

# ITALIAN PRIMARY SCHOOL PROSPECTIVE TEACHERS BELIEFS ABOUT KNOWLEDGE CONSTRUCTION: A CASE STUDY ABOUT MODELS

Benedetto DI PAOLA<sup>1</sup> and Claudio FAZIO<sup>2</sup>

## TITLE

**Les croyances des futurs enseignants de l'école primaire italienne au sujet de la construction de la connaissance: une étude de cas au sujet de la modélisation**

## ABSTRACT

In this paper we discuss a study on the approaches to modeling of students of the 4-year Primary School Teacher program at the University of Palermo, Italy. The answers to a specially designed questionnaire are analyzed on the basis of an a-priori analysis made using a general scheme of reference on the epistemology of mathematics and physics. The study is performed by using quantitative data analysis methods, i.e. analysis of implicative and similarity trees.

*Key.words* : teacher beliefs, modelling, implicative analysis

## RÉSUMÉ

Dans cet article, nous discutons une étude à l'Université de Palerme (Italie) concernant les approches de modélisation des élèves de quatrième année du programme scolaire d'enseignement de l'École primaire. Nous analysons les réponses à un questionnaire conçu spécialement à cette occasion sur la base d'une analyse a priori qui utilise un schème général de référence de l'épistémologie des mathématiques et de la physique. L'étude est réalisée en utilisant les méthodes d'analyse quantitative, c'est-à-dire l'analyse des arbres d'implication et de ressemblance.

*Mots-clés* : croyances des enseignants, modélisation, analyse implicative

## 1 Introduction

In these last years the education research community has shown a great interest in problems facing the implementation in the school practice of pedagogical activities based on scientific and mathematical modeling (Gilbert et al., 1998). According to Niss (2001), models can be used by science and mathematics teachers in order to help students to analyze and assess a given situation, consolidate the analytical skills acquired during learning and improve learning due to specific, scientific contexts in which models are constructed and discussed.

---

<sup>1</sup> GRIM (Mathematics Education Research Group), Dipartimento di Matematica e Informatica, Via Archirafi, 34, Università di Palermo, Italia, benedetto.dipaola@unipa.it

<sup>2</sup> UOP\_PERG (University of Palermo Physics Education Research Group), Dipartimento di Fisica, Viale delle Scienze, ed. 18, Università di Palermo, Italia, claudio.fazio@unipa.it

On the other hand, as Viennot *et al.* have pointed out (2005), it is important to take into account that a factor that critically influences the educational practice may be the teacher. Exactly as students cannot be considered passive receivers of what they are taught, teachers are not simply passive transmitters of pedagogic innovation defined by research. More or less explicit disregard of critical details of a proposed pedagogical sequence, more or less evident dislike for the planned strategies are likely to deeply influence student's learning. Moreover, besides possessing content knowledge and technical abilities appropriate to implement in her/his classrooms the suggested approaches, like the ones based on modeling, the teacher will probably look at them more or less favorably depending on her/his personal lines of thought, or beliefs, about knowledge construction.

In this paper, we discuss some results of a research study carried out with respect to the conceptions and beliefs about knowledge construction and to the approaches to modeling activities of pre-service teachers attending the 4-year program for Elementary Teacher Education at University of Palermo, from now on called student teachers (STs). The main hypothesis of our work is that elementary school pre-service teachers implicitly have their own beliefs with respect to the construction of scientific knowledge and to the understanding of reality, which then become explicit when engaged in modeling activities and processes. These beliefs turns out to be the result of their past experience as students and of other implicit behaviors of their past school teachers. Experiences from the social context in which they live and work can also play a relevant role.

## 2 Epistemological approaches to mathematics and physics learning

In the literature it is possible to find many references to different epistemological approaches to knowledge construction, or 'schools of thought', more or less explicitly linked to mathematics and physics learning, with particular relevance to modeling abilities. In our research we concentrate only on the most well-known approaches, as they are easily identifiable in future teacher behavior.

1. The behaviorist approach (Pavlov, 1927; Skinner, 1974) sees knowledge construction as a response to concrete external stimuli coming from the real life world. Learning is achieved best when the learner can confront real, concrete situations. She/he uses descriptions of reality mainly based on concrete data coming from the environment. Memory is often used 'on the spot' and out of context.  
A model is, then, seen by the learner as a repetition of facts, or a reproduction of objects really existing or a scale reproduction of reality, aimed at completely describing what is observed.
2. Cognitive psychology claims that knowledge construction is a process mainly involving the use of memory (i.e. recalling of cognitive resources), motivation, and thinking ( Craik and Lockhart, 1972; Craik and Tulving, 1975; Ausubel, 1974). Description/interpretation of new situations is based on previous learning experience and on contextualized use of memory and other cognitive resources.

The model is, then, a mental construction aimed at making sense of reality by comparing it with the learner resources. The learner is able to recall the variables relevant in a previously studied phenomenon and to find useful relationships between them but is not always able to explain the reasons of her/his answers.

3. Constructivist theory claims that knowledge construction is the product of observation, processing, interpretation, and personalization of the information into personal knowledge structures (Cooper, 1993; Wilson, 1997). The learner interprets the world and builds her/his knowledge by making analogies with her/his previous models of knowledge and making abstract references to objects and ideas coming from experience. Learning is often promoted by peer to peer work and by contextualization for immediate application in order to acquire personal meaning.  
The model is a mental construction built by analogy to situations not necessarily related to the phenomenological world and can be applied to it, if needed

### 3 The research

The study here described is part of a more complete one due to Fazio et al., 2012. Here we discuss the results obtained by quantitative research methods, involving the analysis of data obtained by the administration of an open-ended questionnaire. Data coming out from the questionnaire have been analyzed by means of implicative statistics methods (Gras *et al.*, 2008). The main objective is not a final testing of the hypothesis resulting from previous studies (see, for example Kagan, 1992 and Pintrich, 1990) rather its further development.

The questionnaire was administered to 78 STs enrolled at the third year of the program for Elementary School Teacher Education during Academic Year 2009/2010, before the beginning of the courses of physics and mathematics education. The questionnaire is made of two parts: a six-item one on the processes of modeling and a four-item one on the connections between models and real situations, i.e. on how the personal ideas on modeling are put into action when related to concrete situations. The questionnaire was first a-priori analyzed, searching for the possible answers to its items (Brousseau, 1997). Each item has been studied in terms of the strategies that the students use when answering it. The a-priori analysis was independently performed by the researchers, and then a consensus was negotiated to obtain the final, shared list of the analysis. During the analysis of the actual ST answers each researcher used the list to draw up a table resuming the strategies actually used by each ST to answer the questions.

The main research questions involved in this study are the following:

- What are the main epistemological approaches to mathematics and physics learning evidenced by a sample of student teachers that followed a traditional high school curriculum?
- What kind of implications can be deduced between the strategies put into action by ST in answering to questions related to the use of models to make sense of proposed situations.

The questionnaire's 10 questions are reported below. Each question is followed by the set of possible strategies we hypothesized STs would put into action when answering the question, and the unforeseen strategies, in italics.

### Questions and their respective answering strategies

#### 1) Models are very common in science and mathematics, but what actually is a model in physics?

- 1A A faithful or reduced scale reproduction of a real object.
- 1B *An operative procedure to follow in order to simplify and describe phenomena from the natural world.*
- 1C A reproduction of a real object, not necessarily on a reduced scale, aimed at helping us to interact with it and/or describe it.
- 1D A stylized/simplified reproduction of a real object, aimed at helping us to interact with it and/or describe it.
- 1E A mental representation of a real object or phenomenon, which accounts more or less accurately for its mechanisms of functioning.
- 1F A real or abstract object that behaves like another real object, but does not necessarily look like it.
- 1G A physical model is a mental formalization of real phenomena.

#### 2) And what is a model in mathematics?

- 2A A picture of a geometrical shape, maintaining fixed proportions between its elements.
- 2B It is a method to faithfully describe reality.
- 2C It is a quantitative but essential reproduction of a phenomenon.
- 2D A mathematical model is a symbolic/quantitative representation of a situation/phenomenon.
- 2E *A mathematical model is a guideline or a formula, aimed at resolving a problem.*
- 2F A mathematical model is a simplified representation of a system, whose basic elements (variables, sources and contexts) are connected by relationships (a set of rules).
- 2G *A mathematical model is a reference for the construction of a line of reasoning or the demonstration of a hypothesis.*
- 2H It is a description of a situation/phenomenon that is useful for predicting the evolution of the situation/phenomenon itself.
- 2I It is an abstract construction that allows different quantitative representations of the same object to be built.

#### 3) Are the models creations of human thought or do they already exist in nature?

- 3A They are creations of human thought based on pre-existing 'natural models'.
- 3B *Models really exist and are simple, real life situations.*
- 3C Models already exist in nature and humans try to understand them, sometimes only imperfectly.
- 3D Models are simply creations of the human mind, like mathematical formulas.
- 3E Many models are creations of the human mind and are what we call 'theories'.

- 3F Models are creations of human thought; their creation comes from continuous interaction with the 'real' external world.
- 3G Models are creations of human thought, and their purpose is to predict and make sense of natural phenomena.

**4) What are the main characteristics of a model? Give at least one example.**

- 4A A model has to start from some hypotheses of the real world that have to be verified.
- 4B It must be able to account for all the features of the real object it represents.
- 4C The model must simply be a description of the reality.
- 4D *It must be fixed and immutable. It is the modeler that chooses a model suitable for the real situation.*
- 4E It must be able to account for the features of the real that are of practical interest.
- 4F It must highlight the variables that are relevant for the description//explanation of the phenomenon and their relationships.
- 4G It must be expressed in mathematical language and/or accepted by a scientific community.
- 4H *It can be qualitative, semi quantitative or quantitative.*
- 4I It must allow what we observe about different phenomena/situations to be generalized.
- 4J It must be useful for analyzing and making predictions about the behavior of a more or less complex system.

**5) Can all natural phenomena be described or explained by a model? Carefully explain your answer.**

- 5A *Yes. A natural phenomenon can always be described by a physical model, as physics is the natural world, with all its laws.*
- 5B No. There are phenomena that cannot be described/explained with a model and/or that cannot be defined in terms of precise physical quantities.
- 5C Not always. Even the ablest modeler will not be able to reproduce particularly complex systems (for example human behavior).
- 5D No. Some phenomena still have not been explained, but they will be in the future.
- 5E Yes. It just depends on the modeler's ability to carefully reproduce the features of interest.
- 5F Yes and no. In fact the way nature works is not completely known to man, so further study is necessary to explain all phenomena.
- 5G Yes. If the modeler is able to find all the relevant variables that characterize the phenomenon.

**6) Is a mathematical formula always a way to express a real situation? Carefully explain your answer.**

- 6A No, as mathematics is an abstract construction and does not always represent reality.
- 6B *Yes, but only if it quantitatively describes the entire real situation.*
- 6C No, because reality is so complex that it cannot always be expressed by a mathematical formula.
- 6D No, because not all phenomena can be described mathematically/quantitatively.

- 6E Yes, because mathematics is the language the human brain uses to quantitatively describe/explain a real situation.
- 6F No, as a real phenomenon can have characteristics that cannot easily be expressed in mathematical language.
- 6G *Yes, because a mathematical law is always verifiable, starting from well-defined hypotheses.*
- 6H Yes, but it is necessary to carefully choose the mathematical variables needed to express the real situation.

**7) Can the mathematical formula  $y=ax$  be used to calculate the circumference of a circle? Carefully explain your answer.**

- 7A No, as in the formula for circumference calculation the radius and the circumference are present, and not the variables  $x$  and  $y$ .
- 7B *No, because the constant  $a$  does not have the correct value, i.e.  $2\pi$ .*
- 7C No, because  $y=ax$  is a direct proportionality, i.e. a straight line, while the circumference is a curve.
- 7D No, because the formula  $y=ax$  is an algebraic one, while the circumference calculation is a geometric task.
- 7E *No, because  $y=ax$  is not the correct mathematical relationship between  $x$  and  $y$ .*
- 7F Yes, because the circumference is directly proportional to the radius, as  $y$  is with respect to  $x$  in the formula  $y=ax$ .

**8) An object is free falling. Report the variables that you think are relevant for the description of the phenomenon and verbally describe the relation that you think exists between these variables. Carefully explain your answer.**

- 8A The speed of the object depends on certain parameters, like the object's weight, its shape or the forces acting on the object.
- 8B The relevant variables are space and time. They are linearly dependent.
- 8C The relevant variables are space and time. Space is proportional to the square root of time.
- 8D *The relevant variables are the acceleration caused by gravity and/or the starting height and/or the mass and/or the force of gravity.*
- 8E In order to describe the phenomenon we must determine all the forces acting on the object and then use Newton's 2nd law.
- 8F The relevant variables are time, space, velocity and acceleration – an explanation is given, but the relationships between the variables are not completely or clearly expressed.
- 8G The relevant variables are time, space, velocity and acceleration. Space is proportional to the squared time and/or velocity is proportional to time – examples are clearly given.

**9) Write the mathematical formula that represents the relation you found in the previous question. Carefully explain your answer.**

- 9A Verbal explanation based on concrete situations, but no formula reported.
- 9B *Graphic representation of non significant variables that come from real experience.*
- 9C Use of incorrect formulas, like  $s = vt$  and/or  $F = Ma$ .

9D  $s = \frac{1}{2}at^2$  - no explanation.

9E  $s = \frac{1}{2}at^2$  and  $v = at$  - no explanation.

9F v-t and/or s-t formulas/graphs are reported and correctly commented on/applied.

10) **Consider the free falling object in the previous two questions. How would you modify the model to take into account other elements that can influence the motion of the object, like the medium in which the motion takes place?**

10A The motion of the object can be influenced by environmental conditions, like wind or temperature.

10B *The motion can be influenced by a collision with another object.*

10C Friction with air can influence the motion of an object.

10D Friction with air can influence the motion of an object, so density may be a relevant variable.

10E If we want to improve the model, we should take into account one or more forces opposite to motion, for example, friction with air, which increases with the velocity of the object, with its surface area, etc.

We then built a table that identifies three ‘profiles’ containing the answering strategies that can be considered typical of each epistemological approach reported in Section 2. Each profile defines, then, the ‘ideal model’ of a ST answering to all the questionnaire items by always evidencing a given epistemological approach.

These profiles, reported in Table I, have been used for the quantitative analysis of the research data.

TABLE 1 - *ideal profiles of ST and the related answering strategies for the 10-item questionnaire*

Behaviorist	Cognitivist	Constructivist
1A, 1B,	1C, 1D	1E, 1F, 1G
2A, 2B, 2C,	2D, 2E, 2F, 2G	2H, 2I
3A, 3B, 3C,	3D, 3E	3F, 3G
4A, 4B, 4C, 4D	4E, 4F, 4G, 4H	4I, 4J
5A, 5B, 5C, 5D	5E, 5F	5G
6A, 6B, 6C, 6D	6E, 6F, 6G	6H
7A, 7B	7C, 7D, 7E	7F
8A	8B, 8C, 8D, 8E	8F, 8G
9A, 9B	9C, 9D, 9E	9F
10A, 10B	10C, 10D	10E

## 4 Results and discussion

Figure 1 shows the implicative graph obtained by means of C.H.I.C. ST answering strategies are implied each other by means of arrows. For the sake of simplicity, we chose to represent in figure 2 only answering strategies that imply another one with a significance level of 99% (Red, double lines), 95% (Blue, solid lines) and 90% (green,

dashed lines). We remark that in CHIC graphs implications are to be read only between couples of strategies. So, as an example, implication chain 2F-9E-7F is to be read by considering the “single” implications between 2F-9E (99%) and 9E-7F (99%).

In the following we discuss some of the implications, by considering the higher percentages of implications, but also taking into account the number of STs involved<sup>3</sup>.

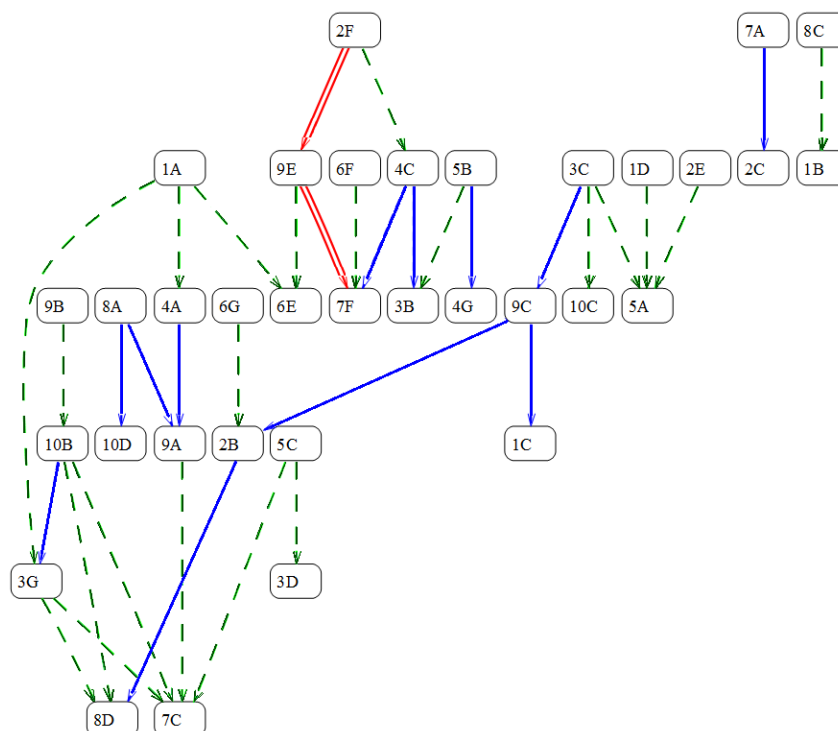


FIGURE 1 - *Implicative graph for answers to the test. Red, double line arrows indicate a 99% incidence of implication between two strategies, blue, solid arrows evidence a 95% incidence and green, dashed arrows indicate 90% incidence of implication.*

Implication between strategies 2F and 9E (revealed practically in all the 10 STs exhibiting strategy 2F) states a close link between two cognitivist strategies, i.e. the recognition of the formal structure of model and the ability to report mathematical formulas to resume a phenomenon (not supported, however, by an explanation of the reasons of the answer).

The 99% implication between 9E and 7F seems to evidence that 18 STs, not being able to explain the reasons of their (correct) writing of mathematical formulas to resume a phenomenon, appear to be able, in item 7, to put into action a constructivist-like answering strategy. The 95% significant implication between strategies 10B (behaviorist) and 3G (constructivist), revealed in 12 STs, seems to again evidence a correlation between the use of low-level and higher level strategies. On the other hand, we must also consider that item 3 is one of the questionnaire items aimed at exploring the general, theoretical aspects of the process of modeling, while item 10 is an applicative one, aimed at testing the actual capabilities to expand a model to represent new situations. So, implication 10B-3G actually gives us notice of 12 STs that are not able to generalize a model by applying it to wider situations and whose constructivist-

<sup>3</sup> We will not discuss here implications involving less than 10 STs.



type idea of the nature of a model, expressed in 3G, is probably to be considered developed only at a declarative level.

The 90% implication between strategy 3G and a cognitivist one (7C), evidenced by 17 STs, and the 90% one between 3G and the cognitivist 8D (again true for 17 STs), go along the same line. We can, then, hypothesize that the previously considered implications may be ascribed to the use of resources coming from previous instruction experience, i.e. “memories” coming from mathematics and physics courses attended by the STs in previous years (all our STs attended a 5 year course of physics and mathematics at Secondary Schools, although only limited to a few hours per week).

Implications 1A-4A and 8A-9A, true for 10 and 11 STs, respectively, give evidence of the persistence of behaviorist strategies applied by STs in answers to questionnaire items on the nature and characteristics of models and in trying to give a verbal and then a formal description of a real physical situation. A persistence of behaviorist strategies can also be found in the interesting implication 5B-3B (true for 14 STs), where the idea of the existence of phenomena that cannot be explained by a model is related to the idea of a model as something really existing in nature and identified as simple, real life situations.

The 90% implication between answering strategies 9A and 7C (in 13 STs) makes evident a link between a behaviorist approach to the formalization of a situation and a cognitivist-like use of formulas. The use of strategy 7C, although attesting the correct recognition of  $y=ax$  as a direct proportionality, makes evident an imperfect transfer between algebraic and geometrical representations, and can, so, be an obstacle to procedures based on mathematic modeling.

Other implications worth noting are the ones between 3C and 5A and 2E and again 5A (both in 10 STs). These implications highlight that the idea of model as something existing in nature, that humans can only imperfectly understand, or as a formula aimed at solving a problem, is linked to the identification of physics with the natural world, with its laws.

Figure 2 shows the similarity tree obtained from our data. Each ST is represented by  $s_i$  (where  $i$  goes from 1 to 78) in the rightmost column of the graph. The three ideal profiles: *behav. IST*, *cogn. IST* and *const. IST* (representing the ‘Behaviorist’, ‘Cognitivist’ and ‘Constructivist’ approaches to knowledge, respectively) are considered as ideal STs and placed in the same column of ST. The tree makes evident relationships and similarities between the general answering strategy evidenced by STs and also allows to study the similarity between each ST and the ideal ST profiles.

The horizontal axis reports the similarity level between STs. For example, similarity between  $s_{11}$  and  $s_{55}$  is weaker than similarity between,  $s_1$  and  $s_{47}$  as the link between the first two variables corresponds to a lower similarity level with respect to the link between  $s_1$  and  $s_{47}$ . Note also that these four variables are linked to the Behaviorist ideal profile, even if with a lower link strength.

Figure 2 reports the similarity tree obtained by C.H.I.C. It shows that the STs are grouped in several similarity clusters, at different levels of strength of the link. With respect to STs’ similarity with the ideal profiles, three ‘macro clusters’ are evident. The great majority of elements in our sample globally exhibit a Cognitivist answering strategy, with a 74% confidence level, and nine evidence Behaviorist-like attitudes, at

70% confidence level. Only two STs show answering strategies that can be resumed as Constructivist, at 89% confidence level. The three macro-clusters shown in figure 2 are disjointed at the reported confidence levels.

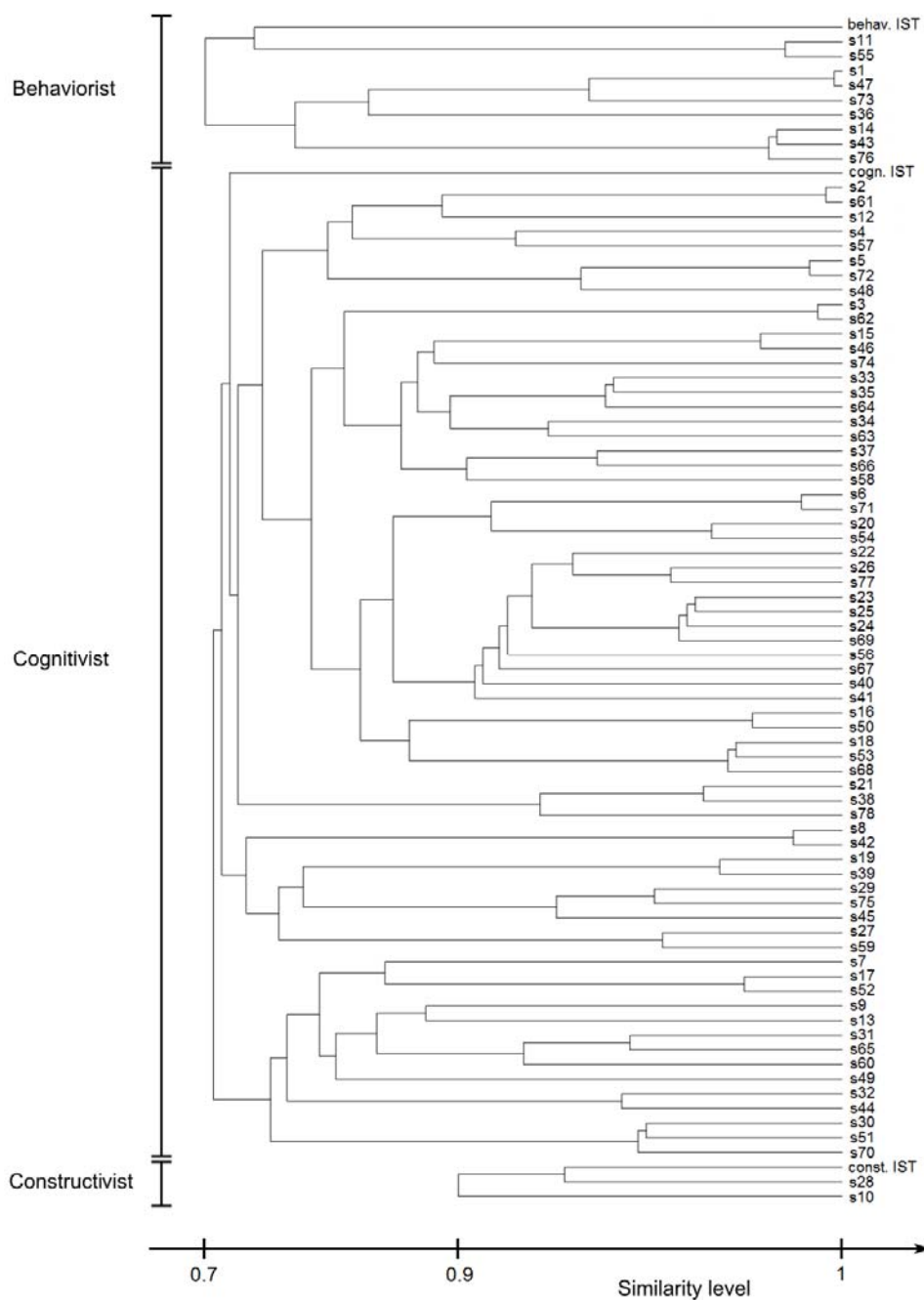


FIGURE 2 - Similarity tree for the study variables (STs answering to the test and the three ideal profiles identified on the basis of the *a-priori* analysis). The horizontal axis reports the similarity level between variables, but it is not represented in scale.

## 5 Conclusion

The similarity tree analysis discussed above allows us to say that the vast majority of our elementary school student teachers made use of answering strategies that can be generally defined as cognitivist, with only a small group showing clear behaviorist attitudes and only two showing a well defined constructivist approach. The implication graph and the qualitative analysis of interviews help us to refine this result, by giving more detail about relationships and implications between the answering strategies used by STs.

The personal views revealed by our analysis of the beliefs and approaches to modeling of our sample may be the result of the typical way in which STs have been taught mathematics and science in the past. In fact, very often, concepts relevant for the understanding of scientific questions are introduced in Italian schools by following a traditional teaching approach, without any advantage for the understanding of the implicit scientific content concerning real life phenomena. Such traditional approach is usually based only on the transmission of contents and integrated with sometimes meaningless workshop activities. In fact, these are very often performed directly by teachers with the sole purpose of contextualizing ideas already taught as they are presented in traditional textbooks and passively accepted by students. These types of teaching methods tend to stimulate rigid mnemonic attitudes in more passive students, fostering a behaviorist-like approach to new situations that are presented to them. More active students are at best motivated to build links bridging the concepts they have studied with real life contexts in an attempt to give them meaning, thus making use of a typical cognitivist-like approach, which is not wrong in itself but not always sufficient for a meaningful approach to scientific knowledge. However, it is well known that an effective scientific education needs to be supported by activities deeply rooted in a constructivist-like approach, (Nersessian, 1995; Watts & Jofily, 1998; von Glasersfeld, 1994) capable of helping students to observe and make sense of suitably designed experiences related to everyday life phenomena. In fact, as research into science education has largely shown, the more learning environments are able to stimulate student interests related to their own everyday lives, the more effective they are.

Our results are consistent with data from the literature (Klein, 1996; Collinson, 1996; Calderhead, 1996). In particular, we find that STs' beliefs can be eclectic, and sometimes contradictory. Many STs hold more than one view about knowledge construction, with particular reference to strategies that are inefficient for correctly connecting mathematical modeling to real situations. This is an ability that can be considered an important part of the construction of elementary school STs' own science understanding (Koch, 2006).

Our findings allow us to go in depth with respect to the STs' epistemological approaches to knowledge. They highlight a significant presence of behaviorist ideas, even in student teachers that generally adopt cognitivist strategies. Moreover, our data evidence a ST general approach to knowledge too grounded on a rigid use of cognitive resources, mainly coming from memories of past instruction and not based on a solid understanding of modeling strategies. When we analyze the implicative graph we also notice that in some cases cognitivist strategies are linked to constructivist ones. A more

detailed study, also based on qualitative analysis method (Fazio et al., 2012) shows that in some cases these constructivist strategies are used by STs only at a declarative level. In these cases such use is not supported by a suitable application of constructivist strategies to the analysis of the real situations presented.

## References

- [1] Gilbert, J.K., Boulter, C. and Rutherford, M. (1998), Models in explanations: part 1, horses for courses? *Int. J. Sci. Educ.* **20**, 83
- [2] Niss, M. (2001), Issues and problems of research on the teaching and learning of applications and modeling. In *J.F. Matos, W. Blum, S.K. Houston & P. Carreira (Eds.), Modeling and mathematics education: ICTMA 9 – Applications in science and technology*. Horwood Publishing, Chichester, England), 72.
- [3] Viennot, L., Chauvet, F., Colin, P., and Rebmann, G. (2005), Designing strategies and tools for teacher training: The role of critical details, examples in optics. *Sci. Educ.* **89** (1), 13
- [4] Pavlov, I. P. (1927), *Conditioned reflexes*, Clarendon Press, London.
- [5] Skinner, B. F. (1974), *About behaviorism*, Knopf, New York.
- [6] Craik, F.I.M. and Lockhart, R.S. (1972), Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior* **11**, 671.
- [7] Craik, F.I.M. and Tulving, E. (1975), Depth of processing and the retention of words in episodic memory. *J. Exp. Psychol.* **104**, 268.
- [8] Ausubel, D. P. (1974), *Educational psychology: A cognitive view*. Holt, Rinehart and Winston, New York.
- [9] Cooper, P. A. (1993), Paradigm shifts in designing instruction: From behaviorism to cognitivism to constructivism. *Ed. Technol.* **33**(5), 12.
- [10] Wilson, B. G. (1997), Reflections on constructivism and instructional design. In *C. R. Dills & A. J. Romiszowski (Eds.), Instructional development paradigms*, Englewood Cliffs, NJ: Educational Technology Publications, 63.
- [11] Fazio, C., Di Paola, B. and Guastella, I. (2012), Prospective elementary teachers' perceptions of the processes of modeling: A case study. *Phys. Rev. ST Physics Ed. Research*, **8**, 010110.
- [12] Ertmer, P. A. and Newby, T. J. (1993), Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Perform. Improv. Q.* **6**(4), 50.
- [13] Gras, R., Suzuki, F., Guillet, F., Spagnolo, F. (2008), *Statistical Implicative Analysis: theory and applications*, Springer, Germany.
- [14] Kagan, D. (1992), Implications of research on teacher belief. *Educational Psychologist*, **27**(1), 65.

- [15] Pintrich, P. (1990), Implication of psychological research on student learning and college teaching for teacher education. In W. Houston (Ed.), *Handbook of research on teacher education*, Macmillan, New York, 826.
- [16] Brousseau, G. (1997), *Theory of Didactical situations in mathematics*. Edited by M. Cooper, N. Balacheff, R. Sutherland, and V. Warfield, Kluwer Academic, Dordrecht.
- [17] Nersessian, N. (1995), Constructive modeling in doing and learning physics, in *Thinking Physics for Teaching*, edited by C. Bernardini, C. Tarsitani, and M. Vicentini (Plenum, New York, 77.
- [18] Watts, M. and Jofily, Z. (1998), Towards critical constructivistic teaching, *Int. J. Sci. Educ.*, **20**, 173.
- [19] von Glasersfeld, E. (1994), Questions and answers about radical constructivism, in *The Practice of Constructivism in Science Education*, edited by K. Tobin Lawrence Erlbaum, Hillsdale, NJ, 18.
- [20] Klein, P. (1996), Preservice teachers' beliefs about learning and knowledge. *Alb. J. Educ. Res.* **42** (4), 361.
- [21] Collinson, V. (1996), Staff development through inquiry: Opening a pandora's box of teachers beliefs. Paper presented at the *Annual Meeting of the Association of Teacher Educators*, St. Louis, MO. (Eric Document Reproduction Service No. ED. 393 842).
- [22] Calderhead, J. (1996), Teachers: Beliefs and knowledge. In D. Berliner, & R. Calife (Eds). *Handbook of Educational Psychology*, Simon & Schuster Macmillian, NY, 709.
- [23] Koch, J. (2006), in *Elementary Science Teacher Education*, edited by K. Appleton, Lawrence Erlbaum Associates, New Jersey, 91