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MODELLING THE EVOLUTION OF TEACHING - LEARNING SEQUENCES: FROM DISCOVERY TO CONSTRUCTIVISM

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ABSTRACT

In this study we study in retrospect three teaching learning sequences in the area of fluids developed over several years. We investigate the factors that affected the development of these sequences by analyzing the developers practice on the basis of Pickering's theory of scientific practice. We argue that, in science education, the researchers' practice towards meeting his/her/ objectives is influenced by the dominant approach to science teaching and learning but is also constrained by the material factor and the educational introduction.

In recent years, many research based teaching-learning sequences (TLSs) have been developed and studied on a wide range of topics (Anderson and Bach, 1996; Meheut, 1997; Psillos, 1998; Duit, 1999; Psillos and Meheut, 2001). TLSs are considered as a medium-scale curriculum development, a product of developmental research. By developmental research we mean the interlacing of research, development and application of a teaching-learning sequence on a specific topic, usually lasting a few weeks, in a cyclical evolutionary process enlightened by rich research data (Lijnse, 1995; Kattmann and Duit, 1996).

The nature and evolution of scientific knowledge, research on students' conceptions and reasoning, epistemological assumptions, learning beliefs, existing resources, current pedagogical theories and educational contexts are among the factors which are involved in the development of such TLSs. Yet, whereas the learning outcomes from the various TLSs are often published to a considerable extent, explicit and implicit assumptions and decisions that affect the design and development of TLSs are less widely discussed or even made clear by the researchers.

In our case, we have been involved in long-term research and development concerning the teaching and understanding of conceptual and procedural scientific knowledge involved in the area of fluids. Our work has focused on the development and investigation of three innovative sequences on fluids. In this context, rich data exist about teaching practices and learning results over a long period. In the present paper, we study these sequences in retrospect, in order to identify factors and assumptions that affected their development and evaluation in different educational settings in Greece.

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1. MODE OF INQUIRY

The existence of data about the sequences on fluids, which were developed and evolved by almost the same scientific staff, in a changing educational and scientific landscape over the past twenty (20) years, constitutes a significant advantage of the present paper. We consider these three sequences as three successive TLSs, namely TLS1, TLS2, TLS3. As data we take documents concerning the theoretical foundations of the TLSs within the context of Science Education appearring in the teacher guides and plans, the equivalent successive proposals on teaching/learning activities both for the teachers and the pupils (worksheets, plans). Besides we take into account the obtained learning outcomes from each TLS following their classroom application. In addition, our data include documents concerning the initial official curriculum/textbook that obtained during the initiation of the TLSs in the early '80s.

Our approach to the analysis of the data is an epistemological one and aims at revealing the practices that shaped the successive TLSs as scientific products in the domain of Science Education. In our case, following Pickering, we regard as scientific practice (Pickering, 1992; Pickering, 1995) a changeable "behavioural model" that unravels through time. Such a model is structured by the relations between the scientist's knowledge, handling beliefs and experiences as well as his social/institutional relationships, at least in the area of (science) education. We accept that the science education researcher's scientific practice on the one hand exposes the features of the TLSs, which either change or remain stable as time passes, and on the other reveals the relations between the stability or the variability of the factors that influence the science educators' scientific work running over the evolution of these particular TLSs.

More specifically, we assume that in our case the Science Education scientist (or didactician), through his practices, constructs and connects teaching / learning activities in order to produce a TLS. The various activities and the connections between them are constrained by a) educational and institutional, b) material and physical and c) scientific (Science Education) factors (Pickering, 1992; Pickering, 1995). In so doing the didactician is aiming at accomplishing his various objectives and overcoming the specific resistances his work runs into, through a process of accommodation.

As an example, we consider that the objective of a science education researcher in developing a TLS may be the learning of a specific topic by certain students as stipulated by the curriculum that obtains in a specific educational context. **He/she probably is approaching certain resistances to the TLS objectives in terms of the dominant teaching/learning theory (e.g. discovery, constructivism).** We consider though that the choice of the relevant teaching-learning activities does not depend only on the researcher's theoretical preferences. The objectives which have been set, the anticipated resistances and the envisioned adaptations under certain contextual and material constraints also affect the shaping of this TLS. In this way a TLS, being a product of scientific practice, is more of a changeable structure of interrelated teaching/learning activities than a final product. We envision the overall process to be illustrated in the schema that is presented in Figure 1.

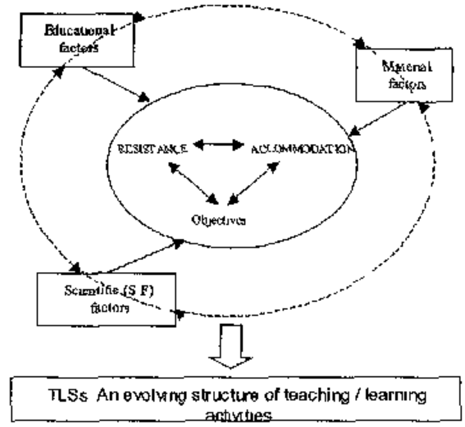

Figure 1. The dynamic that shapes scientific practice in the development of a TLS

Following the above rationale, the scientists' (science educators) practice may derive from the very analysis of the various features of each TLS as materialised in the relevant documents. Such an analysis is presented in the next sections. It was carried out, at an initial stage, by one of the writers (who did not participate in the construction of the sequences) and the results were validated afterwards, during the three (3) researchers' discussion.

2. DOCUMENTING THE EVOLUTION OF THE TEACHING-LEARNING SEQUENCES (TLS) ON FLUIDS

In this section, we describe the evolution of the three TLSs with regard to their content, learning objectives, relevant students' achievements and the dominant approach to science teaching and learning in which each TLS evolved. We also present the official Greek curriculum on fluids obtaining in the early '80s. We must note that these three TLS were small scale innovations not widely adopted changes.

The 1st TLS, developed in the early '80s, arose from the need to introduce students to labwork, since in Greece traditional teaching was based on lecturing and, possibly, on some demos. For that purpose, a 6-unit teaching sequence on Fluid Mechanics was developed on the basis of the official curriculum and the school textbook. The main objective of the TLS is student practice in experimental skills and some understanding of fluid concepts and laws in relation to everyday applications. TLS1 was applied to 13/14-year-old pupils in the 2nd form of Greek Gymnasium. For reasons related to educational context, the application of TLS1 activities follow some lecturing on the basic concepts/principles of fluid phenomena in line with the official curriculum. The units include labwork in small groups, using rotating laboratory exercises and structured worksheets) on themes such as the fundamental law of hydrostatics, Pascal's principle and factors affecting buoyancy.

TLS1 was evolved and applied at a time when discovery approaches to teaching and learning science were dominant. For this reason labwork was based on guided discovery approaches with regard to principles and laws. In addition, there are experiments that students are asked to interpret, aiming to connect physics with everyday life. For example a) compression/extension of the piston of a syringe containing first water and then air, in order to observe similarities and differences between liquids and gases, b) experiment with an egg floating in salted water which shows off the role of the density of the liquid in buoyancy, a case connected with everyday experiences, like brine c) experiment on shipping to point out floating condition cases where weight was a variable.

Table 1 presents the historical evolution of these TLSs, in connection with their content, learning objectives, and student achievements. At the beginning of this table, the content, objectives and perceived result of the official curriculum of that time are also presented as reference material.

PHASES PERIOD POPULATIO N	**CONTENT OF THE TEACHING SEQUENCE**	**LEARNING OBJECTIVES**	**RESULTS**
Official curriculum Early '80s, Gymnasium	Concepts, Laws/Principles and Phenomena of Fluids Mechanics	Conceptual learning of the basic issues of Fluids Mechanics	Limited conceptual improvement
TLS1 Early '80s, Gymnasium	Verification experiments of rules and principles Interpretation of experiments in order to connect Physics to everyday life.	Learning experimental skills Connection of Physics theory to practice	Positive attitudes to labwork Improvement of **experimental skills** Limited conceptual improvement
TLS2 Late '80s, Gymnasium	Fluids' content transposition (introduction of P as primary concept) Experiments on Fluids to facilitate conceptual knowledge	Learning conceptual knowledge e.g. differentiation between pressure and force Learning procedural knowledge	Sufficient learning of conceptual knowledge e.g successful differentiation between pressure and force Insufficient learning of procedural knowledge
TLS3 '90s University	Fluids' content transposition (introduction of P as primary concept) Experiments on Fluids to facilitate both conceptual and procedural learning	Conceptual learning e.g. Differentiation between pressure and force Learning procedural knowledge	Improvement of conceptual learning, - Differentiation of Pressure / Force described in 3 distinctive steps Moderate **procedural learning** Difficulty in manipulating concepts as entities

Results from the application of have shown positive student attitudes towards the lab as well as substantial student familiarization with experimental skills. However, this was not the case on the conceptual level **(Kariotoglou et al, 1988)**

The 2nd TLS refers to the transformation of guided labwork into the constructivist context and the pursuit of mainly conceptual learning, driven by conceptual change. This transformation is based, on one hand, on the "students' conceptions" movement and on the other hand on content transposition. As far as "students' views are concerned, TLS2 takes advantage of their classification, regarding pressure, into three models: packed crowd, pressure – force and liquidness, in order to introduce and negotiate the pressure concept (see Kariotoglou and Psillos, 1993; Kariotoglou et al., 1995; for an extensive discussion of the models). To avoid reinforcement of the pressure – force model (non-differentiation between pressure and force), the pressure concept is introduced independently, qualitatively and experimentally, without connecting it with force. Such an approach arises from students' conceptions, which are reinforced by the introduction of the pressure concept in the traditional way (P=F / s). However, at the end of TLS2 the concepts of pressure and force are connected with each other following their assumed differentiation.

Table 1. Evolution of the content, objectives and learning achievements of the TLSs

In the process of differentiation we induce students to cognitive conflict. For example, they are exposed to the following critical experiment: predict and test experimentally a) the comparison of pressures in a wide / narrow vessel that contains water to the same depth, and b) the comparison of forces exerted in order to detach a narrow sucker and a wide one). Based on the model of non-differentiated concepts (pressure – force model), predictions about pressure and force are expected to be uniform, that is, students claim either that they are equal or that the bigger the size of the vessel / sucker the bigger the pressure or force exerted. However, the experimental data are different, that is, equal pressures and unequal forces were observed. Discussion on this issue leads to most students' differentiating the two concepts.

The results of TLS2 have shown success concerning conceptual learning and the differentiation of pressure and force concepts. As for the **experimental skills**, no significant improvement was observed since it was not the main objective. The experiments are mainly regarded as a means to conceptual learning in combination with guided discussion (Kariotoglou et al., 1993; Kariotoglou et al., 1995).

TLS3 is an extension of TLS2 that was applied to a different population, namely student primary teachers with a limited amount of conceptual and procedural knowledge in science. Empirical data point out that their conceptual knowledge had similar features to those of 13/14 year-old pupils , though richer in interpretations and terminology. Besides, the equivalent pursuit of learning experimental procedures and conceptual learning constitutes a fundamental change in the constructivist context. This fact bears a double justification: on the one hand, procedures are an inseparable part of science and, on the other, prospective teachers ought to become acquainted with this part of scientific knowledge as well. In that way, experimental activities become enriched and aim to facilitate not only conceptual learning but procedural learning as well. For instance, a) prediction, planning and realization of experiments aimed at testing variables affecting hydrostatic pressure, b) experimental investigation of Pascal's principle using a specially designed vessel fitted with three manometers and a pump to increase pressure (see also Table 1 and Table 2, below).

The results have shown success in the conceptual domain combined with a refined presumption of learning in three levels (Psillos and Kariotoglou 1999). The objective concerning procedural learning proved to be less successful, chiefly due to a difficulty in handling theoretical concepts like entities of the material world, with which students would be able to intervene in the experiments. For example, while pressure seems to be understood as a representation and differentiated from force, it cannot be handled as an entity and used to intervene in the experiment. That is, students cannot, when asked, intervene to increase or decrease pressure (see for details Kariotoglou, 1998) (see table 1).

3. ANALYSING THE SCIENTIFIC PRACTICE: RESISTANCE AND ACCOMMODATION

In Table 2, we present the official curriculum as well as all three TLS in terms of the factors we take into account in our analysis of scientific practice, namely educational context, the dominant scientific approach to teaching and learning and the material conditions. As mentioned before (see Figure 1), these factors are considered to be taken into account by a didactician in his/her attempt to promote the achievement of certain objectives by the targeted students an assumption which is verified by our analysis of the documents. We note that our analysis focus on the researcher's practice not policy makers' or teachers' practice. In this table we codify and present the proposed teaching/learning activities in order to show their relation with the envisioned factors and the relevant learning results. Table 2 reveals whether there is a resistance to achieving the set objectives in a TLS the interpretation of which will guide the accommodation of this TLS.

The 1st TLS was developed within a context. in which learning by reception of a scientific topic was a widespread practice, and not just within Greek educational tradition. This tradition is governed by the rationale of expository teaching and is reinforced by the limited material/technical school infrastructure: that is, absence of laboratory premises and a limited number of experimental set-ups. The basic resistance that appears within this practice has to do with the limited learning results in relation to scientific subject matter , and is located within the educational framework (compulsory education) whose objective is learning of scientific content

In the face of this sort of resistance, the options of the researcher for accommodation were either to modify the scientific content or to select an appropriate teaching approach. In the general education framework of the early 1980s, modification and/or abandonment of the relative content did not appear compatible with current views on science teaching. The second approach, however, that of discovery-oriented teaching, seemed more plausible. The students would discover knowledge and learn by doing. Adapted to the framework of the existing material restrictions (limited material/technical infrastructure), this option resulted in labwork performed on a rotation basis with a single set of instruments. On this basis, the didactical proposal of TLS1 was the addition of discovery based practical labwork to the lectures of the typical curriculum. This practice, regarded by the researchers as necessary and potentially effective as far as **the linking of theory with practice and the απόκτηση of laboratory skills is concerned**,was successfully realized within the contemporary educational context, although under material constraints. Despite the successful results of the application, the resistance towards conceptual learning persisted.

Table 2. Analysis of the scientific practice

Teaching Learning Sequence	EDUCATIONAL Factor	Scientific Factor (Science Education)	Material Factor	Learning Objective	Accommodation: Didactical Proposal in terms of Activities	Resistance
Official Curriculum	General Education Context 9th form	Hypothesis of learning by reception	Limited number of standardized set-ups of simple demo experiments	Learning of scientific content	Lecture) + Demo experiments)	Limited Conceptual Learning
TLS1	General Education Context 9th form	Hypothesis of Discovery Learning	Standardized set-ups of simple demo experiments + Limited number of experimental set-ups with simple / everyday materials	Learning of scientific content + Linking theory and practice + Experimental skills	Lecture + student guided discovery labwork in a rotating lab form	Limited Conceptual learning
TLS2	General Education Context 9th form	Students' Pre-existing Conceptual Models + Hypothesis of Learning by Constructing Knowledge	Limited number of experimental set-ups both standardized and with simple / everyday materials	Learning of Specific content, transposed from scientific theories + Learning of scientific procedures	Familiarization experiments, Testing ideas by guided experiments Demos inducing conflict Discussion of applications	Limited learning of Procedural Knowledge

TLS3	Primary School teachers' education context	Students' pre-existing conceptual models + Hypothesis of Learning by Construc-ting knowledge	Experimental set -ups with simple / everyday materials + Standardized experimental set - ups (corresponding to the multitude of students' practicing groups)	Learning of specific content transposed from scientific theories + Learning of scientific procedures + Experimental skills	As TLS2 +open investigation Guided discovery experiments	Diffi-culty in Mani-pulating concepts as entities of the real world

The new resistance, i.e. limited conceptual learning, that emerged at the end of the 1980s has to be seen in the context of the students' conceptions movement and the emergent constructivist approach to teaching and learning in science education. This new scientific framework affects the new accommodation. The 2nd TLS consequently exploits students' conceptions while at the same time transforming the didactical content in order to render it appropriate for the target population. We may detect here a substantial change in teaching aims, from the learning of the relevant scientific theory and models to the learning of a transposed scientific theory and models. Within this framework the objective of learning laboratory procedures remains, but is subordinated to the basic objective of conceptual learning. Based on this rationale, the learning of scientific methods was scarcely pursued and therefore was not achieved. This fact constituted the new resistance (see table 2, TLS 2).

In the TLS3 there was a change in a significant educational factor, with the attempt to apply the basic principles of the sequence to a new population, namely student primary school teachers. At the same time the resistance to procedural learning remained, since the new population required them for professional reasons. What was the outcome of this new accommodation? Since the need for conceptual learning remained, the role of students' ideas and the constructivist approach could not be ignored. But the requirement of scientific procedures restored the idea of guided labwork. The difference between this and the 2nd TLS lies in the fact that in this case experimental skills are pursued for themselves rather than as an adjunct to conceptual learning. Accommodation in the 3rd TLS led to a combination of constructivist teaching with guided labwork, a novel connection between the scientific and the material factor within the current educational context (see table 2, TLS 3).

The above description of the dialectical relation between resistances and accommodation in the evolution of the TLSs shows that material, scientific and educational factors have all played an important role in the changes that have taken place. These factors led to changes in both the objectives of the TLSs and the didactical proposal.

A global presentation of the preceding analysis is given in Table 2. The resistances and accommodations are shown in the last two columns of the table. The resistances are mainly related to learning of conceptual knowledge (Official Curriculum, 1st TLS) and of procedural knowledge (2nd and 3rd TLS). The accommodation that led to the development of the 1st TLS is related to the educational framework (content learning), the predominant scientific paradigm of the period (discovery) and the material factor (limited materials / rotating labwork). In the case of the 2nd TLS, we have a change in the scientific paradigm (constructivism), the same educational framework, and a material factor adapted to the new scientific paradigm: that is, demonstrations of critical experiments. Finally, in the 3rd TLS the scientific paradigm remains the same (constructivism) but is enriched (guided labwork) on account of the priorities of the new educational framework (university education). This new educational framework also affects the material factor (existence of sufficient material means). We observe that all three factors of our theory – that is, the scientific, the educational and the material – play a role in each separate accommodation. We further observe that in each case the accommodation is realised within the framework of the currently predominant scientific approach.

4. CONCLUDING REMARKS

This paper is a retrospective critical review of the evolution of a series of Teaching-Learning Sequences in the field of fluids with the objective of revealing the factors that affected the development and modification of these TLSs as they were applied at different educational levels. In our study we argue that the development of these Teaching-Learning Sequences is as scientific practice within science education. Accordingly we study such a practice by a method developed on the basis of Pickering's theory (1992, 1995) of scientific practices.

The analysis of the dialectical relation between resistances and accommodations with regard to the evolution of the TLSs that was carried out in the previous sections reveals that scientific and educational factors as well as material ones have played an important role in the changes that have taken place. The changes related both to the objectives and the relevant teaching proposal.. Our basic position is that prevailing approaches to science teaching and learning (expository, discovery-based or constructivist) constitute the scientific factor that influences the practice of the science education researchers and this is verified from the analysis of the data. Besides a privileged relation between learning results and scientific factor emerges as the researchers attempted to make up for the noted limitations in students' learning. Our study reveals that this relation is constrained by the educational and material factors which affect the specific materializations of the TLS. Yet in discussing TLSs in the public domain these factors are not usually taken into account.

We believe that the practices of science education researchers are becoming of an age so there may be enough historical documents whose study warrants investigation. In our case we believe that this review of the development practices applied to the sequences as the object of scientific investigation contributes from both the methodological and the conceptual point of view to the modelling of explicit and implicit assumptions and decisions that have a considerable effect on the design and development of a sequence and therefore on the relation of research to development in Science Education.

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