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TEACHING LOWER-SECONDARY CHEMISTRY WITH A PIAGETIAN CONSTRUCTIVIST AND AN AUSUBELIAN MEANINGFUL-RECEPTIVE METHOD: A LONGITUDINAL COMPARISON

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ABSTRACT: Two methods of teaching lower secondary chemistry were compared in this longitudinal study: a constructivist method (CM), based on Piaget's theory of cognitive development; and a meaningful-receptive method (MRM), based on Ausubel's theory of meaningful learning. In CM, students had an active involvement, while MRM was applied as a teacher-centred method with a number of improvements from learning theory e.g. use of advance organisers and of concept maps. 144 students of an urban experimental lower secondary school in Athens were divided into two groups and taught chemistry according to the two methods respectively. Teaching lasted two school years (grades eight and nine). One test on knowledge and simple application of basic chemical theory, and another test on stoichiometric calculations were used, at the end of the two grades, for the comparison of the two methods. Although the overall student achievement was low, the CM group scored statistically higher in theory in both grades, while in stoichiometric calculations, the superiority of the CM group occurred only in grade nine. The effect of developmental level, of gender and of motivational traits was also examined. Finally, the students generally expressed a preference for the CM. [*Chem. Educ. Res. Pract. Eur.*: 2000, 1, 37-50]

KEY WORDS: *lower secondary chemistry; constructivist method of teaching; Piaget's theory; meaningful-receptive method of teaching; Ausubel's theory; basic chemical theory; stoichiometric calculations; developmental level; gender; motivational traits*

INTRODUCTION

Low achievement and negative attitudes of secondary school students are basic problems of chemical education. This is very much the case in Greece, where chemistry is taught for the first time as a separate subject in grades eight and nine (age 12.5-14) of lower secondary school (*gymnasion*). Prior to that there is an integrated science course in grades five and six (primary school), where chemistry has a limited participation. According to the programme of studies and the corresponding standard chemistry textbooks that were used until the school year 1996-97, many abstract chemical concepts at the submicro (molecular, atomic and subatomic) level were introduced quite early in the course: atomic and molecular structure, relative atomic and

molecular masses, the mole, molar volume, Avogadro's constant, the building-up of the periodic table on the basis of the atomic (electronic) structure, chemical bonds (ionic and covalent), chemical reactions, stoichiometric calculations. (Since 1997-98, the situation has changed with a new programme of studies and new books that have removed most of the above.) It is well known that these concepts require formal operational reasoning in the Piagetian sense, and at the same time pose a heavy burden on students' working memory (Herron, 1978; Johnstone, 1991; Tsaparlis, 1997). This fact, combined with the very low (just one period of forty-five minutes per week per year) teaching time allocated to chemistry as well as the lack of experiment/practical work from teaching, must be the causes of the very low knowledge of basic chemistry that Greek students used to demonstrate at the beginning (grade ten) of upper secondary school (*lykeion*).

An investigation of the above knowledge was carried out by Tsaparlis (1991, 1994) in ten upper secondary schools in Ioannina, Athens and Piraeus with two tests, one on theoretical topics (see Table 1), the other on stoichiometric calculations (see Table 4). The tests were given right at the beginning of grade ten. The average achievement was 20.5% (with standard deviation, SD, equal to 15.0%) in chemical theory, while in the calculations it was 21.0% (SD = 26.4%). As we commented (Tsaparlis, 1994), 'it is as if students came to upper secondary school, and their only knowledge from foreign-language teaching was only the alphabet; no vocabulary, no grammar, no structure of the language'.

A major target of chemistry education research is to compare various instructional methods, to examine their efficiency, and to suggest improvements or new methods. In this paper, we describe the main findings of a comparative study of the long-term influence of two methods: a constructivist method (CM) and a meaningful-receptive method (MRM). The constructivist method is based on Piaget's theory of cognitive development and tries to achieve the construction of knowledge by the students under the teacher's guidance. Note that, in Greece (and we assume in many countries) constructivist methods are not employed by teachers, the great majority of whom follow traditional expository methods that scarcely diverge from that of the lecture-monologue. On the other hand, the MRM as carried out in this study constitutes a considerable improvement on the traditional expository method, and is based on Ausubel's theory of meaningful learning. A preliminary account of this work has been presented at the 2nd ECRICE (Tsaparlis & Zarotiadou, 1993).

RATIONALE AND REVIEW OF PREVIOUS STUDIES

Traditional methods of teaching are *verbal (expository, didactic)* and *formal*, that is teacher-centred, with the teacher lecturing and the student being the passive recipient of knowledge. Research on concept acquisition has revealed that children learn by active interaction initially with concrete objects and later with abstract entities. In addition, Piaget has suggested that cognitive development itself occurs through such an active involvement, an interaction of the child with objects and phenomena, that leads to *cognitive conflicts* and subsequently to *equilibration* or *self-regulation* (Piaget, 1964). On the other hand, Ausubel has suggested that *meaningful learning* can be achieved only when there pre-exist in the mind the necessary relevant concepts and cognitive structures (*subsumers*) that will subsume the new knowledge; otherwise, *rote learning* has to be invoked (Ausubel, 1968).

The above empirical findings and theoretical positions have led to a strong criticism of the prevailing formal methods of instruction, and have instead advocated student-centred (*concrete*) methods, in which the student has an active part in the construction of new knowledge. For instance, *discovery methods* and their variants (*guided discovery*) were used as a replacement of purely verbal methods, but their effectiveness has been controversial (Rowell, Simon, & Wiseman, 1962; Hermann 1969). Hermann evaluated researches about discovery learning and found almost equal numbers of studies claiming a superiority of discovery learning and expository teaching, respectively. On the other hand, the application of Piagetian theory to teaching and learning, as well as the foundation of the student alternative conceptions movement on the philosophical-epistemological theory of constructivism has led to the advocacy of so-called *constructivist methods* of teaching. (Strictly speaking, guided-discovery methods fall also into constructivist methodology.)

A question that is often asked by both science-education researchers and practitioners is whether the use of constructivist methods instead of the traditional didactic methods is actually more effective. It is pertinent at this point for us to make a review of the relevant science-education literature; of necessity, our survey will not be exhausting.

Moreira (1978) compared two teacher-centred methods, one based on Ausubel's theory, the other a traditional one, with respect to the ability of pre-college students to apply and correlate concepts of electromagnetism; although, no statistically significant difference was found, there were indications in favour of the Ausubelian approach. Also based on physics was the work of Schneider and Renner (1980); they studied for twelve weeks an active (a *concrete*) method that made use of Karplus's learning cycle (Karplus, 1977) versus a traditional (*formal*) lecture-type method and found that the active method was superior with respect to achievement and concept retention.

Kletzly (1980) used an experimental method that was based on Piaget's theory for the teaching of the abstract concepts of the mole and atomic theory, and found that it was superior to a traditional expository method; in addition, it was found that formal students (in the Piaget sense) were not affected by the instructional method. On the other hand, the use of a method based on Ausubel's theory with a small sample for preparatory college chemistry resulted in certain cognitive changes that were correlated with students' preference for meaningful learning.

Kempa and Diaz (1990a; 1990b) have carried out a particularly useful analysis. They determined the motivational traits of their subjects according to the classification of Adar (1969), by using an adaptation of the Adar's questionnaire. Accordingly, 390 students, aged 15, from five Spanish schools, were classified as *achievers*, *curious*, *conscientious*, or *social*, and their preference for various instructional methods were examined. Well-pronounced distinct links for all but the achiever students were reported. Achievers were found to have no special preference, except that they require specific learning objectives. Curious students prefer to actively be involved in learning activities that require them to discover, to seek information, and to make decisions; consequently, they dislike formal methods. Conscientious students, on the other hand, are happier with expository methods with clear and precise instructions about what to do, while they do not like discovery methods unless they are provided with clear objectives and supported by adequate guidance; these students then are more teacher-dependent. Finally, social students have a moderate preference for discovery learning and for practical work, because generally these learning situations provide them opportunities to personal/social interactions (with students working usually in groups). Of particular interest are the gender differences, with girls being more conscientious and social; on the contrary, boys are more achievers and curious, and less co-operative and social.

Robinson and Niaz (1991) studied the effect of a ten-week intervention on the solution of stoichiometry problems by students in a preparatory college course in the US. They used a method in which students were allowed to interact, and compared it with the traditional lecture method. It was found that students in the interacting group were more successful in solving stoichiometry problems than the lecture group. In addition, students with lower information-processing capability in the interactive group performed better than students in the lecture group with higher such capability.

Odubunmi and Balogun (1991) compared a laboratory-based method with one based on lecture for the teaching of biology and geology concepts. The laboratory-based method was found superior with respect to student achievement, and especially for students with lower abilities. On the other hand, boys demonstrated a liking for the laboratory, while girls had a preference for the lectures. Positive results in affecting changes in conceptual structures with a laboratory-based method were reported by Westbrook and Rogers (1996), after a study in which grade-nine students worked under the instructor's guidance, using Karplus's learning cycle and drawing their own concept maps for the concept of flotation.

To the teaching of biology was related the study of Ajewole (1991), that compared guided discovery with the expository method, and found more favourable attitudes in the case of the guided-discovery method, but no difference between boys and girls. The latter finding contradicts that of Raghurbir (1979) that girls are more interested than boys in biology.

Returning to chemistry, we have a two-year long study by Hand and Treagust (1991) of the effect of a constructivist versus a conventional, non-constructivist method, with tenth graders studying acids and bases. The students were of average and below-average achievement, and had no special desire to study science. Students of the constructivist method had superiority not only in the understanding of the concepts but also in their application for solving relevant problems.

Cohen (1992) carried out a six-week study of the effect of two methods for the teaching of the geology concepts of rocks and weather to twelve-year olds (grade seven). In one method instruction was provided through purely verbal means, while in the other method use was made of activities and manipulations of objects along with some verbal interactions. The second method was found superior especially with average and low-achieving students, but not in the case of high achievers.

Finally, Cavallo and Shafer (1994), working with tenth graders on the biological concept of meiosis, suggested that meaningful-learning orientation of students contributed to their attainment of meaningful understanding, independent of aptitude and achievement motivation. In addition, meaningful-learning orientation interacted with previous knowledge to predict student attainment of meaningful understanding, while the instructional treatment had little relationship to student acquisition of meaningful understanding, except for learners midway between meaningful and rote.

METHOD

A total of 144 pupils of the state experimental lower secondary school '*Evangeliki Scholi Smyrnis*' in Nea Smyrni (Athens) (grades eight and nine, age 12,5 to 15) participated in the research. The school is a relatively prestigious experimental school, for which, however, the students (as for all experimental schools in Greece) are selected by drawing lots among all applicants. The study lasted for three consecutive school years (1990-91, 1991-92, and 1992-93).

TABLE 1. *The chemical topics taught in grade eight.*

| | |
|--|--|
| <ul style="list-style-type: none"> • Chemistry as an experimental applied science. • Soil - Mixtures. • Atmospheric air. • Water - Pure substances. • Decomposition and synthesis of water - Compounds and elements. • Molecules and atoms. • Atomic and molecular mass - Avogadro constant - The mole - Molar volume of gases. • The building up of atoms (electronic shell | <ul style="list-style-type: none"> structure) - Periodic table. • Formation of compounds - Types of bonding in molecules (ionic - covalent) - Valence. • Chemical formulae - Writing and naming of inorganic compounds. • Chemical reactions - Chemical equations - Stoichiometric calculations. • Categories of inorganic chemical reactions. • Acids - Hydrochloric and sulphuric acid. • Bases - Sodium hydroxide. |
|--|--|

TABLE 2. *The chemical topics taught in grade nine.*

| | |
|---|---|
| <p>A. INORGANIC CHEMISTRY</p> <ul style="list-style-type: none"> • Metals and their alloys. • Minerals, ores, and metallurgy. • Aluminium. • Iron. • Copper. <p>B. ORGANIC CHEMISTRY</p> <ul style="list-style-type: none"> • Introduction – Classification of organic compounds. | <ul style="list-style-type: none"> • Nomenclature. • Methane – Alkanes. • Ethene – Alkenes. • Ethine – Alkynes. • Benzene – Aromatic hydrocarbons. • Crude oil and its products. • Petrol - Chemicals from crude oil. • Coal – Coke – Coal gas. • Ethanol – Fermentation – Enzymes. • Acetic acids – Organic acids. |
|---|---|

The same research methodology was used in all three school years of the study. Each school year, the students were randomly divided into two groups that were taught chemistry by a constructivist method (CM) and a meaningful-receptive method (MRM) respectively. Tables 1 and 2 have the topics that were taught each year in the two grades.

Special features of this study were: a) the three-year duration of the research compared with previous shorter ones; b) the wide range of the concepts of elementary introductory inorganic and organic chemistry that were taught; c) the planning and teaching of the course by the chemistry teacher (E.Z.) herself; and d) the attempt to increase the effectiveness of the teaching methods by the use of a variety of techniques.

The constructivist method

The CM was student-centred, but with the teacher playing an active role in the organisation of the lessons, trying to lead the students through questions, activities and proper structuring of the lessons to the construction of new knowledge by the students. More specifically, the method was characterised by the inductive teaching of concepts, co-operative learning (Solomon 1991), the use

of learning cycles (Karplus, 1977) and the construction of concept maps (Novak & Gowin, 1984; Novak, 1990) by the students themselves.

As far as practical work is concerned, two methods were employed: One in which students attended demonstrations of experiments or the use of models that were carried out by pairs of students working in front of the rest of the class, under the close guidance and observation by the teacher; in this way, about five pairs of students, that is about one third of the class, experienced hands-on activities during a teaching period. In the second method, students themselves performed experiments or manipulated models in groups of five or six; this method was restricted to practically feasible cases, depending on the experiment and the availability of equipment and/or chemicals. The pupils worked in carefully composed groups and, under the guidance of their teacher, discussed (agreeing and disagreeing with reasoned arguments), faced difficulties with greater success, avoided or corrected misunderstandings and acquired different experiences, techniques and skills.

Stoichiometric calculations were taught by a logical method that was rather unusual in Greece. The method was based on the unit-basis method (Beichl, 1986), that employs simple arithmetic, thus overcoming the complexity of working with proportions. As a teaching method it differs from the traditional; 'rule-of-three' method that was used by the standard schoolbook (Zarotiadou, Georgiadou, & Tsaparlis, 1995).

Each forty-five minute teaching period of the CM was organised as follows:

1. Revision of the previous lesson through questions or a written test, or a discussion of student achievement in the end-of-previous-lesson written test (about 7 minutes).
2. Teaching of new material according to the CM (about 30 minutes).
3. Revision of the new material by the students through the concept map of the lesson (about 3 minutes).
4. Evaluation of student learning of the new material through a written test (about 5 minutes).

The receptive meaningful method

The MRM was mostly teacher-centred, and characterised by the deductive teaching of concepts. The teacher, using language together with a variety of other means, was attempting to incorporate the new concepts hierarchically into the students' cognitive structure, with the objective of meaningful learning. The means used were mainly drawn from Ausubel's theory: advance organisers, application of the principle of progressive differentiation and consolidation (Ausubel, 1968), use of concept maps constructed by the teacher, study of parts of the school textbook by the students, continual revision and presentation of the lessons in the pupil's own words, questions and answers and frequent exercises. Student participation consisted only in answering teacher's questions, aiming at checking the extent and depth of understanding. In accordance with this approach, the teacher, without the students manipulating them, always demonstrated experiments and models.

In addition, for the solution of problems in the MRM, a mechanical method of solving the problems was used, the 'rule of three', which is the most popular and common method for performing stoichiometric calculations in Greece (Zarotiadou, Georgiadou, & Tsaparlis, 1995).

A typical forty-five minute teaching period of the MRM had the following structure:

1. Revision of previous lesson, as in the CM (about 7 minutes).
2. Teaching of the new material according to the MRM (about 20 minutes): first, an advance organiser was presented through a concept map constructed by the teacher; then followed the verbal introduction of the new material.
3. Study of the relevant material from the textbook by the students, answering of student questions by the teacher, and oral presentation by the students (about 10 minutes).
4. Revision of the new material through the teacher's concept map (about 3 minutes).
5. Evaluation of student learning of the new material through a written test (about 5 minutes).

Note that because of the expository mode, instruction is faster in the MRM, and this explains the extra activity of student study from the textbook introduced into the MRM. This activity has the advantage of direct contact of the students with the written material from which they will do most of their further study.

Psychometric testing

At the start of the research the subjects of our study were checked for their developmental level according to Piaget's theory, and their motivational traits according to the classification by Adar (1969). Developmental level was determined by means of Lawson's paper-and-pencil test of formal reasoning (Lawson, 1978); students were classified into stages of concrete, transitional and formal thinking. Motivational traits were determined by means of a simplified version of Adar's test material questionnaire (Johnstone & Al-Naeme, 1995). The classification of each subject into one of the Adar categories was made according to the dominating view that was relevant to him or her, as it resulted by summing his/her preferences for all four subject areas (Johnstone & Al-Naeme, 1995). Note that, according to Kempa & Diaz (1990a), the classification of students in terms of the four motivational patterns does not imply that the patterns should be fully independent of each other.

Both the CM and the MRM groups were found to be statistically equivalent in relation to their developmental level and their motivational traits. On the other hand, in the general achievement in grade seven, there was some difference in the achievement in the range 12-15.4 in favour of MRM (16 students in MRM, versus 12 in CM) and in the achievement in the range 15.5-18.4 in favour of CM (44 versus 50). Finally, with regard to gender, there was a difference in the number of boys and girls in the two methods (MRM: 38 boys and 31 girls; CM: 31 boys 41 girls).

Chemical testing

At the end of each grade, student achievement was evaluated with respect to the theoretical concepts taught and their ability to perform stoichiometric calculations. Each test was given without notice. Table 3 provides an outline of the theoretical test, together with the allocated marks, for grade eight; the reliability of the test was judged by Cronbach's coefficient *alpha*, which was found 0.96 for our sample. For grade nine, two theoretical tests were given, one on inorganic, the other on organic chemistry; Tables 4 and 5 describe these two tests and their marks; Cronbach's *alpha* was 0.72 for the inorganic test, and 0.91 for the organic test. Finally, for both grades a test on stoichiometric calculations, was used, and this is described in Table 6; Cronbach's *alpha* was 0.87.

TABLE 3. *Outline of the theoretical test for grade eight. Within parentheses, the percentage marks/weights, corresponding to each test item, are given.*

| | |
|---|--|
| A. CHEMICAL NOTATION (40%) | 7. Number of electrons in ions (in comparison to neutral atoms). (5) |
| 1. Symbols of elements. (5) | |
| 2. Symbols of ions. (5) | |
| 3. Symbols of charged molecular ions. (5) | C. MOLECULAR STRUCTURE (15%) |
| 4. Compounds. (25) | 8. Diatomic molecules. (7.5) |
| | 9. Ionic and covalent compounds. (7.5) |
| B. ATOMIC STRUCTURE (15%) | D. CHEMICAL REACTIONS (30%) |
| 5. Number of electrons in a neutral atom, given the number of protons and neutrons. (5) | 10. Coefficients of chemical equations. (10) |
| 6. Arrangement of electrons to electron shells. (5) | 11. Chemical reactions (product prediction). (20) |

TABLE 4. *Outline of the theoretical test on inorganic chemistry for grade nine.*

| No. | Type of question | Chemical topic | Marks (%) |
|-----|--|--|-----------|
| 1 | Grid 3×3 ^a with 7 questions | Metals, non-metals, alloys / Physical state / thermal and electric behaviour / Action of air | 25 |
| 2 | Grid 3×3 ^a with 4 questions | Single replacement reactions / Activity series of metals / Reactions of metals with water, acids, salts / Selection of feasible reactions and balancing. | 25 |
| 3 | Open question | Oxidation reaction / Various definitions of oxidation / Reducing power of aluminum. | 25 |
| 4 | Filling in of blanks | A redox reaction / Oxidising and reducing agent / Redox. | 25 |

^a (Johnstone, MacGuire, Friel, & Morrison, 1983).

TABLE 5. *Outline of the theoretical test on organic chemistry for grade nine.*

| No. | Type of question | Chemical topic | Marks (%) |
|-----|---|--|-----------|
| 1 | A set of four reactions, with reactants given, and unknowns the products and type of reaction | <ul style="list-style-type: none"> • Incomplete burning of butane. • Preparation of ethene from ethanol. • Bromination and polymerisation of ethene. • Preparation of ethyne from CaC₂. | 50 |
| 2 | Grid 3×3 ^a with 6 questions | Carbon structures / Nomenclature / Addition, polymerisation, substitution reactions / Valence of carbon and hydrogen / Homologue series, alkenes / Molecular, and structural formulae, alko-group. | 50 |

^a (Johnstone, MacGuire, Friel, & Morrison, 1983).

TABLE 6. Outline of the test on stoichiometric calculations. Each problem had an equal weight (50%). Equal weight (10%) was given to each of the five steps of the first problem.

| | | |
|---|--|--|
| A. PROBLEM IN FIVE STEPS | | question (3) above. |
| 1. Number of molecules of products, given the number of molecules (or atoms) that reacted. | | 5. Volume under STP of moles of gas that was produced according to question (4) above. |
| 2. Number of moles of products, given the number of molecules (or atoms) that reacted. | | |
| 3. Number of gr-atoms or gr-molecules, given the number of molecules (or atoms) that reacted. | | B. COMPOSITE PROBLEM |
| 4. Number of moles that are produced from the reaction of the gr-molecules or gr-atoms of | | A complete chemical equation is given, and the student is asked to calculate the volume of the gas produced under STP from given mass of one of the reactants. |

Apart from the chemistry tests, the opinion of the students on the two methods was sought, as well as their overall attitude towards chemistry, and their relationship to their teacher. To this end, towards the end of grade eight, all students were taught one lesson not with the familiar to them method, but with the other method (CM or MRM). Immediately after that lesson, students were called to fill in a Lickert-type questionnaire, including five questions and the students had to choose one out of three answers: positive, neutral or negative.

RESULTS AND COMMENTS

Influence of teaching methods

TABLE 7. Achievement in theory and in stoichiometric calculations of and grades eight and nine, and statistical comparison between the CM and MRM groups.

| | | Mean % score (standard deviation) | | <i>p</i> (statistical significance) | |
|-------------|--------------|--------------------------------------|----------------|--|---|
| | | CM | MRM | for the <i>t</i> Statistic | for the unpaired <i>z</i> statistic |
| Grade eight | theory | 48.7 (20.9) | 41.2 (23.4) | 0.04* | 0.05* |
| | calculations | 28.0 (27.8) | 31.1 (28.7) | 0.50 | 0.36 |
| Grade nine | theory | 37.9 (20.3) | 30.7 (17.9) | 0.02* | 0.04* |
| | calculations | 47.1 (39.9) | 29.7 (36.6) | 0.01* | 0.04* |

* Statistically significant difference.

Table 7 compares the achievement of grades eight and nine students respectively, in theory and in stoichiometric calculations. Despite the fact that the achievement was rather low, there was a clear superiority of the CM. In theory, this superiority was observed for both grades, whereas in the calculations only for grade nine.

Low achievement of both grades in theory and in stoichiometric calculations is not unusual and is due to the difficulties of the subject. The wide gap between the abstract chemistry concepts taught and students' developmental level made the course difficult and unpleasant. It is well known that only a small number of pupils aged 13-15 have developed formal thinking (Shayer, 1991). It has also been observed that while students of this age can cope successfully with familiar everyday problems, it is difficult for them to carry out mathematically analogous chemical calculations; this must be attributed mainly to the abstract concepts involved (atoms, molecules, mole, molar volume, chemical notation, etc.). Finally, the limited teaching time (one 45-minute period per week) does not provide the opportunity for consolidation and application of knowledge.

Effect of developmental level of students

Table 8 lists all the statistically significant instances of superior achievement between the two methods, with respect to students' developmental level. The statistical comparison is based on both parametric and non-parametric analysis of variance (ANOVA and Kruskal-Wallis respectively). In grade eight, achievement in theory of the concrete thinkers of the CM was higher than that of the concrete thinkers of the MRM; on the other hand, in grade nine, achievement in

TABLE 8. Relationship between developmental level * of students and achievement in theory and in stoichiometric calculations. **

| | | | | | | |
|-------------|--------------|--|--------------------|--------------------|--------------------|-------------|
| Grade Eight | Theory | $C_{CM} > C_{MRM}$ | $F_{CM} > T_{MRM}$ | $F_{MRM} > C_{CM}$ | | |
| | Calculations | $T_{MRM} > C_{CM}$ | $F_{MRM} > C_{CM}$ | $F_{MRM} > T_{CM}$ | | |
| Grade nine | Theory | $T_{CM} > C_{MRM}$ C_{CM} | $F_{CM} > C_{MRM}$ | $F_{CM} > T_{MRM}$ | $T_{MRM} > C_{CM}$ | $F_{MRM} >$ |
| | Calculations | $C_{CM} > C_{MRM}$ $>F_{MRM}$ $F_{MRM} > C_{CM}$ | $T_{CM} > C_{MRM}$ | $F_{CM} > C_{MRM}$ | $F_{CM} > T_{MRM}$ | F_{CM} |

* Concrete (C), transitional (T) and formal (F) thinking pupils; constructive (CM) and meaningful-receptive (MRM) teaching methods.

** Only differences between the two methods are reported; that is we do not report here frequent and expected differences within each method, such as $F_{TM} > T_{CM} > C_{CM}$ or $F_{MRM} > T_{MRM} > C_{MRM}$.

calculations of concrete and formal thinkers of CM was higher than that of concrete and formal thinkers of the MRM. Other instances of superior achievement within each method and between methods are also observed.

The differentiation of the student achievement from lower to higher developmental level, in both methods, was expected. The lack of differentiation between lower and higher developmental levels that were observed within the CM would be an advantage for that method if it could be attributed to it. Active participation that characterises the CM may be more essential for the lower-level

students. The superiority of CM students of certain developmental levels over corresponding MRM students is likely to be due again to superiority of the CM.

Effect of gender

In both grades, CM girls achieved higher in theory than MRM boys. The same was the case in the calculations for grade nine. In grade eight, CM boys achieved higher in calculations than girls of the same method.

The lack of an overall differentiation in achievement between boys and girls in both methods is probably due to the fact that the two methods were not planned to match with the particular characteristics of either gender, thus being more effective for one or the other. On the contrary, they included techniques that cater for both genders, thus affecting similarly boys and girls. The superiority of girls over boys in the MRM is probably due to the ability of girls to learn better than boys through of girls in calculations can be attributed to the mechanical method of the 'rule of three', since girls - passive attendance that characterises the method. In addition, the superiority

On the contrary, the superiority of boys compared with the CM girls in the calculations was probably due to the active participation of students, which is a feature of the CM. This active participation characterises mostly the boys, being also a result of the social belief that natural sciences are considered to be a subject more suitable for boys. Furthermore, boys are favoured by the logical method of performing the required calculations that was taught in the CM (Kahle & Meece, 1994).

Effect of motivational traits

As far as motivational traits are concerned, in both grades, conscientious students of the CM outperformed in theory all students of the MRM. In addition, conscientious students of the CM outperformed in theory the curious pupils in grade eight, and all other students of the CM in grade nine. In the calculations of grade eight, there were no differences, while, on the contrary, in grade nine many differences were observed, usually in favour of the conscientious and the achievers of the CM. The observed superiority of the conscientious students is easily explainable (Kempa & Diaz, 1990b).

Students' opinion about the two methods

As mentioned at the method section, at the end of grade eight, students, towards the end of grade eight, all students were taught one lesson not with the familiar to them method, but with the other method (CM or MRM). Immediately after that lesson, students were asked to fill in a Lickert-type questionnaire that dealt with students' preference for the instructional method, their overall attitude towards chemistry, and their relationship to their teacher. The questionnaire included five questions and the students had to choose one out of three answers: positive, neutral or negative. The results were as follows:

- All (100%) of the students of the MRM ($N = 72$) and 94.4% of the students of the CM observed differences between the familiar and the new method.
- 94.4% of the students of the MRM and 81.9% of the students of the CM stated their preference for the CM.
- 97.2% of the students of the MRM preferred to have been taught chemistry with the CM, while only 59.7% of the students of the CM preferred the MRM.
- 94.4% of the students of the CM preferred the teaching of chemistry with the familiar to them CM, while only 51.4% of the students of the MRM preferred the familiar to them MRM.
- 81.9% of the students of the MRM agreed that the CM brings them closer to their chemistry teacher, while, 62.5% of the students of the CM agreed that the MRM keeps them away from the teacher. We can support that the students of both methods admitted that chemistry is best taught with the CM, since the teacher comes closer to them and they enjoy all the positive effects of such a relationship.

In conclusion, students of both methods observed differences between the two methods, expressed their preference for the CM in chemistry teaching, and noticed the close relationship between students and teacher in the case of the CM.

CONCLUDING REMARKS

The role of the teacher in the science and chemistry classroom, and the extent and mode of participation of the students is a recurring issue in the science education literature. Although, it must be admitted that the issue of whether one instructional strategy is superior to another cannot be answered in a generally valid way (Kempa, 1993), we must take into account that only in few of the previous studies has it been reported that expository, teacher-centred instructional methods were found superior to active, student-centred methods, for instance with respect to an increase of short-term knowledge retention (e.g. Ray, 1961; Hines, Cruick, Shank, & Kennedy, 1985).

This work, in line with the majority of previous studies, resulted in favour of a constructivist, student-centred method of teaching lower secondary school chemistry, over a receptive, teacher-centred one. The superiority of the constructivist method of teaching could be attributed to the active participation of students in all processes of learning. This develops a positive attitude towards chemistry, and consequently results in higher achievement. Conversely, the passive role that the receptive, teacher-centred method reserves for students leads to many of them experiencing boredom, decreases their interest and develops a negative attitude towards chemistry, thus resulting in lower achievement. These findings are in accord with many studies that suggest

that every teaching method that involves students in an active way in the learning process increases their positive attitude towards science.

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