TEACHING EVOLUTION WITH THE LABORATORY APPROACH

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Abstract

The present research compares the results obtained by using two different methods of instruction in teaching Darwin's evolution theory: laboratory activities and traditional lessons based on textbooks. We built up a teaching path on evolution using laboratory activities, to highlight how the main concepts of this theory (selection, adaptation, variability, inheritance, case, time) can be handled also by doing, interacting, and cooperating, in other words by "putting students' thinking into action". This path does not refer to a real scientific laboratory (meaning a physical space with materials and instruments) but to an educational laboratory, "poor" and characterised by limited time activities. Widening the definition of laboratory allows teachers to create active and informal learning contexts, exploiting educational resources supplied by those centres which promote both culture and knowledge, as well as by specific events organized in the scientific network. Every activity has been planned to explain one or more of the main themes, using the following methods: economy of ideas, logical consistency, introductory value, and scientific accuracy. The experimental groups were third-year students attending secondary school. A questionnaire was used before and after the course, to assess students' acceptance and understanding of evolution. With both methods results highlighted relevant differences in understanding concepts, in religious-based questions and scientific facts regarding evolution. Moreover, the comparison of answers obtained using either the traditional or the laboratory method shows several differences. In particular, the percentage of students accepting and understanding the evolution theory is much higher in those who participated in laboratory lessons. In conclusion, it can be assumed that, in teaching evolution, lessons proposing scientific experiments through active and practical activities are much more effective than lessons based on school books and frontal methods. Thus, a teaching path based on interaction and cooperation of students in a scientific laboratory is to be considered more successful.

Keywords: education, evolution, teaching, workshop activities.

1 INTRODUCTION

Evolution is a subject of great interest, because it allows teachers to deal with naturalistic facts in an active and modern way and to highlight the different logical approaches of contemporary scientific research (Tura et al., 2018; Bortolami et al., 2020; Tonon et al., 2020, Furlanetto et al., 2021; Cazzador et al., 2022).

Those who think of a school as a place where young people can build knowledge in a social environment

starting from real life, the "obvious" question is whether the theory of evolution is accessible for students from 11 to 14 years of age (Zanata & Santovito, 2020).

Evolution is certainly a difficult subject to learn, because it deals with phenomena that cannot be observed directly, its explanation requires an excursus through other concepts integrated in a sophisticated network of knowledge and relationships and implies considerable complexity (Gaiotto & Santovito, 2016; Rossi & Santovito, 2016; Favaron et al., 2017; Meneghetti et al., 2017; Fassinato et al., 2018; Palmieri et al., 2019; Gaiotto et al., 2022). However, if one considers the high scientific and didactic value of the theory of evolution, it is clear that its teaching requires, rather than a postponement in time, the adoption of appropriate didactic methods. It is a real challenge for those who believe that learning comes from experience (Pavan & Santovito, 2014; Trevisan & Santovito, 2015; Barana et al., 2021; Pavan et al., 2021; Lago et al., 2022; Massaro et al., 2022).

1.1 The teaching Role of the Workshop

Direct methods, such as discovery and experience, in the field or in a laboratory, are extremely useful in teaching scientific subjects (Toninato & Santovito, 2015; Lago et al., 2017; Furlan et al., 2021; Bolzon et al., 2022; Masiero et al., 2022). However, given that scientific subjects are still limited to learning through textbooks, it is essential to restructure the way scientific information is explained in school books. Evolved scientific language is often short-lived and insubstantial to students: it should be practices every day, to tackle everyday problems.

Science teaching in schools is still connected to a view of science as a compact and progressive set of cumulative linear knowledge, albeit an updated one. The information and transmission role of scientific knowledge must certainly not be abandoned, but the teaching of natural sciences must accept the new image of science, which is less coherent and less converging, more critical and more dialectical and also more historical, as it pays attention to internal diversity and external contextualisation. It is also useful to pay attention to the methodologies inspired by the sciences themselves, such as those of discovery, research and justification (Chiesa et al., 2019; Gallina et al., 2019; Bertoncello et al., 2021; Bassi et al., 2021; Zandonella Necca et al., 2021).

1.2 Purpose of Research

The purpose of this research is to assess the different consequences, in terms of learning, of different didactic methods. To this end, several life sciences syllabuses were prepared for Junior High Schools, based on a contents-methods association that includes the offerings of a didactic workshop and the teaching of the theory of evolution. The purpose was to promote the creation,within the context of teaching-learning dynamics, of a valid and effective didactic action. The research had the following goals:

- Determine the basic nuclei of the theory that respect its scientific-rational structure and its historic-epistemological value, as they can be transferred and made concrete through the didactic workshop;
- Identify which type of workshop activity is best suited to the teaching of the concepts at the basis of evolutionary biology;
- Build some learning paths that cover the fundamental featuires of evolution using processes that can be activated through laboratory techniques, and test their effectiveness through a comparison with learning paths base on traditional methods;

2 RESEARCH TOOLS AND METHODS

2.1 Learning Path Organisation

The main points that characterised this phase are:

- Identification of pivotal concepts pertaining to the theory of evolution, through an analysis of the relevant literature and texts. The following factor were taken into account: heredity, randomness, selection, adaptation, time;
- Analysis of the curricula of Junior High Schools, to identify the most appropriate grade and moment for the experiment. We chosen Junior High School third year classes, whose syllabuses showed that they had already treated some biology (including human biology) and genetics themes;
- Preparation and/or adjustment of guide cards and identification of the appropriate teaching tools. We created several protocols inspired by the abovementioned subjects, to be used as guidelines for the

performance of laboratory activities. The included activities were chosen on the basis of their relevance to the basic Life Sciences syllabus, of the possibility of adapting and reproducing them in different teaching contexts (see High School), of the ease if supply of the necessary materials, and of the originality and topicality of the examples.

- Identification of activity monitoring, results collection and statistical analysis tools. A questionnaire on the acceptance of the theory of evolution used in a similar study to this (Chinsamy. & Plaganyi, 2008) was freely translated and administered. We included in the questionnaire four simple, but highly specific questions on the comparison between the human species and other living organisms, in order to leave the way open for a possible future natural extension of the project. We also used a 5-step agree/disagree scale for data collection, the Likert scale.
- Teachers training Teachers who participated in the research agreed to participate in the class experience. the teachers attended a refresher course of four 2-hour lessons in which the laboratory experiments that would be carried out by the students were explained and demonstrated. The purpose of the course was to develop the project in the classrooms of the participating teachers, intervening at a supervisory level. In order to increase the reliability of the research and reduce the subjective components, the involved teachers operated in at least two classes, using both learning paths.
- Classes subdivision. We tried to choose the most homogeneous classes, in particular in terms of gender, performance, students attending Catholic Religion classes, some students who needed support, school location (city centre/outskirts). With regard to special needs students, questionnaires were administered with the help of the appointed special needs teacher and included in the results only after said teacher confirmed that the students had understood the questions.

2.2 Learning Path Development

The project involves about 600 students attending third year classes in 28 Junior High School in the Veneto region.

The theory of evolution was taught in the "traditional" way (frontal lessons with the help of textbooks) in half the classes, while in the remaining half the same subject was taught using the experimental workshop approach. Time dedicated to the project was the same in both cases, namely, eight one-hour lessons for each class.

All students had to fill in the questionnaire on the acceptance of the theory of evolution twice, before and after the experimentation, to ascertain prior knowledge and didactic advantages, respectively.

3 RESULTS

For each question in the questionnaire, the answers for each of the five possible choices were summed, and a percentage average of each sum was calculated. Questions were grouped in sections as follows:

- Science/religion relationship: questions 1 to 4;
- Comprehension: questions 5 to 9;
- Scientific facts: questions 10 to 14;
- Human evolution: questions 14 to 18;
- Specious questions: numbers 19 and 20

Questions 19 and 20, the so-called "specious" questions, are items that were included in order to promote the test internal standardisation. Indeed, these patently false questions concern two imaginary scientist whose identity is not recognisable, even though their names sound like the names of actual scientists (Sherwin, sound like with Darwin, and Bernelli, sounds like Bernoulli). If the test is filled in randomly, by crossing boxes without reading the questions, a uniform distribution of the answers for each attitude is to be expected. On the other hand, if the test is filled in after reading the questions, a predominance of the "I don't know/uncertain" answers is expected.

In order to improve data processing, the percentages for each answer were grouped according to the level of correctness, this overlooking the depth of feeling for the chosen answer. For instance, for question "The Earth is 4.5 billion years old", both the "Strongly agree" and the "Agree" answers were considered correct, while the "Disagree" and "Strongly disagree" answers were considered incorrect. The grouping was made in the opposite way if the correct answers required a negative attitude, such as for the question "Evolution took

place millions of years ago, and is no longer going on".

If the lessons on evolution were effective, a significant increase in the number of correct answers would be expected in the questionnaires takes at the end of the learning path. In order to measure the significance of such an increase, a one-tailed paired t-test was used for each group of questions; this means that a significant change occurs only when the probability observed by applying the t-test to the sample is lower than the threshold value (α <5%). The results are shown in the following sub.sections.

The one-tailed paired t-test was used also to assess whether the increases in correct answers obtained after following the lessons on evolution differed significantly between the two groups (threshold value α <5%). The data show that in all four sections of the questionnaire, the increase in correct answers after the workshop-based approach is always significantly bigger than that obtained after the traditional approach.

3.1 Science/Religion Relationship

With regard to the investigation on the relationship between science and religion, the percentage of correct answers goes from 45.3% before the lessons, to 55.5% after the teachings with the traditional approach (α=3,04%), and to 78% after the teachings with the workshop-based approach (α=0,30%); as can be seen, in both cases the change is statistically significant (Fig. 1). Students in the workshop branch of the experiment, therefore, consider scientific reasons more acceptable than religious ones. This refers, in particular, to the creation of the universe and the development of life on earth, as well as the time when and how of its modification. About half (55.5%) of the students taught with the traditional method is still attached to a creationist concept.

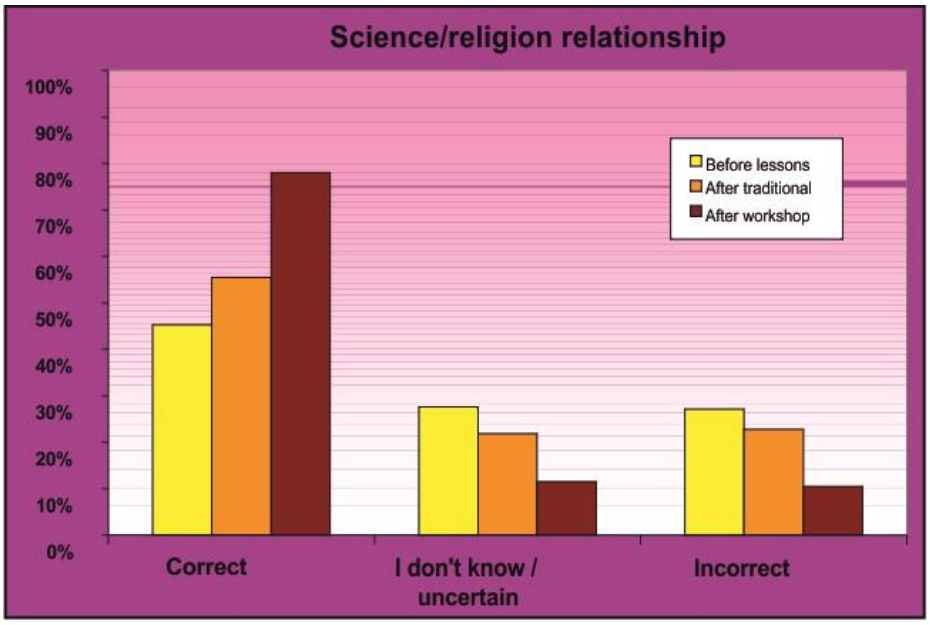

Figure 1 Science/religion relationship results

3.2 Comprehension

The percentage of students who demonstrate to gave understood the fundamental processes the theory of evolution is based on is higher among the students who participated in workshop lessons than among those taught with the classic method, even though in both cases there are significant improvements (Fig. 2). In the workshop-based branch, over 83.5% (α=0,02%) of the group demonstrate that they understood the structural design of the theory of evolution, of the pivotal concepts it is based on and which are the mechanisms at the basis of the process of descent with modification; whereas, in the second branch, the level stops at 69.9% (α=3,99%), with a percentage of undecided of 20.9%.

3.3 Scientific Facts

The difference in knowledge of scientific data related to evolutionary dynamics is quite clear-cut: while on the one hand a difference between before and after the workshop teaching is significant (it goes from 40.8% to 81.1%), the same assessment in the traditional teaching branch shows that the percentage is almost the same (around 46.3%, α=21,95%, which is a not significant change); moreover, almost one student in three in

this branch is undecided (Fig. 3).

Figure 2 Comprehension results

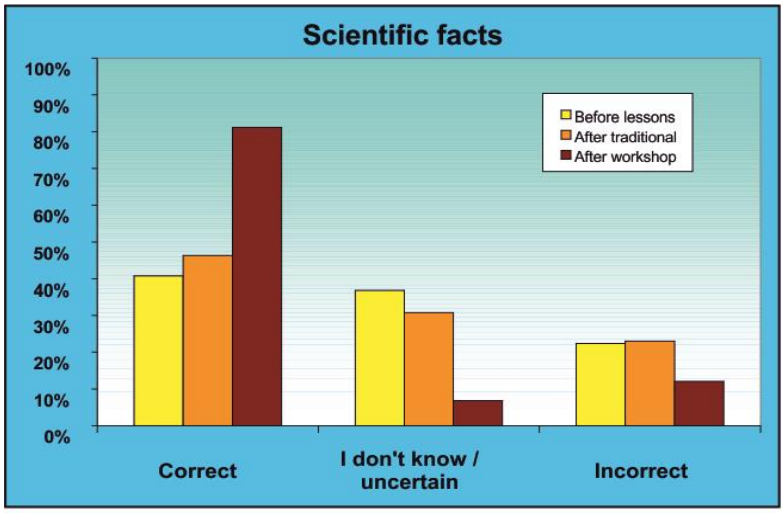

Figure 3 Scientific facts results.

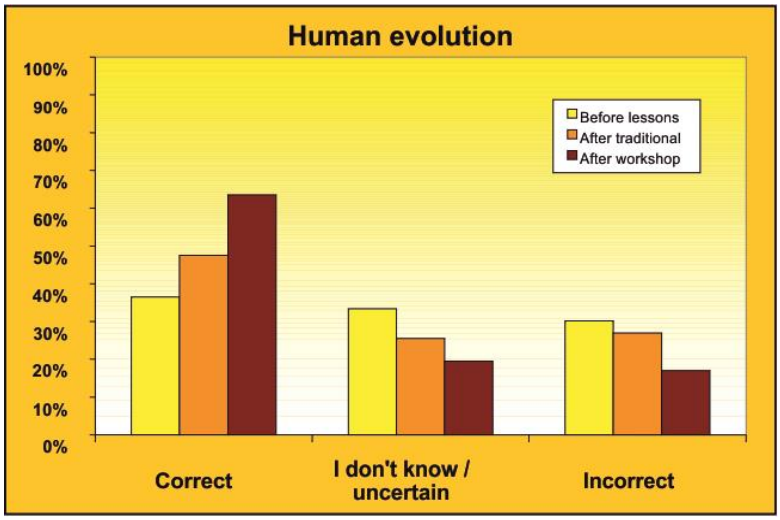

Figure 4 Human evolution results.

3.4 Specious Questions

With regard to the results of the answers to questions 19 and 20, in all three groups of questionnaires the percentage of "Neither agree nor disagree" answers is much higher than that in both the agree (sum of "Agree" and "Strongly agree" percentages) and the disagree (sum of "Disagree" and "Strongly disagree" percentages) categories (Figs. 5-6). As the distribution is not divided in equal parts (each 1/3 of the total), the conclusion may be drawn that the questionnaire was not filled in randomly.

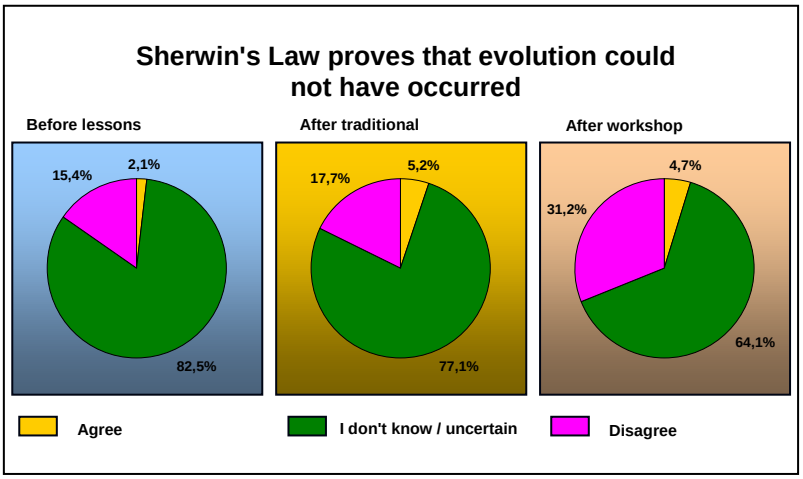

Figure 5 Question n. 19 results.

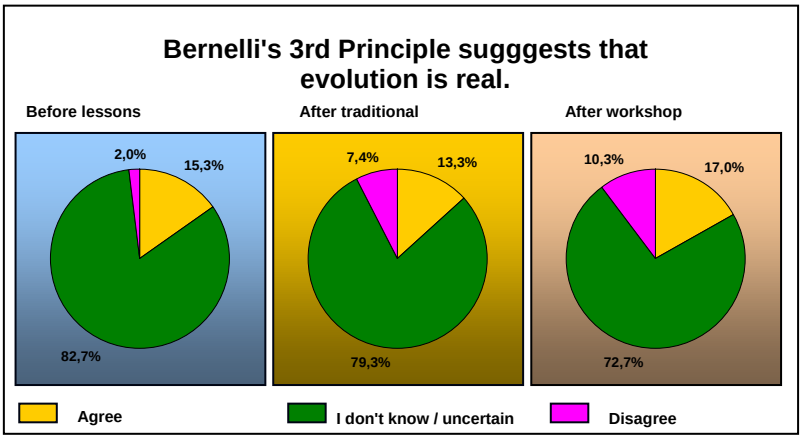

Figure 6 Question n. 20 results.

3.5 Traditional Didactics vs. Workshop Didactics

A statistical analysis (Fisher's exact test) was carried out in order to verify whether the increase in correct answers after the learning path depends on the type of teaching under consideration (traditional/workshop). As the test requires a comparison between two different samples with binary-type answers, the "Neither agree nor disagree" and "Incorrect" answer categories were gathered in a single "Incorrect" category. The probability threshold taken into account was 5% (for a critical chi-squared value of 3.84).

The chi-squared value obtained is lower than the threshold for two questions only, and that therefore the frequency of correct answers is not dependent on the group. Therefore, for these two items having attended lessons with the workshop or traditional method did not make any difference.

The items that did not evidence significant differences are:

- N. 8 "Variation and natural selection are two of the basic mechanisms of evolution" The correct answers increased from 53.4% at the start to 72.0% at the end of the traditional learning path and to 78.5% at the end of the workshop-based one. To confirm the improvement obtained also in the first group, it should be underscored that all the textbooks used clearly stated that evolution is based on these two mechanisms;
- N. 16 "The human species went through the same evolutionary changes of all other living beings". Here

the correct answers increased from 35.3% at the start to 45.4 % at the end of the traditional learning path and to 51.7% at the end of the workshop-based one. As can be noted, the results do not imply a huge change, probably because the human evolution subject was not developed fully and because one of the most rooted misconceptions is the conviction that man is a peculiar, somehow improved, life form.

4 DISCUSSION

When the learning paths focus on the theory of evolution, there are changes in students' perception of the theory. The results of this research underscore that, in all the groups of questions, an improvement in the percentage of correct answers is obtained independently from the method used. Teaching the theory of evolution is essential to interpret the changes organisms go through in time as records of the natural selection process, thus creating a direct link between the facts of evolution and the mechanisms that explain their presence (Gaiotto et al., 2013; Capparotto et al., 2017; Fabris et al., 2020; Frigerio et al., 2021; De Rossi et al., 2022). Moreover, understanding the theory correlates directly with its acceptance, given that the number of students who accept the scientific explanations (rather than the religious ones) of the change in living species increases significantly after both learning paths. This demonstrates that students 13-14 years old can understand complex themes and that therefore it is right to include the theory of evolution in the sciences syllabus of Junior High Schools.

The statistical analysis carried out with the paired t-test shows that in all four sections of the questionnaire, the increase in correct answers after the workshop-based approach is always significantly bigger than that obtained after the traditional approach. This confirms that lessons that deal with the theme of evolution in a practical, experimental way are more effective than lessons where a teacher explains the theory with the sole support of a textbook (Tonon et al., 2013; Zandonella Necca et al., 2014; Grando et al., 2018a, 2018b; Lui et al., 2019). Promoting teaching methods based on the investigative method that allows students to be active participants in their own learning process thanks to a direct, Hands-on approach, seems therefore a winning strategy (Barbacovi et al., 2018; Forlin et al., 2018; Corbolino et al., 2020; Gaiotto et al., 2020; Serato et al., 2022).

Although the results discussed here give some clear hints concerning the position taken by students before and after the described learning paths, a more accurate and critical analysis of the individual answers gives some food for critical discussion.

In the results obtained in the questionnaire part concerning the relationship between science and religion, the most plausible explanation is that students find it hard to believe in a single originating temporal event (question n. 3), thinking it impossible to materially construct the variety of complex forms of life that have populated and indeed populate the planet in a very short period of time. Another interpretation might involve the more generally counterintuitive character of the theory of evolution and the consequent difficulties in accepting it that are due not only to religion, but also, more widely, to the cognitive limitations that are at the core of our systems of belief (Pievani et al., 2008). Thus there is still one branch that might be researched, which might help solve the doubts mentioned here.

With regard to the second group of questions, those connected with the understanding of evolution processes, the answers given by the students were satisfactory; they show that the students know the mechanisms of variability and natural selection, as well as the adaptive changes life on earth has gone through, and that they extend these dynamics to all life forms.

The comparison between data highlights an inconsistency: while on the one hand several students consider evolution a valid scientific concept, a lower number of them consider it an evidence-supported explanation. This conforms the misconception on the term "theory" used in common language, which leaves considerable doubts on the student's conception of it. As can be seen, in the group taught with the traditional method, results are satisfactory when the questions concern the relation between humans and chimpanzees and the attribution of evolutionary mechanisms to Darwin, but the correct answer percentages for the remaining questions are discouraging, with a very high level of abstention.

A peculiar aspect of the "scientific facts" section concerns question n. 14 "The fossil record documents changes in all past life on Earth": the percentage of correct answers is decidedly low, with values of 22.6% in the traditional teaching method group and 56% in the workshop-based teaching group. It seems as if students' answers show that the records of organisms that lived in the past are totally available today, thus ignoring the fact that, if it were true, all the criticism of and objections to Darwin's intuitions would become completely void.

As already mentioned, the discussion on the data obtained by the section of questions on human evolution

has relative value, as the subject was not treated exhaustively in the few hours dedicated to the project in each class; for this reason the considerations on attribution of a purpose and/or perfecting processes associated to humans as the ultimate purpose are not very significant.

Therefore, while admitting that the organisms of their own species were also transformed in time, students basically consider man as a separate evolutionary subject, one that undergoes peculiar modification mechanisms. It might be interesting to investigate the nature of said mechanisms in the opinion of the students, and what importance they attribute to cultural evolution.

In conclusion, this research highlighted that evolution should be taught at all school levels, with more effective methods, taking into account prior knowledge and providing teaching methods that actively involve the students. It can be said, therefore, that the careful choice of workshop activities for the students might turn evolution into a dynamic experience, letting them go from passive reading to experimental investigation, to help them discover the enthralling history of biological evolution.

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