An Interview with Dorothy L. Gabel

Una entrevista con Dorothy L. Gabel

Liberato Cardellini

Dipartimento di Scienze dei Materiali e della Terra, Facoltà di Ingegneria, Via Brecce Bianche, 60131 Ancona, Italy
libero@univpm.it

Abstract

This comprehensive interview provides glimpses of Prof. Gabel's life from her early interests in science to her professional work with prospective chemistry teachers. In the interview, Gabel considers the qualities of a good teacher, gives suggestions about textbooks and analyzes their influence in the change of chemistry teaching. She also discusses the development of misconceptions and, derived from her many studies on this subject, the difficulties encountered by students in problem solving. As a leading scholar in students' understanding of the particle nature of matter, she gives advice on how to present this topic at all levels of instruction, recommends the manipulation of a physical representation of the atoms, and suggests the adoption of collaborative learning methods with students discussing in small groups.

Key words: *conceptual understanding, misconceptions, problem solving, particle nature of matter.*

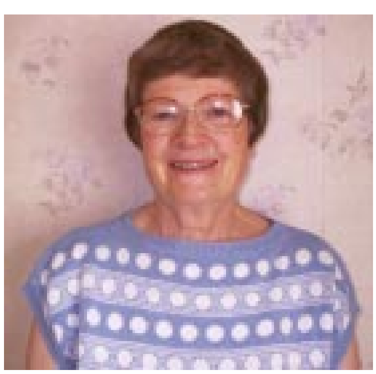
Resumen

Esta entrevista proporciona los detalles de la vida de la profesora Dorothy Gabel, sobre sus intereses tempranos en la ciencia y su trabajo profesional con los maestros destacados de la química. En la entrevista, D. Gabel considera las calidades de un maestro bueno, da sugerencias sobre los libros de texto y analiza su influencia en los cambios de la enseñanza de la química. Discute también el desarrollo de conceptos erróneos y, con base en muchos estudios de este asunto, las dificultades encontradas por los estudiantes en la resolución de problemas. Ella da consejos sobre la naturaleza particular de la materia de cómo presentar este tema en todos los niveles de instrucción, recomienda las manipulaciones de una representación física de los átomos, y da consejos en la aplicación de métodos de aprendizaje colaborativos con los estudiantes que discuten en grupos pequeños.

Palabras clave: *comprensión conceptual, conceptos erróneos, resolución de problemas, naturaleza particular de la materia.*

INTRODUCTION

Professor of Science Education at Indiana University, author of numerous papers on science education, and internationally known for her studies on problem solving and the particulate nature of matter. Dr. Gabel has received seven research awards from the National Association for Research in Science Teaching including two JRST awards for the most significant manuscript published in the Journal in 1977 and 1979 (the first for her dissertation article with her major professor, J. Dudley Herron, and the second with John Staver, for the research report based on his dissertation as his dissertation director. Professor Gabel has been awarded research and teaching grants from various agencies totaling over $2,000,000. She has been a member of the editorial boards for several science education journals, and a reviewer of science education research manuscripts for the Journal of Research in Science Teaching, School Science and Mathematics, and the International Journal of Science Education. She is the author of several books and chapters, and was the editor of the *Handbook of Research on Science Teaching and Learning* (Gabel, 1994). In addition, she served almost two years as a Director of Teacher Preparation at the National Science Foundation (1987-1988), has served as president of the National Association for Research in Science Teaching, the School Science and Mathematics Association, and the Hoosier Association of Science Teachers, Inc. In 1999, she was awarded the National Science Teachers Association Carleton Award for Exemplary Service in Science Education.



Questions*: Let's start with a brief biography: why did you choose to study chemistry, to become a teacher, and to work in science education.*

I was born in New York on Long Island in 1936, moved to St. Louis in 1941, to Washington, DC in 1950, Chicago in 1951, and Buffalo, NY in 1956. My father worked for the US government. Each move was considered an educational experience for my brother, and me and led to very tight family bonds. In 1957, I received BA degree from Rosary College (Dominican University) with a major in chemistry. In 1969, I earned an MS degree through NSF summer institutes at Purdue University. I returned to Purdue as a full time doctoral student in chemistry education one year later, and completed the Ph.D. in 1974.

My interest in science began when I was about ten. We had no science instruction in the Catholic elementary school but I was fascinated with nature. Many of my playtime activities were science related. These ranged from making observations on which insects could swim by placing them on a large rock in a small fish pond in our backyard, to collecting insects with my brother for our live-insect-zoo to which we invited our neighborhood friends, to looking at onion skin and hair through a microscope given to me for Christmas. I enjoyed belonging to a junior garden club in seventh and eighth grades and being a Brownie and a Girl Scout. My first experience with chemistry was coating copper pennies with mercury using a friend's chemistry set. I hope that it has no long term health effect!

In high school I took biology, physics, and chemistry in that order. I liked physics but did not like biology because of the memorization, or chemistry because I didn't understand it – even though I got an "A." I took chemistry in college because I was thinking about becoming a doctor or a veterinarian. Chemistry seemed to make sense in college, and I enjoyed it because there wasn't much memorization. Instead, there was problem solving at which I was quite good. After college I decided to join a religious community that staffed over 100 elementary schools, 14 high schools, and two colleges in the US. Hence during my early formation years I took some education courses and did my practice teaching before assuming the role of a full time high school chemistry teacher in Madison, Wisconsin in 1959. In 1970, I returned to Purdue to pursue the doctorate. Even though I loved teaching high school chemistry, I thought that I could make a greater contribution to society by working with prospective chemistry teachers, than by teaching at the high school level.

You had Prof. Herron as supervisor: what did you learn from him?

Dudley Herron became a member of the Purdue faculty while I was studying for the master's degree and I was fortunate to have him as an instructor in the one education course in the Purdue masters degree program, the "Methods of Teaching High School Chemistry." It was Dudley that actually suggested that I consider getting a doctorate in science education. I was very impressed by his enthusiasm for teaching, his deep religious convictions, and his openness for me to pursue the doctorate in whatever institution I thought best. (He actually supplied me with a list of other institutions that had good programs.) After examining the doctoral programs in several institutions I selected Purdue because of its flexibility, and the financial support that was offered.

During my first year I actually worked in the biology department supervising a large biology course (300+ students for future elementary teachers). Then during the second year Dudley offered me an assistantship to teach chemistry teaching methods and to supervise chemistry student teachers while he developed a general science methods course. I also became the Associate Director of the Chemistry Institute that year. It was during this year that I really got to know Dudley and knew that I had made the right decision to study with him (Gabel, 1999).

Philosophically we agreed in so many areas. Our common interest was in making high school chemistry conceptually understandable for students. During my third year at Purdue, Dudley went to Malaysia for the entire year, and I took over his teaching duties at Purdue. When he returned during my fourth year I taught and supervised Chem 100 for the Chemistry Department. The course was taken by 100 engineering students who needed to take a refresher chemistry course before enrolling in the regular one. During this year I completed my dissertation, a year long study of the effect of self-pacing vs. deadlines, and partners vs. working alone on the rate of learning of science in 12 schools with 1200 seventh grade children participating.

One of the things that I always admired about DUDLEY was how rapidly it appeared that he could get his ideas on paper. He would sit at his typewriter for hours and produce great papers! I remember in the midst of this, he always had time to help me, and was a wonderful mentor. So the first great influence in my life as a science educator (beyond the many positive experiences that I had as a high school chemistry teacher for eleven years), was DUDLEY HERRON. As I reflect on this now, I am not certain of exactly what I learned from him–except to get a lot of work done in a short period of time! It was as if we were sharing ideas all the time, and I knew I had a mentor who was very supportive of me as a person and colleague.

What qualities are important in a teacher and how much is enthusiasm important in teaching?

Teachers need to have an in-depth knowledge of the content they are teaching and need to be able to relate the content to everyday life. An in-depth knowledge implies that they have the appropriate pedagogic content knowledge, that is, they are able to explain particular concepts in several effective ways. In addition, they need to know effective teaching strategies that make learners active in conceptually understanding the content. Enthusiasm is very important. Sometimes it is the enthusiasm of a beginning teacher that helps compensate for his/her lack of pedagogic content knowledge that develops over time while the teacher begins to understand students' misconceptions. Other personal qualities that are important are having a sense of humor, showing interest in and compassion for students, and being fair in all circumstances.

Do you have a recipe for an "ideal textbook"?

No, I don't have a recipe, but I wish I did (GABEL, 1983). So much depends on what use will be made of the textbook and this depends on what happens in the chemistry classroom. From my experience in working with college students who are prospective elementary teachers (all of whom have taken high school chemistry), and also from examining answers and scores on tests that students take at the end of their high school chemistry course in Indiana, it appears that students know very little chemistry that is relevant to life. There appears to be little conceptual understanding of simple topics such as burning, melting, decomposing, and dissolving. It is difficult to see how most students' high school chemistry course would motivate them to appreciate science or motivate them take additional chemistry courses. I believe that the textbooks should show how matter and its changes at the macroscopic level, is related to matter and its changes at the particle level, and how this is represented symbolically. This would probably necessitate the moving of atomic structure to a position from the beginning of most textbooks to a position further back. It would also mean that less algorithmic methods of problem solving (such as the factor-label method) would be replaced by more conceptual ones (multiplication and division). The difficulty in writing a text is that a person who has a deep understanding of the structure of chemistry writes the text and hence this structure informs the order of the content. Instead, the textbook author must get into the mind of the naive learner who does not know the structure and figure out how to best help him/her acquire it. This means starting with something familiar and leading to the abstract structure as an explanation of the familiar. I believe that best high school textbook presently available in the US for all chemistry students (regardless of whether they will major in science or not) is the 4th edition of *ChemCom* (2002) now published by W.H. Freeman and Company. It attempts to do this.

Why do students develop misconceptions, and what is wrong with having some misconceptions?

There are several sources of misconceptions. A true misconception is probably one that is derived from a person's encounter with nature (GABEL, 1989). For example, as I sit at my desk writing this, I place my hand on a piece of paper and on the metal doorknob. I reach the conclusion that the temperature of the paper is higher than the temperature of the metal because the metal is a better conductor of heat than paper (so heat flows from my hand more quickly to the metal than to the paper causing the sensation that the metal is colder). Other misconceptions are learned because sometimes a person makes inappropriate generalizations. For example, in elementary school children learn that water freezes at 0ºC. Some children think that ice is always at this temperature even on a day that is much colder or if placed in a freezer. Others think (or memorize) that everything freezes at zero. They just have not examined the freezing point of other materials or studied the topic in enough depth. This has implications for teaching concepts more completely. Errors that sometimes occur in texts that students read and believe are misconceptions that are avoidable, but nevertheless do occur.

There is nothing the matter with having misconceptions. Everyone has some. Learning is the process of making ones conceptions more scientific, that is, more in agreement with those of others and with what we believe reality is.

You have done extensive research on stoichiometry (BUNCE, et al., 1991; GABEL, 1983; GABEL, et al., 1983; GABEL, et al., 1984). **Why do students go wrong in problem solving?**

This is another big area, and books have been written on it! My own view is that if students have a good conceptual understanding, they can solve the problems. Another view is that students obtain a conceptual understanding by solving the problems. I believe both statements are true. This fall I gave my students some problems that involved making different quantities of brownies when given various quantities of ingredients such as eggs and oil. About 92% got the items correct. I also gave them problems involving moles and masses of less familiar materials, generally referred to as chemicals. The percentage getting the item correct was about 32%. The major difference in the problems was not the mathematics because the same skills were required. It was the lack of familiarity with the materials and the units. I think that what happens in chemistry is that there are too many unfamiliar materials and units in chemistry problems. For some students even mass and volume are new. They also contain unfamiliar units such as grams, liters, and moles. What results is that students are frustrated by so many new terms, etc. that they memorize how to set up the problem and get an answer without thinking about what they are doing. This is promoted by the blind use of the factor-label method (dimensional analysis) where no thinking is required. Just add STP in a mass-mass problem and see how confused students are! They want to solve the problem like a gas law problem because this is what they associate with STP. Students need to analyze problems carefully and be able to explain each step, tell what information is superfluous and what additional information is needed.

Some concepts also need to be taught before students take chemistry in high school, and also in much more detail than is common in the US today. This would reduce the number of new concepts students would need to learn at the high school level. For example, in many elementary science and mathematics textbooks in the US, volume is taught as part of the metric system. After it is taught, however, its formal use is abandoned, and quantities are frequently referred to as size and amount. Why not use words such as diameter, circumference, length, volume, mass, etc. consistently in place of vague words like amount and size? Perhaps by the time students get to high school, some of the needed vocabulary would be in place, and students would be better problem solvers in chemistry.

How will instructional technology change our business—will teachers be replaced by technology?

I have no basis to make a prediction. I think that there will always be a need for teachers. Not everyone is motivated to study chemistry and I am uncertain if technology will supply the motivation or be able to analyze student's needs and prescribe appropriate instruction. In a way it is like medicine. Will computers take the place of doctors? For some functions, yes; for others, no.

Why is the process of transferring the ideas fron research to teaching so slow?

Changing chemistry teaching to include research findings has been very slow (GABEL, 1999). There are two external factors that I see influencing science teaching more than research. These are: (1) increased emphasis on testing, and (2) commercial control of textbooks.

(1) In the US, individual states and school districts have interpreted the National Science Education Standards (NSES) as minimum. Many well-meaning scientists and officials *of state government agencies* think that minimum is insufficient for their State so they have added additional standards. This enlarges the content base in most States that in turn becomes impossible to achieve for many students. Hence students resort to memorization rather than understanding.

(2) Textbooks are a commercial commodity by which the book industry makes a profit. Probably 95% of the book companies are unwilling to take a risk to publish a book based on research recommendations. The driving force of the content of textbooks is the market survey completed by current high school teachers who will be the purchasers of the new textbook. Publishers use the results to determine the structure of the book and other features. Teachers frequently model their instruction on what they have

used in the past, or have studied themselves at the college level, and hence few changes take place in the elementary and secondary textbooks.

There have been two instances where I have seen some research in which I was involved make a difference in textbooks, but only because I personally worked with an author, or was an author myself. The first was the increased use of the particle nature of matter used throughout a textbook rather than being confined to one chapter on kinetic molecular theory. I had initiated a study with CLIFF SCHRADER on his students' understanding of the particle nature of matter using particle pictures representing all types of changes. Results were presented at a NARST meeting in the mid 80s. As a result of this, when CLIFF was asked to be an author of the *Heath Chemistry* textbook (1987) with J. DUDLEY HERRON and others, it included particle pictures throughout the text. In a like manner, when I became a co-author of the Prentice-Hall's, *Chemistry, The Study of Matter* (DORIN, *et al.*, 1992) it included particle pictures in all chapters. Apparently (according to the late MARJORIE GARDNER), I coined the expression "Pictures in the Mind" and the inclusion of these pictures in high school and college textbooks has now become common practice. In addition, in 1979, I did a NSF supported study on using a variety of methods with high school students to solve chemistry problems (GABEL, *et al.*, 1983). Many of the ideas that shaped the writing of the problem solving sections of the aforementioned *Chemistry, The Study of Matter* textbook were drawn from this study as well as the contents of *Solving Chemistry Problems* (1983) by GABEL published by Standex (now Prentice-Hall).

You have done extensive studies on the particle nature of matter. What is the best way to present it to students of different ages?

In the past fifteen years or so I have become increasingly interested in students' understanding of the particle nature of matter. This is especially true since the publication of the *National Science Education Standards* (1995) in the US. My interest was actually sparked by a lecture that I heard by ALEX JOHNSTONE at an American Chemical Society meeting in 1990 when he indicated that 70% of chemistry teaching was on the symbolic level. A recent study (GABEL, *et al.*, 2003), at Indiana University indicates that the symbolic area is more difficult to understand than either the particulate or macroscopic levels. It seems to me that if students cannot translate chemical symbols, such as those that appear in balanced equations, to the representation of atoms and molecules (the particulate level), all they are doing is memorizing symbols that are quite meaningless. The interesting part of chemistry is not in the memorization of symbols and balancing equations. It is in providing explanations of phenomena (the macroscopic level) that is sensed in our three dimensional world! The particulate nature of matter provides the explanations (GABEL, 1993). It answers the question of why and how.

There are various opinions on the appropriate age to introduce children to the particle nature of matter. The research shows that children even at the ages of 10 to 12 view matter as continuous and do not think of it in terms of particles (DRIVER, *et al.*, 1994). Unfortunately, some elementary science textbooks still include particle pictures and symbolic representations as early as grade three. The video series, *Science in Focus: Shedding Light on Science* (1999), endorsed by the Association for the Education of Teachers shows the use of particles as an appropriate exercise for children at about the third grade school level (Annenberg Foundation series). Although I have not personally done research in this area, I am of the opinion that there is no need to introduce children to "particles" at this early age. One might argue by analogy that things can be broken down into little pieces, and that these little particles can be sensed when one smells a perfume or not seen when something dissolves. This explanation on an informal basis is fine, but at what age do children understand analogies?

The evidence that convinced me that children do not understand much about the particle nature of matter stems from an informal conversation that I had many years ago (in the 80s) with GLEN BERKHEIMER from Michigan State University. GLEN was the author of a well-known science book textbook series for a major publisher. The textbook had pictures of particles in the early grades and probably also balanced chemical equations, as did many other textbook series at that time. GLEN was awarded a sizeable NSF grant to develop materials for a new science series using the particle nature of matter. After developing the materials, he field-tested them with children in the Detroit area. What he found was that children below grade six did not understand the particle nature of matter, and that even children in middle school (grades 6-8), had difficulty understanding the particle nature of matter as related to chemical changes. These excellent materials (BERKHEIMER, *et al.*, 1988), are now available for teaching middle school children.

Many current textbooks for elementary and middle school textbooks still include the teaching of chemistry at the particle and symbolic levels. However, the latest edition of FOSS (2003), one of the best hands-on approaches to teaching chemistry in grades 1-6 in the US, introduces particles very briefly and as an optional explanation in grade six. This is in accordance with our *National Science Education Standards* (1995) that does not include the particle nature of matter in elementary science instruction. I am in complete agreement with the philosophy in our National Standards. Why spend an excessive amount of time trying to teach elementary-aged children explanations using particles, and their symbolic representations, when they have had such a limited exposure to the phenomena for which particles are used as explanations. Instead, use the time for studying chemistry at the macroscopic level so that when particles and symbols are introduced later, they will be more fully and readily understood!

For all other levels beyond middle school, chemistry should first be introduced at the macroscopic level in a laboratory, or hands–on environment. Then particles can be used as an explanation of what has been seen on the macroscopic level. I highly recommend that students actually manipulate a physical representation of the atoms. Several years ago, teachers were successful using magnets of different diameters representing atoms arranged as molecules on metallic surfaces to represent chemical reactions, equations and physical changes (GABEL, 1992). I currently recommend the approach taken by MARK WALTERS (1993) in teaching chemistry at the introductory college level, as well as at the middle school and high school levels. MARK represents atoms and molecules using Play-Doh. The advantage of the Play-Doh is that it is flexible and requires students to consider properties of atoms such as their diameter, molecular mass, and the packing in crystals, as well as whether the material is a heterogeneous mixture, solution, substance, and also whether it is a solid, liquid or gas. Combining the use of these three dimensional atoms and molecules with computer simulations that provide particle movement and collisions should deepen students' understanding of the particle nature of matter at the high school and college levels. Using these models to show how atoms and molecules form intermediate compounds when they successfully collide at the proper angle and with sufficient energy, should help students understand chemical and physical changes, and be useful in representing atoms and molecules in writing balanced chemical equations.

In working with the models, students will profit more using collaborative learning where they freely discuss their ideas with other students in small groups. The phenomena that they represent should begin with familiar, everyday occurrences for which particles give a ready explanation such as burning, decomposition, melting, dissolving and other simple chemical and physical changes and occurrences. For example, many of my college students (prospective elementary teachers all of whom have taken a course in high school chemistry as a prerequisite to admission at Indiana University) do not know the difference between the humidity in the air and fog. Preliminary findings of a study now being analyzed (GABEL, *et al.*, in progress) show that students' understanding of "everyday" chemistry concepts increased significantly when they used PlayDoh in an interactive learning environment. Unless chemistry is meaningful and related to explaining observations in the real world, few students will find the pleasure in chemistry that those of us involved in teaching it or who have majored in it have found! Hence few will choose a career that is chemistry-related!

In summary, I want to thank LIBERATO CARDELLINI for encouraging me to reflect on the questions that he asked. Sometimes one wonders if the things that they have done in a lifetime have made any difference whatsoever. I had not thought about some of these topics for a very long time. My current research is still on student's understanding of chemistry. I have recently found that more students appear to understand chemistry better on the particle level than on the macroscopic and symbolic levels. Next year, as in the past, I will use my research findings to see if I can improve chemistry instruction in my own classes. I will be emphasizing what is occurring on the particle level with certain macroscopic chemical and physical changes before using symbolic representations as is commonly done at the present time.

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La comprensión de las propiedades físicas de la materia: motivación y cambio conceptual
The understanding of physical properties of matter: motivation and conceptual change

ALFREDO GOÑI GRANDMONTAGNE [1], JOSÉ DOMINGO VILLARROEL VILLAMOR [2]

[1] Departamento de Psicología Evolutiva y de la Educación. Universidad del País Vasco, España, aralfredo@euskalnet.net
[2] Colegio La Salle, Bilbao, mintxo@teleline.es

Resumen

Para adquirir el conocimiento científico es preciso que se produzca, de una u otra forma, algún cambio conceptual. El cambio desde las teorías personales (basadas en representaciones macroscópicas que se atienen a la descripción de hechos y fenómenos experimentales observables) a la teoría científica (basada en representaciones microscópicas vinculadas a la comprensión de teorías químicas abstractas) ni es simple ni exclusivamente cognitivo. Al objeto de superar el modelo del "cambio conceptual frío", PINTRICH, MARX y BOYLE (1993) propusieron indagar las eventuales relaciones entre variables motivacionales y cognitivas. Este trabajo aporta corroboración empírica que, en una muestra de 202 alumnos de enseñanza secundaria obligatoria, la motivación y la comprensión científica de las propiedades físicas de la materia guardan relación mutua.

Palabras clave: creencias motivacionales, cambio conceptual, naturaleza de la materia, enseñanza secundaria, química.

Abstract

Acquiring scientific knowledge requires in some way some conceptual change. However, the change from personal theories (based on macroscopic representations which deal with describing observable phenomena on a experimental basis) to the scientific theory (based on microscopic representations related to the understanding of abstract chemical theories) is neither simple nor exclusively cognitive. With the purpose of overcoming the model of "cold conceptual change," PINTRICH, MARX and BOYLE (1993) proposed to analyze the possible relationships between motivation and cognitive variables. This research provides empirical information about the following subject: the assessment was done in a sample of 202 students from obligatory secondary education, and the conclusion was that the motivation and the acquisition of scientific knowledge are connected to each other.

Key words: *motivational beliefs, conceptual change, nature of matter, secondary school, chemistry.*

INTRODUCCIÓN

Durante la etapa de la Educación Secundaria Obligatoria, uno de los aspectos fundamentales de la enseñanza de la química es el estudio de las características de los sistemas materiales y de las transformaciones que éstos pueden sufrir sin cambiar su esencia molecular (BENARROCH, 2000; CAAMAÑO, 2000; POZO, 1998). Las *transformaciones físicas* de los sistemas materiales incluyen procesos de agregación de la materia y fenómenos como los de dilatación, contracción, expansión o compresión. Los estudiantes deben entender que, más allá de las apariencias externas, la materia es discontinua ya que está compuesta por partículas (moléculas, átomos, etc...) que están en continuo movimiento. Tales partículas interactúan de distintas maneras en cada uno de los estados (gaseoso, líquido y sólido) en los que la materia puede aparecer, estados que, más allá de las diferencias observables entre ellos, comparten la misma composición química.

Sin embargo, tras estudiar química durante la enseñanza secundaria e incluso durante la universitaria, muchos estudiantes siguen manteniendo una representación intuitiva de la materia. Como ocurre en otros dominios científicos, la mayoría de los estudiantes no remplazan sus teorías personales por la teoría científica que les han enseñado; en lugar de representaciones microscópicas sobre el movimiento de las partículas, mantienen una representación macroscópica sustentada en la apariencia inmediata de la realidad entendiendo la materia como continua, estática y sin espacios vacíos entre las partículas. La causa de ello es que el aprendiz, enfrentado al esfuerzo cognitivo de organizar el conocimiento científico, suele preferir utilizar el conocimiento desarrollado con la finalidad de dar sentido a su experiencia diaria (PRIETO y BLANCO, 2000; POZO, 1998).

La investigación sobre el cambio conceptual conforma una tradición con una antigüedad de bastantes años. Aborda una temática que no es precisamente simple ni cabe reducirla a saber si tiene lugar o no la sustitución de las teorías personales por las teorías científicas. Puede suceder, en muchos casos, que coexistan representaciones macroscópicas y microscópicas, activándose unas u otras en función de las tareas, de los contenidos o de determinadas variables contextuales. Puede ocurrir, incluso, que se aplique de forma confusa la teoría corpuscular de la materia o que se mezclen interpretaciones microscópicas y descripciones macroscópicas atribuyendo a las primeras determinadas características (color, textura, estado físico, dilatación, etc.) que son propias de los sistemas materiales macroscópicos (POZO, GÓMEZ y SANZ, 1999).

Esta línea de investigación, en definitiva, permanece abierta, con temáticas