An Interdisciplinary Project Integrating Natural Science, Mathematics and Computer Science

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Abstract— **In scholar curriculum, the integration of contents from different learning areas has been always a challenging issue, but with very few practical experimentations. This paper reports an experimental project of teaching natural science, mathematics, and computer science (technology education) in the first level of the Italian secondary school, by means of a common integrate path based on practical experiments. We show effectiveness of the conceived interdisciplinary approach by means of a case study in a network of thirty classrooms of 11 years old scholars.**

***Index Terms* — Interdisciplinary approach, Educational technology, Science education, Computer science education;**

I. Introduction

TRADITIONALLY, school curriculum has been largely based on the concept that instruction should be separated into distinct subjects, for ease of understanding, and then reassembled when complex applications are required. Such a fragmented learning approach seems less appropriate in our modern society, where it is well understood that combining different disciplines, pedagogical approaches, people, and skills deeply improves scholar learning [1,2].

Also, present-day scholars are much more stimulated by modern multimedia teaching methods, especially when they are based on modern technologies. These concepts are even more convincing by looking at the dramatic statistics produced by the Organization for Economic Co-operation and Development (OECD) Program for International Student Assessment (PISA) 2006, specifically for the Italian country [3]. We recall that this program surveys 15-year-olds scholars in the principal industrialized countries. Every three years, starting from 2000, it assesses how far students, near to the end of compulsory education, have acquired some of the knowledge and skills essential for a full participation in society. In 2000, the OECD PISA core has been *literature*, in 2003 *mathematics*, and in 2006 *science*. In 2006, 57 industrialized countries have been surveyed and Italian students got position 36 for science and position 38 for mathematics. These results put Italian scholars at a very low level and underline the need for innovative learning approaches for both mathematics and science. By looking at the punctual results, one can observe that the situation is even worst in South Italy. Indeed, while North and Center Italy have reached a score of 520 and 486, respectively (the average PISA 2006 score is 500), South Italian scholars have reached a dramatic score of 448. In particular, as far as the mathematics concerns, more than 50% of scholars have given wrong answers at the supplied tests.

These reasons have been spurred overall Europe several initiatives for the promotion and integration of different teaching approaches. In Italy, this has been also done via the INNOVASCUOLA call [4] (founded by the Department for Innovation and the Ministry of Education, Universities and Research).

INNOVASCUOLA intends offering to all schools in Italy, of all order and degree, all the opportunities given by the ICT. The objectives of the initiative are:

- to facilitate the introduction of innovative didactic methods for teachers and students;
- to trigger a virtuous innovation process starting from inside the schools themselves, favoring the expressiveness of teachers and students, allowing them to develop and share digital contents.

Our project, called INNOVAMBIENTE, is aimed to experiment an innovative learning approach for the natural environment education through a combined application of mathematics and computer science (technology education) notions, in the curriculum of first level scholars of Italian secondary school, by means of real experiments. In particular, we have focused our attention on South Italy schools, due to the fact that they suffer more of the "early school leavers" problem, and because of the much lower instruction level of their scholars, as it is reported by OECD [3]. The project has been accepted for founding in a very selective review process (it got one of the first positions, over more than 1000 projects presented in Southern Italy).

II. The INNOVAMBIENTE Project

A. Overview

The project is devoted to 11 years old students. It has started in September 2008 and will hold for two years. It involves a network of 30 classrooms, each one with an average of 20 students and 3 teachers. The methodological approach is mainly based on practical experiments of natural science, realized either in school or in the natural environment. The intent is to let student to learn the natural science with fun, and the accompanying mathematics and computer science concepts just "for free", while using them along with the experiments. The integration of the disciplines is thought in such a way that the base knowledge of each of them converges in a single subject without losing their own identity.

B. Aim

The proposed teaching approach intends to attract students much more than the classical ones. First, it helps students to become more conscious regarding the natural environment in which they live and of which they are an integrating part. Second, students take benefits from the immediate application of mathematical concepts, which are often perceived as a very abstract topic, as they do not see any immediate applicability of them. Third, the application of computer science techniques and tools to realistic problems helps students to learn and increase their abilities on multimedia and data evaluator tools.

The new approach will also help teachers understanding that their specific educational areas do not stand alone within the school curriculum and that, by combining them, students can have benefits in learning.

Finally, students are naturally accompanied to organize the logical aspects of each experiment roadmap in terms of a simple algorithm, with the intent to introduce the classroom to the basic aspects of the computer programming

III. Case Study Lessons

In this section, we focus on how to combine in a very attractive way (from students' point of view) natural science, mathematics and computer science, in a common subject of study. In particular, we are less interested in examining the empirical evidence about whether or not the interdisciplinary study "works", since there is a huge amount of research in literature of this sort [5]. Within the INNOVAMBIENTE project, we have elaborated a set of lessons regarding different topics related to cell theory, water analysis, reproduction and biodiversity. Here, for the sake of space, we only report three experiment proposals, which are respectively introduced to show effectiveness of the interdisciplinary study inside the school and outside, in the natural environment.

A. The Lepidoptera Biodiversity

This experiment starts in the landscape and manly considers butterflies as bio-indicators. By following a fixed path (300 meters) in Mediterranean Maquis protected natural area, students count all butterflies and repeat the counting several times. They may also catch some samples, recognize them following a book guide, and then quickly release them. Successively, students repeat the same experiment in an unprotected environment (but with similar vegetation) and compare the obtained data. As an example, assume that scholars have observed during the experiment 8 different species (see Fig. 1).

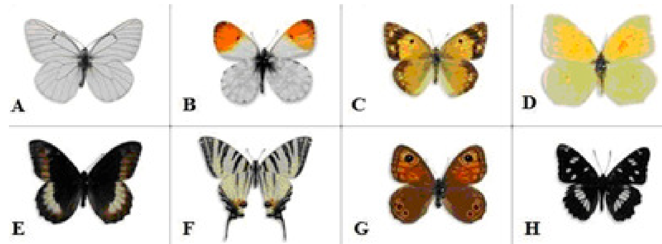

Fig. 1 **Butterfly species:** *A) Aporia crata, B) Antocharis cardamines, C) Colias Crocea, D) Gonepteryx Cleopatra, E) Hipparchia fagi, F) Iphiclides podalirius, G) Lasiommata maera, H) Limenitis reducta*

At this stage, students are invited to create a mathematical model of the experiment for a better representation, organization, and evaluation of the achieved data. In particular, the mathematical model has to help students to come out with a relationship between data and results. This is usually done by using the concept of *function* that in the specific example returns from the input data (the butterfly species) a number that corresponds to a Biodiversity index. Therefore, the aim of this experiment is: to simplify the Biodiversity concept (easily understandable by the scholars) and to give scholars a real application on which test arithmetic theories. Coming back to our example, suppose that students have collected the following data in the natural (**N**) and unprotected (**U**) environment, with respect to Fig. 1:

A. (N=7, U=0)	B. (N=12, U=3)
C. (N=20, U=32)	D. (N=4, U=1)
E. (N=3, U=0),	F. (N=5, U=1)
G. (N=10, U=2),	H. (N=7, U=0)

Hence, the total numbers of butterfly species observed are 68 for N and 39 for U. Let p_i, for i in {A,...,H}, be the numbers of samples recorded, for each species and environment, with respect to the total species observed in that environment. For each species, we have:

p_A: 7/68 for N and 0/39 for U (species A);
p_B: 12/68 for N and 3/39 for U (species B);
p_C: 20/68 for N and 32/39 for U (species C);
p_D: 4/68 for N and 1/39 for U (species D);
p_E: 3/68 for N and 0/39 for U (species E);
p_F: 5/68 for N and 1/39 for U (species F);
p_G: 10/68 for N and 2/39 for U (species G);
p_H: 7/68 for N and 0/39 for U (species H).

Students can then calculate the Simpson's biodiversity index [6]:

$$\mathbf{D = p_A * p_A + p_B * p_B + ... + p_H * p_H.}$$

So, they obtain, respectively for N and U, the values D_N= *0.01384* and D_U= *0,0254* and, as it was expected, both numbers are between 0 and 1. Hence, students understand the biodiversity concept directly from the experiment they have performed: *"the more the obtained index is close to zero the more diverse and heterogeneous is the considered ecosystems"*. Therefore students logically conclude that the unprotected environment is, with respect to these data, less heterogeneous than the natural one. Both the input and output data of the experiment are successively organized via simple databases (for the data storage) and multimedia tools. Scholars can experiment the integration of media contents and therefore the production of a digital didactic contents CDD, (one of the main goals of the INNOVAMBIENTE project). So, *what do the scholars learn from the whole interdisciplinary learning process*? They learn how to study the environment, through the Biodiversity analysis. Moreover, with such an experiment, they are "kindly forced" to use both arithmetic and computer science concepts.

B. Cell Theory Lesson

The experiment starts by picking human cells from the internal cheek of a voluntary teacher. The mucosa cells are weakly connected and they can be taken away without any pain with a light scraping, via a pipette (Fig. 2).

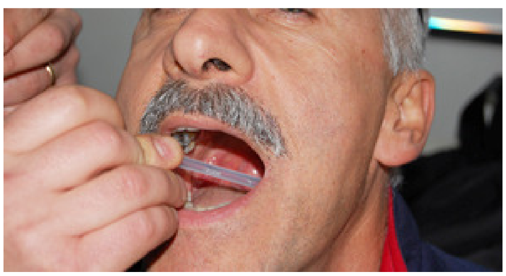

Fig. 2 **Picking of human cells with a pipette**

The pipette is successively smeared on a glass where the cells naturally adhere and are colored with methylene blue. Then, the glass is mounted for observation on a microscope where cells appear light blue (Fig. 3).

Starting from the acquired image, we observe that the figure has a geometrical structure. The cells in the figure may be "approximate" with hexagons. For simplicity, suppose that they are regular (see Fig. 3).

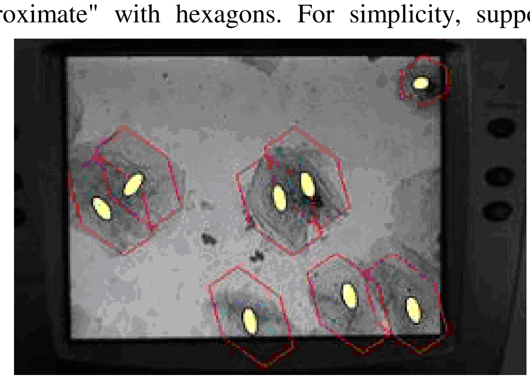

Fig.3 **cells with hexagonal approximation.**

Let **l** and **a** be respectively the side and the apothegm of each single cell-hexagon, by defining its perimeter (**p**) and Area (**A**) to be equal to:

$$\mathbf{p = 6 * l} \qquad \text{and} \qquad \mathbf{A = a * p / 2.}$$

The teacher can ask students to calculate the total area covered by all cells on the glass. He can also propose new problems such as the following: *observe microscopically the cells and their size in (μm), assuming we can measure the side of the regular polygon; what size should the nucleus have?* Regarding computer science, first consider that the above experiment is reproduced on an interactive white-board connected to the microscope by an USB camera. To let students better understanding the developed geometry concepts, teachers are helped by interactive software for Euclidean geometry such as *Cabri Geomtrie*. Then, students use spreadsheets to collect all data and develop counting results. Finally, a multimedia representation will help to reproduce the basic steps of the experiment, with the possibility to serf it for deepening.

In conclusion with this experiment, students are able to experimentally study the feature of animal cells, the basic Euclidean notions of plane figures, its software graphical representation via geometrical software, few basic computer science tools for collecting data and virtually reproduce the experiment and show the obtained results.

C. pH and Electric Conductivity Measurements Lesson

This experiment illustrates how to measure and collect the pH and the electric conductivity (CE) of chemicals in water. This experiment can be seen as the core part of a more complex test that concerns the evaluation of the health of the natural environment and in particular the status of the surface water (lakes, rivers, sea, etc) in consequence of the eutrophication[1] phenomenon [7]. We describe here all steps of this experiment, and for each of them, we describe how natural science, mathematics, and informatics are involved.

We start the experiment by taking two empty beckers. In one of them (called becker A), we pour 50ml of tap water and in the other (called becker B) we pour 50ml of distillate water. In the becker A, we introduce a *pH-Meter*, an instrument that allows to measure the pH value of the water present in the becker. In the becker B, we put a conductivity meter (*conduct-meter*), an instrument that allows to measure the CE of the water present in the becker. Then, we prepare two solutions to be added to both beckers, in order to change the pH and the CE of the water they contain. The first solution consists of

[1]Eutrophication is an increase in the concentration of chemical nutrients in an ecosystem to an extent that increases in the primary productivity of the ecosystem. Depending on the degree of eutrophication, subsequent negative environmental effects such as anoxia and severe reductions in water quality, fish, and other animal populations may occur

lemon juice (full strength, fresh squeezed, at room temperature). This solution, opportunely filtrate (possibly with cotton wool) will be used to lower the pH. The second solution consists of dissolved sodium chloride, i.e., the common cooking salt (NaCl), which will be used to increase the CE of the distilled water.

Both the solutions will be added drop-wise by using a common pipette. The experiment proceeds in rounds and at each round it is added to becker A a drop of lemon juice and to becker B a drop of NaCl. At each round, pH and CE are measured and the relative values are collected, by means of an electronic spreadsheet program. The experiment ends in 10 rounds. As it will be clear in the following, the data that students collect in these 10 rounds represent a right amount for the aim of this lesson.

After few drops, by looking at the measurements, the students will immediately realize that the addition of lemon juice in the becker A increases the water acidity and the addition of NaCl in the becker B increases the water conductibility. In particular, they can observe certain regularity among the differences of two successive measurements. By letting the students observing this regularity, after one or two rounds, i.e., after one or two drops of solutions have been added to both beckers, one can ask them to "guess" the value of the next measurement. More formally, it is asked to the students to calculate the "expected value" (EV) of the next measurement, starting from the measurements they have got up to that moment. This part introduces the students to the orthodox application of the scientific method, which prefigures the experimental proof of the hypothesis [8]. This requires a mathematical representation of the experiment and an interpolation of the experiment data, by means of simple arithmetic operations. Let us see the application of these concepts in practice, by considering the case we require the students to calculate the EV of the pH.

First, we let the students to understand that the drop they add at each round is actually the basic unit of the experiment. So, they can come up with a mathematical model of the experiment in which the single drop is intrinsically used as a mathematical unit. Then, a mathematical model for the calculation of the EV of the pH can be obtained by assuming that the variations of the pH induced by adding lemon juice drops is linear, and more specifically, it represents an *arithmetic progression*. For example, assume that at the beginning of the experiment (i.e., at the time the water has no lemon juice inside) the pH of the water is a_0 = 6,53 and that after one lemon juice drop it becomes equal to a_1 = 6,22. Then the *common difference* **d** of the progression is

$$d = 6,22 - 6,53 = -0,31$$

Hence, the pH EV at the round n, i.e. a_n, can be calculated using the following formula:

$$a_n = a_{n-1} + d$$

This formula represents a mathematical model of the experiment, which relates the next measurement to the previous one. I.e, it reveals to the students, by means of the experiment, that there exists a mathematical rule f of the following type:

$$a_n = f(a_{n-1})$$

that is able to establish "with precision" which pH value will be observed at the measurement in the next round. Then, at each real measurement, the student will check whether the EV and the real value coincide, in order to validate his model and the relative calculation.

Clearly, an analogous mathematical procedure can be performed to calculate the EV of the CE of the water contained in the becker B. Indeed, this value can be calculated by adding to the actual value of the CE the difference between this value and the one we have measured in the previous round.

The table shown in Fig. 4 reports the values we have collected from a real experiment, along with the extra data we have calculated by using the EV function introduced above. Note that the table is obtained by means of a spreadsheet program, where the EV function has been introduced to calculate automatically the interpolated data.

	A	B	C	D	E	F	G	H
1		electric conductivity					Ph	
2	units	values	difference	expected value		values	difference	expected value
3	0	0				6,53		
4	1	111	111			6,22	0,31	
5	2	218	107	222		6	0,22	5,91
6	3	302	84	325		5,8	0,2	5,78
7	4	416	114	386		5,6	0,2	5,6
8	5	505	89	530		5,42	0,18	5,4
9	6	620	115	594		5,25	0,17	5,24
10	7	693	73	735		4,95	0,3	5,08
11	8	798	105	766		4,68	0,27	4,65
12	9	898	100	903		4,4	0,28	4,41
13	10	992	94	998		4,15	0,25	4,12

Fig. 4 **Experiment data**

After all data have been arranged in the table, the students realize that rarely the EV corresponds to the real measurement. In particular, they can observe that while the discordance is usually small in the case of the pH, it is a little more consistent in the case of the CE. This will immediately lead the students to think that the hypothesis of a linear change of the pH and the CE is not completely supported in the reality and this induces the teacher to introduce the concept of "*measurement error*". To this purpose, we first let the students to observe that the *common difference*, obtained as a difference between to successive measurements, changes at each round. This clearly makes the sequence of the measurements not properly an arithmetic progression. Clearly, a more uniform distribution of the EV can be obtained by using at each round an average common difference. The mathematical concept of the *average* is then introduced and calculated by the students, using the following formula:

$$d^* = (d_1+d_2+d_3+\ldots d_n)/N$$

where each d_i is the common difference obtained at the end of the round i. Using the value d* value as a common difference, the students can recalculate the sequence of EV, which is obviously an arithmetic progression.

As an advance argument, teachers can also discuss other perturbations that can arise in the measurements of the pH and the CE. Among the others, we mention here those relate to: (i) the low accuracy of the tools used to measure the pH and CE, (ii) the non-constant amount of liquid contained in a drop, and (iii) the human error.

Finally, all the values measured and calculated can be represented in a graphic format, where the differences between the values are much more evident, as shown in (Fig. 5).

As homework, teachers can also ask the students to prepare

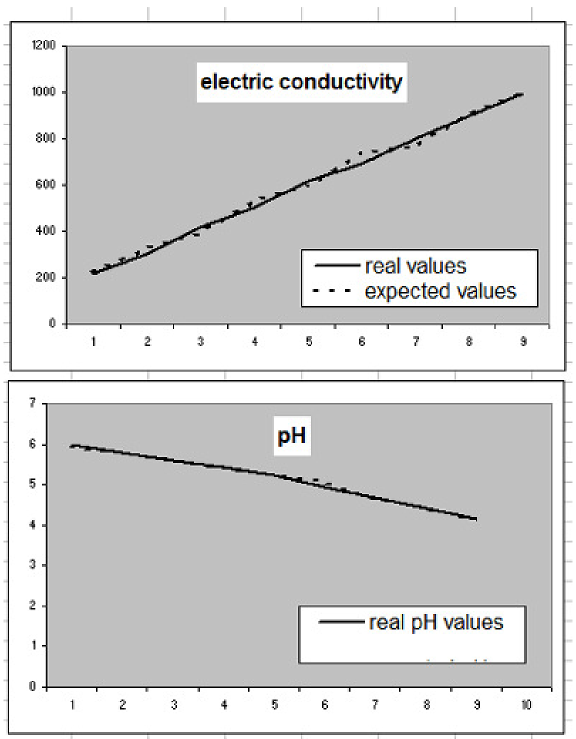

Fig. 5 **Experimental data table**

an animated model of the CE of the water, by means of a multimedia presentation program. The students need just a way to represent graphically the positive ions (Na^+) and the negative ones (Cl^-), as well as their random movement between the anode and the cathode. In figure (Fig. 6) there is a snapshot of a real experiment we have realized, where positive ions are represented by blue balls and negative ions by red balls.

In conclusion, this experiment allows students to learn the following arguments:

1. to measure and collect data from an experiment.
2. the concepts of the pH and the CE of the water and how they can be modified.
3. to apply the scientific method.
4. to use mathematical operations to get new data by interpolating existing ones.
5. to mathematically represent the relationship among experiment data obtained in different rounds.
6. the concept of "measurement errors".
7. to represent data by means of spreadsheet programs.
8. to use multimedia presentation programs to represent

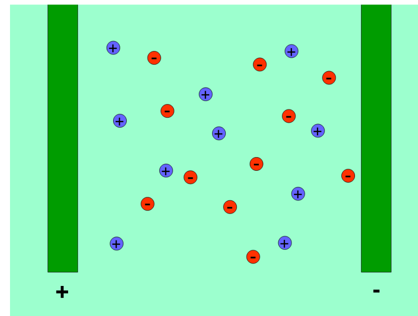

Fig. 6 **Experiment reproduction**

particular aspects of the experiment.

IV. CONCLUSIONS

This paper reports an innovative learning approach, which we have named INNOVAMBIENTE, for teaching natural science, mathematics and computer science (technology education) in the first level of the Italian secondary school. This approach extends classical ones in two different dimensions. In one, we consider real experiments in which all the disciplines are applied to solve practical problems. In the other, we integrate all the above disciplines by following a common path, in such a way that every discipline becomes complementary to each other.

We have shown benefit and feasibility of the project by means of a case study in both the natural environment and the laboratory where students, starting with a real experiment, first collect information from tangible surrounding data, and then elaborate them by applying mathematical and computer science theory in order to get back natural science information. Hence, starting from natural science, every experiment immerses students into mathematical theories, in the management of the electronic data acquired, and in the reproduction of the experiment via multimedia tools. Also, the application of mathematics to real experiments allows to eliminate the annoying problem that scholars often perceive this discipline as a set of isolated notions, far away from the reality and therefore with very few applications.

Following the INNOVAMBIENTE project, a student becomes the main actor of his education. Since he needs to face time by time new problems, he will be induced to develop and refine its intuitive abilities. In this way, teachers can use in a better way the students "emotional intelligence", which is the ability of motivating the student to pursue a target in spite of frustrations [9]. Moreover, by working on data produced personally, a scholar will be much more motivated to learning and deepening knowledge.

ACKNOWLEDGMENT

We wish to thank the headmasters and the teachers of all schools involved in the INNOVAMBIENTE project, in particular Prof. Podda of S.M.S. “G. Mameli” in Nola (NA) and Prof. Riemma of S.M.S. A. “Moro” in Casalnuovo (NA), for their help and support.

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