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Progettazione di sequenze didattiche di insegnamento/apprendimento della chimica secondo un approccio inquiry-based

Design of teaching/learning sequences for the chemistry curriculum according to an inquiry-based approach

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Abstract

Viene illustrata la progettazione di linee guida (sequenze didattiche di insegnamento/apprendimento) per gli insegnanti di chimica nel primo biennio della scuola secondaria di secondo grado. Questa proposta didattica è concepita secondo un approccio inquiry-based, e segue la struttura a spirale dei diversi livelli di concettualizzazione della chimica (dal macroscopico al microscopico). Scopo del progetto è, da un lato, il miglioramento della significatività dell'apprendimento degli allievi e il raggiungimento di alcune competenze trasversali di base, dall'altro, fornire agli insegnanti uno strumento da utilizzare nella pratica di classe per implementare la trasposizione didattica della disciplina. Gli esempi illustrati riguardano le sequenze relative alla trasformazione chimica e al modello particellare. Vengono infine mostrati i risultati di uno studio che supporta l'efficacia dell'approccio proposto sulla base dei risultati conseguiti dagli allievi.

Parole chiave: chimica; insegnamento; apprendimento; guided inquiry-based.

Abstract

Outlined are guidelines (teaching/learning sequences) for chemistry teachers in the first two years of secondary school. This educational proposal is grounded on an inquiry-based approach, and follows the spiral structure of the different levels of the chemistry concepts (from macroscopic to microscopic). Our aim is both the assessment of a more significant learning process and the achievement of some students' basic skills, as well as to provide teachers with a tool for implementation in class. The examples illustrated refer to the sequences relative to chemical transformation and the particle model. In closing, the results of a study are exhibited, which support the effectiveness of the proposed approach on the basis of the results obtained by the students.

Keywords: chemistry; teaching; learning; guided inquiry-based.

1. Introduction

Pupils in the secondary school often show poor comprehension of contents and purposes of the teaching/learning process (EC, 2007; Lijnse, 2005); this lack of understanding seems to be particularly relevant for science courses, and it seems to play an essential role in increasing a negative image of science as incomprehensible and irrelevant (http://www.invalsi.it/invalsi/ri/pisa2012/rappnaz/Rapporto_NAZIONALE_OCSE_PISA2012.pdf). If one does not understand, one tends to loose interest and this leads not only to poor school performance, but also to low self-esteem.

Therefore an increased need of research in the educational field has been emerging (Leach, 2007): this latter's aims can be formulated as dealing with the basic questions of *how* (centering the process of teaching and learning around the student) and *what* (reduction of the amount and the complexity of the contents) to teach in a given science course, in a given social framework, though appropriate knowledge about cognitive processes is obviously useful (Lijnse, 2001).

2. Inquiry-based teaching and learning

Nowadays it is widely known that scientific knowledge is learned in a non-significant way when proposed by means of transmissive teaching; educational research shows that students generally experience improved and more meaningful learning when they are actively engaged in the classroom and when they are asked to enrich their own knowledge by facing problems (Minner, Levy & Century, 2010). An approach to science education that aims at this might be classified as a guided inquiry-based one. According to this model, learning begins with a problem to be solved, and the problem is posed in such a way that students need to gain new knowledge before they can solve it (Roletto, 2005). Thus starting point of this process are students' misconceptions or common-sense ideas. Well-designed problematic situations might be identified with the so-called conceptual questions or challenge problems, which ask students, either individually or in small groups, for example to explain why something happens, to predict what happens next, to analyze data sets and so on. Discussions include individual thinking, as well as social interactions with peers and careful guide given from the teacher. The experiments hold a double role: they can be used to create the problematic situation, or they can be designed to check the force of the hypotheses previously made (Elliott, Stewart & Lagowski, 2008). This model is correct from a pedagogical (Vygotskij's zone of proximal development), historical (pretty often the problems can be the same faced by scientists throughout history) and epistemological point of view (scientific knowledge is interpreted as a process and not a product), and it may represent a natural way to integrate teaching about the nature of science with the teaching of science itself (Regis & Roletto, 2004).

The importance of what to teach of a school subject should also be considered, not only in terms of the choice of the topics, but also in terms of the teaching transposition of those topics: what we teach at school must undergo transformations to meet students cognitive abilities and interests. What seems to be apparent from much of the literature is that science education research does not so much aim at developing content specific didactical knowledge, creating a sort of theory-practice gap. The missing necessary level to make a real impact on science education is that of describing and understanding what is, or should be, going on in the classrooms in terms of content-specific teaching/learning processes (Lijnse, 2004).

3. The Teaching/Learning Sequences (TLSs)

On these bases, our goal is the design of teaching/learning sequences (TLSs), primarily meant for students and teachers of the first two years of the secondary school, to provide a practical tool to guide professional action within the framework of a guided inquiry-based model. TLSs basically consist of lessons' descriptions and work material for students, including activities to be carried out in the classroom or in the lab, texts to read, problems to discuss, and so forth. All this is written down in a form of detailed guidelines for the teacher, which also include background information, work sheets for students (what we call FOL, FOglio di Lavoro), suggestions to handle the classroom discussions, expected students reactions, lists of materials needed, as well as evaluation tests. The design phase requires a certain degree of creativeness, but various aspects of the teaching and learning process must also be taken into account, namely epistemological (contents to be taught, nature of problems, historical genesis of knowledge), psycho-cognitive (students' conceptions, misconceptions, reasoning, cognitive structures), didactic (educational constraints, functioning of the teaching institution) and psycho-affective (pedagogic model, social interactions) ones (Méheut & Psillos, 2004).

In general, the design of TLSs should start by justifying one's view on teaching and learning, on science education, but also on science itself, and on the nature of chemistry in our case. Chemistry is a difficult subject to teach, and the one reason for this is that chemists describe the matter at several levels, only one of which can be directly observed, and namely level one of macroscopic phenomena. Levels two and three consist of mental entities created by scientists to describe and explain what happens at level one. What usually happens at school, is that teachers want to get to levels two and three as quickly as they can, divorcing them from the empirical level, that is, students are introduced to atoms, molecules, and electrons early in the course, and have to accept the teacher's word that they exist. A better method is to teach chemistry progressively, starting with analyses of macroscopic phenomena, interpreting these at an atomic and molecular level, and then at an electronic and nuclear level (Nelson, 2002).

We have designed our TLSs to cover the most of the chemistry curriculum of a basic course according to the above mentioned hierarchical structure. The going back and forth between the phenomena and their microscopic interpretation is the main cognitive obstacle for pupils. The particle model and the atom model are the bridges which allow this going back and forth between the three levels, therefore we believe that the importance of interpretative models creation and abstract manipulations must be stressed. At level one the concepts of body physical state, pure body and mixture are reconstructed by students, as referred to the "identity card" of substances as a document containing the physicochemical parameters which allow the identification of a given body (melting and boiling point, density, solubility). The next step is to introduce students to physical changes first (physical state changes, mixtures formation, separation of mixtures) and then to chemical ones by analyzing whether the identity of the substances is conserved or not. No reference is made at this stage to microscopic entities, since, as already mentioned, we strongly believe that this first-one is a vital part of a chemistry course, and should not be hurried. In the second part of the curriculum the particle model is built and used to interpret and represent the physical changes already discussed at macroscopic level. The analysis of the chemical phenomena will then allow the introduction of the concept of molecule and atom and the chemical language. Finally, level three is required to interpret electrical phenomena by means of a simple atom model. This way of meaning and teaching chemistry requires a curriculum structure which not only is progressive, but also shows a spiral structure, so that the same topic can be tackled more than once during the course, each time at a different level of conceptualization. This approach has the advantage of introducing students to the way pioneers of chemistry reasoned, since it follows the historical development quite closely.

In the next section we present a few examples which show how a TLS is meant to implement the didactical transposition.

4. Chemical changes

4.1. Macroscopic level

The first example is taken from the physical and chemical transformations sequence and is meant to introduce the concept of chemical change, which is often neglected from the macroscopic point of view (Chandrasegaran, Treagust & Mocerino, 2009). At the very beginning of textbooks a definition is usually provided referring to microscopic entities, which does not make much sense indeed. In our work students are previously introduced to many physical phenomena, where the nature of the substances do not change during the transformation: mixing sodium nitrate and potassium iodide together, dissolving potassium iodide or lead iodide in water, and so forth. Of course, students might be asked to prove that the identity doesn't change by designing suitable laboratory practices.

The next step is to introduce students to phenomena where something new occurs, and namely the formation of a new substance which wasn't there before. In the case of mixing solid lead nitrate and potassium iodide, this might be noticed because a new color appears, but also phenomena where precipitates formation or effervescence occur might be successfully used. Then a chemical transformation is defined according to the identity change of the substances, and no reference is made at this stage to microscopic entities. Suggestions for the teacher on what might happen during the lessons are proposed in the TLS, for example "Some students might propose that the yellow color was somehow already present into the starting substances", or ways to begin the discussion, like "This yellow powder looks like a body we've already met before, etc.", and so forth.

4.2. The particle model

The particle nature of matter is often taught in a sort of dogmatic way, and the students have to trust somehow the teacher or the textbook that everything around us is made of small, invisible particles. This leads pretty often to a missed comprehension of various chemical concepts in the future lessons; to avoid this we propose to follow the historical development of the concept of matter's discontinuity. Of course, many adjustments in this sense are required. Pupils are introduced to the first ideas about the nature of matter given to Aristotle and Democritus (continuous and non-continuous), then asked to evaluate their plausibility on the bases of some empirical evidences (for example Torricelli's experiment with mercury, volumetric shrinkage). If students admit the existence of vacuum (empty spaces), then the particle model of matter must be accepted.

The teacher should now introduce the "seed" of the model, and namely a series of basic characteristics of the particles which allow the students to interpret simple macroscopic phenomena: they cannot be divided, they maintain their shape, volume, mass (Roletto, Albertazzi & Regis, 1996).

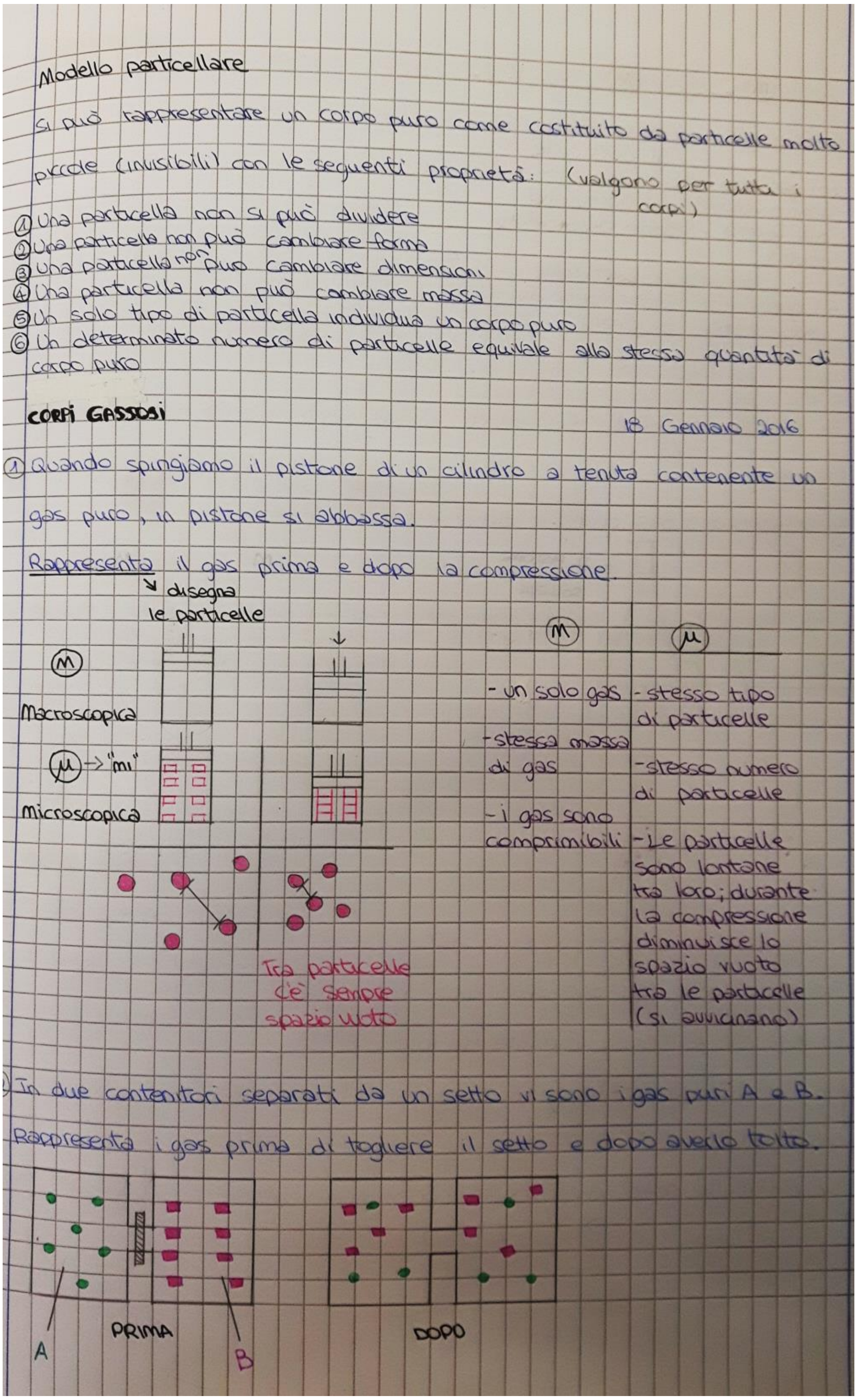

Figure 1. A sample of the particle model TLS (FOL 1 and FOL 2) as developed in a student's notebook.

First of all they are asked to represent by means of the particles the compression of a pure gas: their drawing must explain every aspect of the gaseous bodies characteristics and the compression (non defined shape and volume, great volume reduction, and so on). During this sequence it is very important to constantly separate the macroscopic level of phenomena description and the microscopic one of phenomena interpretation by means of the particles; the change from one level to the other must always be explicit (Figure 1).

The particle model for gases can now be completed: new characteristics are awarded to the particles (they move, they are far away from each other, and so on) by means of a couple of other experiments about the diffusion, mixing and heating of pure gases.

The intensive use of iconic language is widely accepted as a good method to overcome many cognitive difficulties related to not knowing Italian language, disable, specific learning disabilities (LD); that's one of the reasons we strongly support this approach (MIUR, 2010).

Plenary classroom discussions should take place after each FOL: in the sequences, these discussions are described for the teacher, in terms of expected students conceptions (for example "most students will probably state that the volume of the gas decreases because the particles become smaller"), questions the teacher might ask and suggestions he/she may give to guide the discussion (for example "to state that the two gases mix together, let's focus our attention on the volume of the containers with and without the septum"), as well as conclusions, final statements and schemes.

The next step includes the interpretation of two phenomena involving solid and liquid bodies, and namely the thermal dilation (Gravesande's experiment) and the volume shrinkage of water after cooling; both these phenomena can be described and drawn in the classroom, as well as more effectively created in the laboratory. Several characteristics of the particles must be adapted to explain these phenomena, so that a general model can be built; such a model correlates the properties of the particles (distance from each other, order, etc.) to the physical state of a given pure body. The inquiry-based approach is particularly evident during these activities, since the students are asked not only to activate their previous knowledge, but also to increase it in order to solve the problems. This aim can be achieved during plenary or small groups discussions by means of the cooperative interaction with peers and the teacher's help. Once the model is complete, a series of physical changes can be interpreted and represented, for example the dissolution of a salt, the formation of an emulsion, the sublimation of iodine, the melting of a solid, and so on. A sample of the particle model TLS for teachers is provided as a supplementary file[1].

The school reform asks teachers to evaluate students not only on the bases of the knowledge they have acquired, but mainly on the bases of the competences they have developed (Castoldi, 2009). We believe that this can be accomplished by testing students on brand new problems to solve, which of course should show similarities to those discussed in the classroom. In the case of the particle model students might be asked to interpret and represent physical phenomena which were not yet discussed at the microscopic level. Reasons for the answers given should always be required.

4.3. Microscopic level

[1] https://ceciliagiordano.files.wordpress.com/2016/02/tsl_c_giordano_modello_particellare1.pdf

It is possible now to cover again the chemical changes topic, asking the students to interpret them using the particle model. The examples given could be the same used before, and in particular the solid phase reaction between lead nitrate and potassium iodide. From a first representation using the particle model should emerge that a new kind of particles appears, which was not there among the reagents. When the reaction scheme is written using a verbal model (writing the names of reagents and products) it should be evident that these new particles cannot appear "from nowhere" but might be formed by parts of the reagents particles, which recombine to form new particles, therefore new substances. Therefore it is necessary to discriminate between the "main" particles, the molecules, and the "smaller" particles that form the molecules, the atoms (Figure 2). In conclusion the first property of the particles as described by the model (particles are indivisible) has to be modified as follows: the molecules can be divided, and they actually split into atoms during chemical transformations, but not during physical ones. This is an effective way to tackle the concepts of atom and molecule in an appropriate moment in the chemistry course, without introducing them by means of mere definitions: this latter lead in most cases to a missed comprehension of such topics indeed (Roletto, Regis, Ghirardi & Giordano, 2010).

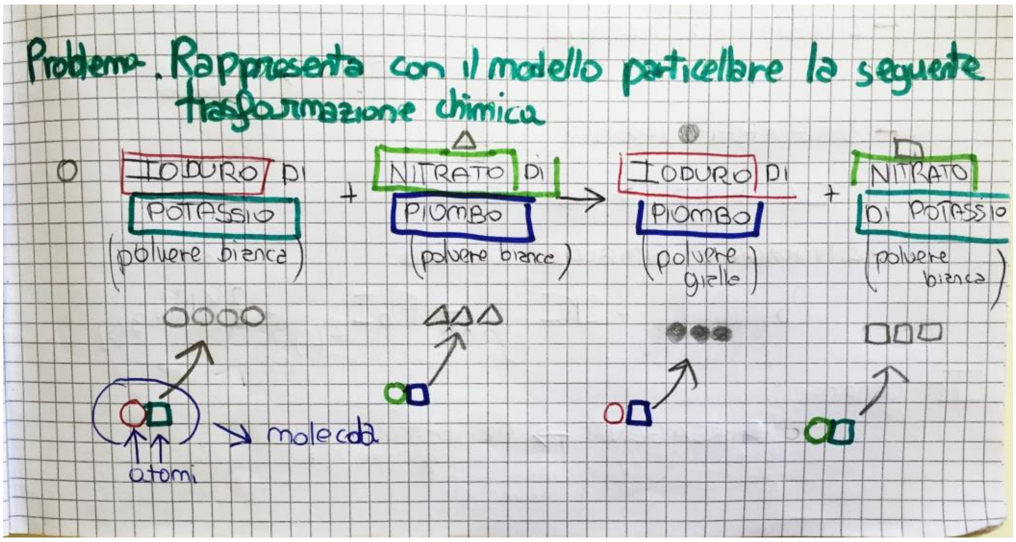

Figure 2. The transition of the concept of chemical change from the verbal language to the iconic and symbolic one as reported in a student's notebook.

At this point the students are given a chemical transformation that occurs between the gases hydrogen chloride and ammonia to form a solid substance, ammonium chloride. The focus must be on the volumes of the reagents, since they react completely during the transformation. Therefore given the microscopic representation of this transformation, and the fact that the reaction appears to be complete, the students should conclude that one volume of hydrogen chloride and one volume of ammonia contain the same number of molecules, which all combine to form the product. It is the formulation of Avogadro's principle. Of course, this plenary discussion needs to be carefully guided from the teacher: an example of this discussion is provided as a supplementary file[2].

[2] https://ceciliagiordano.files.wordpress.com/2016/02/fol_c_-giordano_trasformazioni-chimiche.pdf

Students are at last asked to explain an experimental situation that concerns the interaction between a single volume of chlorine gas and one of hydrogen gas, to form a double volume of hydrogen chloride gas. This experimental data should be surprising to them, since according to their previous knowledge from the combination of one volume of hydrogen with one volume of chlorine should arise one volume of hydrogen chloride. The discussion leads to the only possible explanation that each molecule of hydrogen and chlorine is formed by two atoms, which separate from each other during the transformation and recombine in a ratio 1:1, resulting in two volumes of hydrogen chloride. Such a conclusion allows to distinguish simple substances from compounds, and the transition from iconic language to the symbolic language of chemistry (meaning of symbols, indexes and coefficients).

The chemistry laboratory, if available, can be used for the evaluation of this topic, since we have noticed that a test entirely performed in the laboratory can be very motivating for students. For example students might be requested to produce different kinds of transformations and to identify them as physical or chemical, to draw them using the particle model and to represent them by means of the chemical language.

5. Validating TLSs

TLSs should not only be theoretically grounded, but also empirically supported, since the “design phase” should be followed by a “trial phase”, where the sequences are tested under regular school conditions. The high degree of uncertainty of such evaluations is clearly related to the nature of the teaching and learning process itself, and the number of variables which are met inside and outside the classroom (number and age of students, personality of teachers, kind of school, and so forth) (Andersson, Bach, Hagman, Olander & Wallin, 2005; Méheut & Psillos, 2004). Overall we were able to collect several data in the last few years, and namely comparing the marks obtained by students who had been taught the same topics using various interactive teaching methods based on a traditional curriculum structure (337 students, 3 different teachers) or a carefully guided inquiry-based approach applied to a three levels/spiral curriculum (352 students, 2 different teachers). Data shown in Figure 3 were collected in five secondary schools in Italy (Piedmont and Emilia) between 2007 and 2015; we have reported the final marks after a 1-year or a 2-years chemistry course (second year or first biennium in secondary school). These trials show that the our approach leads to an overall increase in positive notes, and among these to a higher number of good (7/10) and excellent marks (8 or 9/10), with a significant reduction of the very low-ones (below 5/10). These data are still preliminary, and our first goal is the reduction of the variables related to differences in schools and teachers. Since the inquiry-based method itself has proven to be only slightly more effective as compared to other teaching styles (Hattie, 2009), we believe that the good results here reported might be addressed on one hand to the emphasis placed on the classroom activities guidelines, on the other hand to the curriculum structure peculiarity, which was lacking in other methods showing a comparable students participation.

On the bases of students and teachers personal communications that we have collected throughout the last years, we could notice an increased satisfaction related to the teaching and learning process during the chemistry lessons. From the students point of view such satisfaction seems to be related to a perception of major involvement during the activities, better understanding of the topics, and better results achieved. On the teachers side it is increased by personal awareness of adherence to the epistemological status of the subject on one hand, and by the evidence of the learning significance from the other (Sanger, 2008).

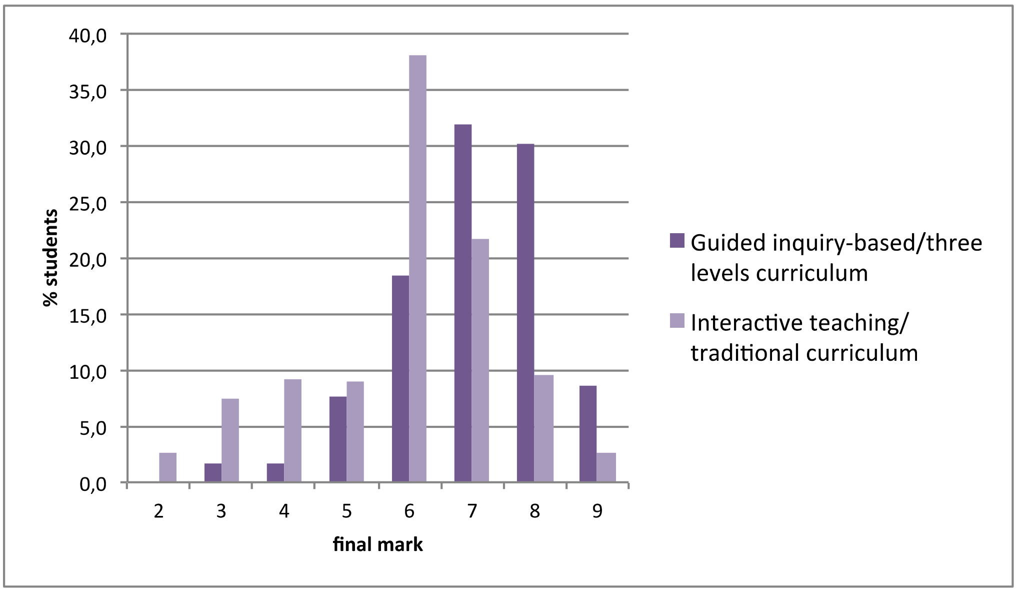

Figure 3. Data sets collected between 2007 and 2015 in five secondary schools in Piedmont and Emilia. The students have been taught by five different teachers, and the comparison of the final marks was made between "traditional" interactive teaching styles (337 students) and a guided inquiry-based one, applied to a three levels/spiral structure curriculum (352 students).

6. Conclusions and perspectives

With this work we suggest the design of a didactical tool for teachers, who are asked to implement the school reform. New objectives of compulsory education might be identified in general skills, and namely "problem setting", "problem solving", "team working", and we believe that the method we described supports precisely such competences. New knowledge is constructed starting from students' own ideas on a problem to solve, and it is structured thanks to the interaction with teachers and peers. Moreover, one of the recent Italian school reforms (D.P.R. n. 87/2010, n. 88/2010, n. 89/2010) mentions an increase in science education and laboratory-based didactic, but actually imposes a dramatic reduction of the chemistry lab availability in technical schools, and in many schools the laboratory does not even exist at all. In our TLSs the lab is considered both as a physical and a mental place, since most of the problems we propose might be somehow created in the classroom, using drawings, existing data sets, teacher's demonstrations, and so on.

In the medium-term we can figure a technological implementation of the TLSs, for example by designing specific digital tools for the modeling of transformations and particles behavior. Perspectives of this work in a medium and long term are related to the "trial phase", during which the sequences should be tested under regular school conditions. Some of them have already proven to be more effective as compared to the traditional curriculum, but many sequences have been created brand new and they are waiting for testing to be performed, either by us or our colleagues. Unfortunately, the comparison of the results obtained by students is hardly useful to make direct judgments about the effect of the teaching sequences upon students' and teachers' motivation. Overall, the trial phase should support the idea that motivation for science learning can come from teaching scientific concepts in such a way that students understand them. And of course, personal freedom and competence of teachers are necessary to make the sequences work in practice.

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