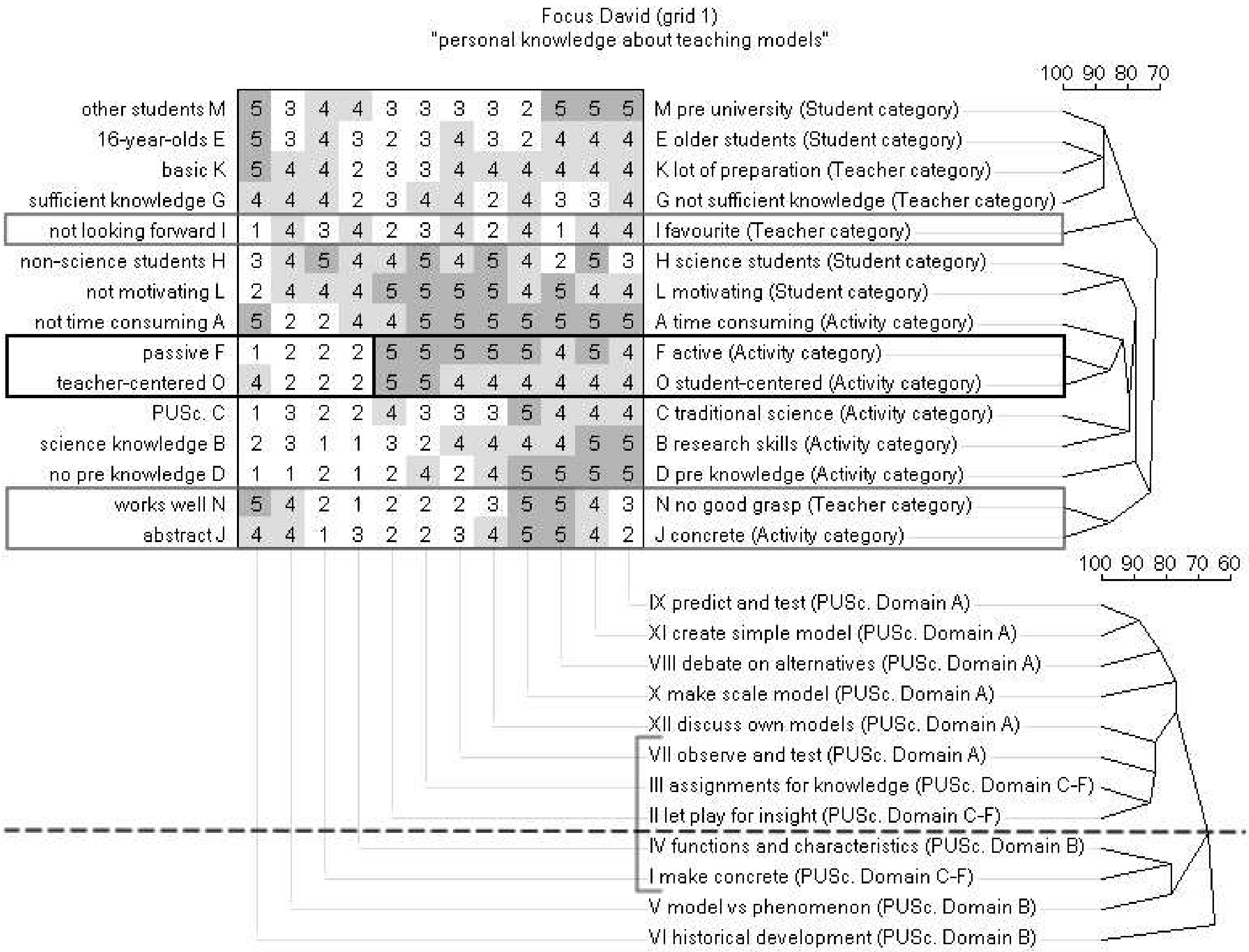

Figure 2: Graphic Plot of FOCUS cluster analysis of grid 1 David (2002)

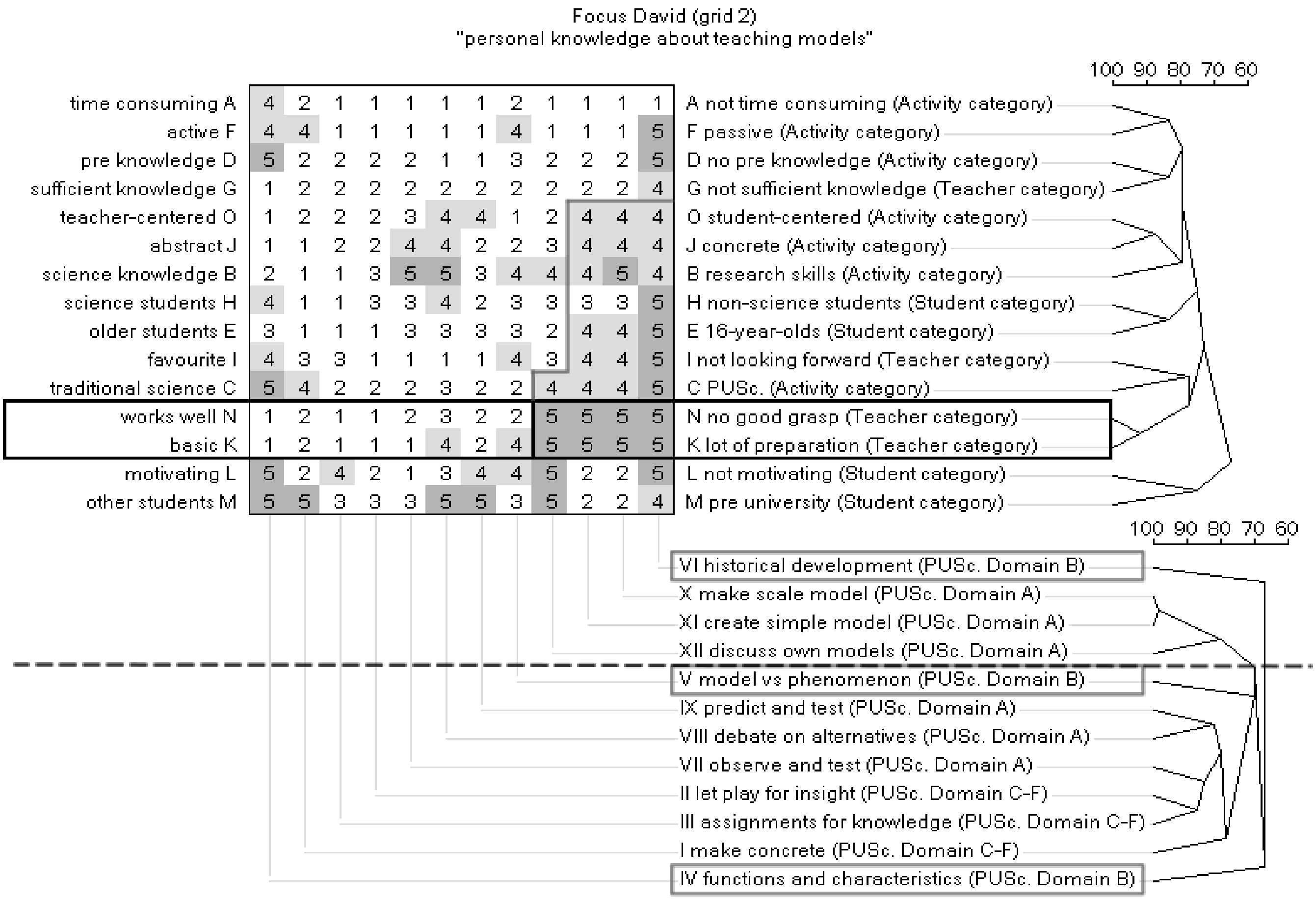

Figure 3: Graphic Plot of FOCUS cluster analysis of grid 2 David (2004)

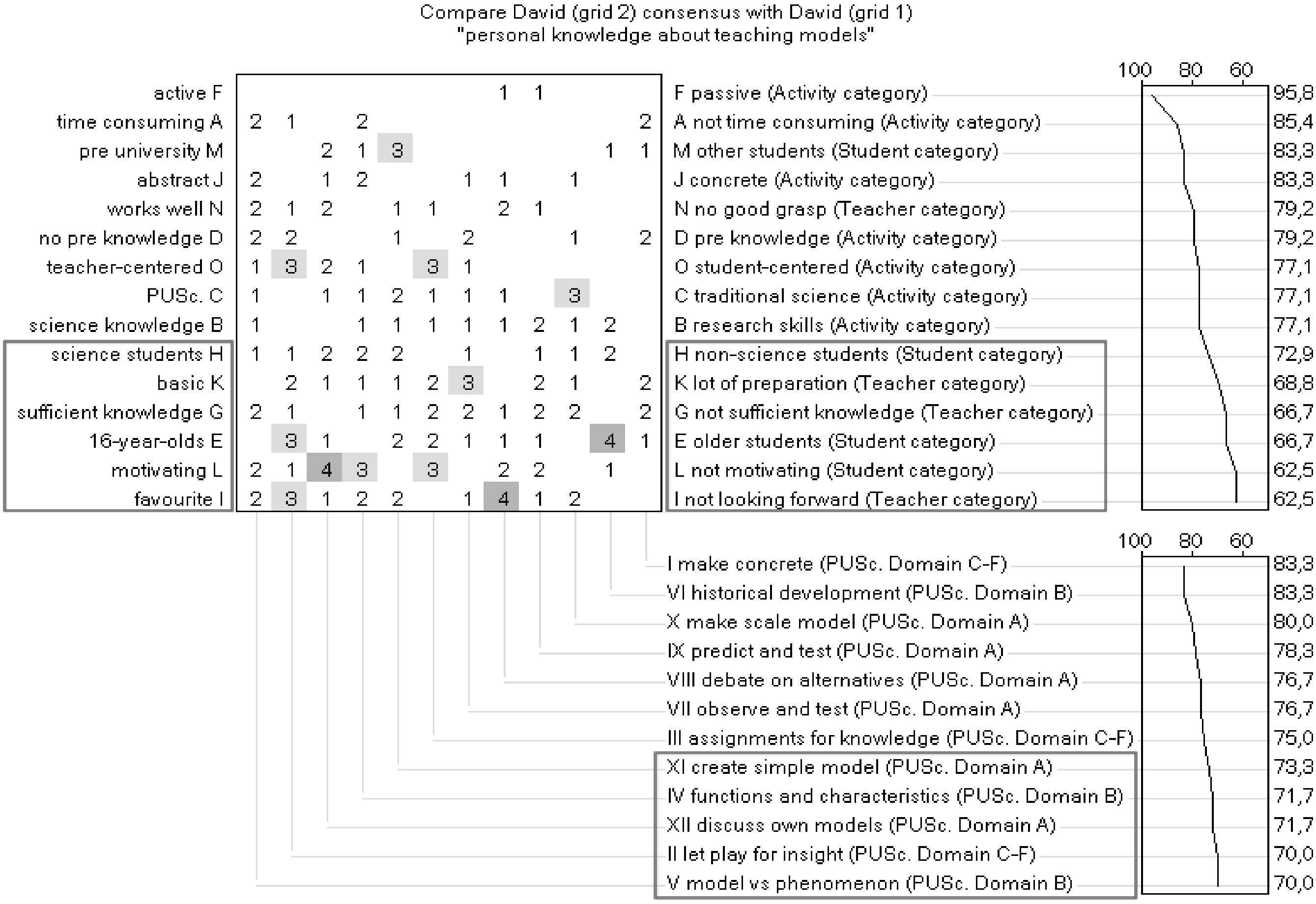

Figure 4: Graphic Plot comparing two grids of David