Can an interdisciplinary approach be an asset for teaching Geosciences in Natural Sciences?

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ABSTRACT

The purpose of the research is to test the feasibility of an interdisciplinary approach to teaching geoscience concepts related to the Agenda 2030 Goals. Feasibility was assessed from two perspectives: students' understanding and teachers' perceptions. Activities integrating Geosciences with Chemistry and Biology and finalized to understand the relationships between environment and society were designed, aimed at Italian upper secondary school students, aged 14-18. The investigation involved the collection of students' reports on laboratory activities, pre- and post-test, questionnaires on students' perception of interdisciplinarity and on teachers' point of view. The results of this research will be discussed, both regarding the understanding of geoscience concepts and the possible difficulties faced by teachers in this kind of approach.

KEYWORDS

Civic Education, Earth Sciences, Agenda 2030, interdisciplinarity, Italian Upper Secondary school

RÉSUMÉ

L'étude vise à examiner la viabilité d'une approche interdisciplinaire pour enseigner des notions liées à l'Agenda 2030. La faisabilité a été évaluée selon deux perspectives: la compréhension des élèves et la perception des enseignants. Des activités combinant les géosciences, la chimie et la biologie ont été proposées à des lycéens italiens (de 14 à 18 ans) pour comprendre les liens entre l'environnement et la société. L'investigation a consisté à recueillir les comptes rendus des étudiants sur les activités de laboratoire, à réaliser des pré- et post-tests, ainsi qu'à répondre à des questionnaires sur la perception de l'interdisciplinarité par les étudiants et sur le point de vue des enseignants. Les résultats de cette recherche seront analysés, tant en ce qui concerne la compréhension des concepts de géosciences que les difficultés rencontrées par les enseignants dans ce type d'approche.

MOTS CLÉS
Éducation civique, sciences de la Terre, Agenda 2030, interdisciplinarité, école secondaire supérieure italienne

INTRODUCTION

The term "interdisciplinarity" became a matter of discussion in scientific literature in the 20th century, when the Social Science Research Council used it to promote studies that cross multiple academic fields (Tripp & Shortlidge, 2019). As Klein and Philipp (2023) point out, in fact, the concept of interdisciplinarity is usually traced back to the 1920s in the context of social-scientific research and in the new forms of general education and core curricula. In the 1960s and 1970s, this approach became widespread mainly to test new educational methodologies and to address emerging problems such as environmental, urban and cultural issues. In fact, in the 1970s, a significant movement developed on a global scale to favour an integrated approach to science teaching (Geraedts et al., 2006). Since the 1980s, the term has found increasing use in industrialised Countries, especially in the scientific world, and thus also in academia, albeit with some difficulties. Indeed, historically, academic disciplines were seen as rigid structures necessary to organise and differentiate the various fields of knowledge. Because of this rigid disciplinary structure, early interdisciplinary initiatives were seen as marginal.

In the Natural Sciences subject in Italian upper secondary school, three different disciplines, Biology, Chemistry and Geosciences, are taught by the same teacher, apparently forming a suitable context to apply an interdisciplinary approach. Instead, in particular concerning Geosciences, the different disciplines are often juxtaposed without making explicit their mutual relationships, as is the case of a mere multidisciplinary approach. Geosciences teaching is particularly suffering in Italy (Bonaccorsi et al., 2020; Greco & Gualtieri, 2010; Realdon et al., 2016), in light of two considerations: the former is that most teachers do not have specific training in Geosciences (Bonaccorsi et al., 2020), the latter is that Geosciences is an often neglected discipline compared to the other two in the teaching of Natural Sciences (Greco & Almberg, 2016).

In this framework, the idea that motivated this study was to see if an interdisciplinary approach could be an opportunity for Natural Sciences teachers to approach Geosciences with greater awareness. To carry out the research, interdisciplinary learning paths were designed and proposed in upper secondary school, and the opinions of students and teachers were collected and discussed. In the interdisciplinary approach used in this research, no attempt was made to 'dilute' the distinctions among disciplines (Lederman & Niess, 1997), but their connections were clarified. Attempts were made to build moments of integration for a number of specific themes. In this way, interdisciplinarity becomes a bridging moment and not a way of overcoming individual disciplines.

REVIEW OF LITERATURE

The Eurydice report (2010) '*Science teaching in Europe: national policies, practices and research*' highlights how different situations exist in Europe with regard to science teaching in schools. Indeed, in different countries, science can be taught with an inter- and multidisciplinary approach. Generally, in primary school, the different sciences are taught as a single subject, while in later grades there is a tendency towards greater specialisation of science teaching. Again, however, official documents in many European countries mention the importance of

emphasising the connections among subjects and, where possible, teachers are encouraged to experiment cross-curricularity. To date, the debate on how natural science teaching should be organised - separate subjects or a single curriculum - during the last years of school is still open also in scientific literature. According to some authors (Geraedts et al., 2006; Lederman & Niess, 1997; Watanabe & Huntley, 1998), this approach does not facilitate students' understanding, because some topics of the subjects concerned could be, in this way, treated superficially or even omitted. Moreover, teachers could find it difficult to integrate subjects for which they are not specifically prepared. On the contrary, other authors (Atkin, 1998; Bransford et al., 2006; Czerniak & Johnson, 2014; Nowacek, 2005; St. Clair & Hough, 1992) state that interdisciplinarity would favour the learning just by building connections among different fields of knowledge, as it happens in real life. As claimed by Tripp & Shortlidge (2019) "interdisciplinarity is a process -not an outcome-".

Between 2005 and 2011, indeed, more than half of European countries revised their primary and secondary education curricula, to align them, including science subjects, with the key competences of the European Union (European Parliament and Council, 2006). The Eurydice report (2010) shows that almost all national curricular reforms have emphasised the need for links between subject areas.

In Italy, the Educational, Cultural and Professional Profile of the student at the end of the second cycle of education (Decree of the President of the Republic n. 89/2010) states that interdisciplinarity is a fundamental characteristic of culture. Different disciplinary perspectives and the ability to transfer patterns among different contexts, combining different codes, are essential tools for tackling complex problems.

In the first part of the National Curricular Guidelines (Interministerial Decree MIUR-MEF October,7/2011 n.211) for upper secondary school, in the section "The relationship between the student's Cultural and Professional Educational Profile and the National Guidelines", it is clarified how each discipline, with all its peculiar characteristics, contributes to acquiring different knowledge and skills.

In the light of this European and Italian regulatory and pedagogical context, and considering the critical challenges that Geoscience education often faces within Natural Science teaching in Italian schools, this article explores the outcomes of interdisciplinary teaching initiatives developed in upper secondary schools, with the aim of addressing the following questions:

- Is an interdisciplinary approach effective in improving students' learning of Geosciences concepts?
- How are these approaches perceived by students and by Natural Science teachers who have no specific training in Geology?

Building on these general aims, interdisciplinary educational paths (IEPs) were designed and proposed in upper secondary school. Four operational research questions, ORQ, were formulated to guide the data collection and analysis phases of the study:

1. Which interdisciplinary concepts emerge from students' production?
2. Does the approach used in the Interdisciplinary Educational Paths, IEPs, contribute to improving students' disciplinary learning?
3. How do students' perceptions of their own active participation change?
4. What elements emerge from the teachers' perspective?

MATERIAL AND METHODS

Design of IEPs

To design IEPs, the contents of the different disciplines of Natural Sciences and Integrated Sciences, as described in the National Curricular Guidelines and reported in Annexe 1, were cross-related and linked together in some macro- interdisciplinary themes.

This process made it possible to highlight the interdisciplinary connections and, on these bases, to propose seven IEPs to the teachers. These were built on the following interdisciplinary themes: climate change, geodiversity and biodiversity, water, biogeochemical cycles, evolution of the atmosphere, minerals and geomorphology. Three of them were chosen by the teachers of a technical school (ITIS, namely *Istituto Tecnico Industriale Statale*), which offered a course in environmental biotechnology, to be put into practice with their students. In Table 1 the originally proposed paths are listed, whereas in Table 2 the final scheme is outlined, as modified according to the teachers' suggestions. The IEPs are:

- IEP-1) Oceans: hydrosphere and biosphere for the 2030 Agenda Goal 14 - Life Under Water. Aim: investigating the relationships between the Earth's different spheres.
- IEP-2) The carbon cycle: Where does a tree's carbon come from? Aim: understanding how the inorganic and organic worlds are connected in this biogeochemical cycle.
- IEP-3) A survey of geodiversity and biodiversity for the Agenda 2030 Goal 15 - Life on Earth. Aim: understanding the relationship between biodiversity and geodiversity and the importance of preventing environmental degradation. The IEP-3 educational pathway also included a field trip in Apuan Alps, Tuscany, to visit the botanical garden "Pellegrini- Ansaldi" and the karst caves "Antro del Corchia".

The activities were carried out during the 2023-24 school year. First-year students participated in the IEP-1, second-year students followed the IEP-2. In view of the topics addressed in IEP-3, the teachers proposed it to the second two-year period of the environmental biotechnology course despite the fact that Geosciences are not, as a rule, carried out according to the Ministry of Education Guidelines (Annexe 1). Thus, third- and fourth-year students were involved in the IEP-3 (Table 2). In summary, the ages of the students involved ranged from 14 to 17 years old (1st to 4th class of Italian upper secondary school).

The activities were proposed mainly as laboratory activities (Table 2) and the student outputs were individual or group reports and peer discussions, as well as pre- and post- test and questionnaires for students' perception of IEP.

TABLE 1

Information about the three IEPs chosen by the teachers

Educational paths	IEP-1	IEP-2	IEP-3
Age of students	14-17 years: the IEPs are modulated in terms of contents, varying according to the age of the students and the specific requirements of the teachers		
Timeline	6 hours	5 hours	6 hours + 1-2 field trips
	Accordingly with the teaching needs, the activities and timetable initially proposed can be modified in itinere		
Main modality	Group activities, observation and discussion of the proposed activities.		

Interdisciplinarity	Link among Geosciences, Biology and Chemistry: hydrosphere, ions and marine organisms.	Link between geological cycle and biological cycle: processes that generate CO2, form C stocks and chemical transformations of matter.	Various geological and chemical aspects relate the biotic component with altitude. For example, flora is linked to the substrate in which it grows.
Student output	Questions uploaded online onto the class digital platform, which the learners had to answer between meetings; shared discussions; pre- and post-test and questionnaire for students' perception of IEP.		

TABLE 2

Scheme of classroom development of IEPs in ITIS school after remodulation with teachers

Selected IEP	IEP-1	IEP-2	IEP-3*
Age of students	14 years	15 years	16-17 years
Number of students	59	50	19
Timeline agreed with the teacher	8 hours	8 hours	10 hours + field trip
Main modality	Workshop activities	Workshop activities	Workshop activities
Student output	- Report at the end of the activity - Drawings - Shared discussions - Pre and post-test - Questionnaire for students' perception of IEP The students prepared and orally presented a group work on the topics addressed during the different activities		- Use of local geological maps - Observation and drawing of rock and soil samples from the territory investigated (botanical garden "Pellegrini Ansaldi") - Shared discussions - Pre and post-test - questionnaire for students' perception of IEP - Creation of a poster presentation for the Apuan Alps Park: the students produced a poster summarising the topics covered, supplementing it with podcasts.

*It won the competition sponsored by the Apuan Alps Regional Park for the 2023/24 School Year

Realisation of activities and their challenges

After planning the chosen IEP with the teachers, one of us (IF) conducted the lessons and laboratory activities in the selected classes. During each lesson, the timing of the activities was recorded and notes were taken. Post-meeting observations, conducted in collaboration with the class teacher, formed the basis for reviewing, refuting and/or confirming the different paths taken.

The reading of short texts to be schematized through a drawing was systematically introduced to facilitate understanding of the content (Table 2). This strategy, namely the reworking of information through student-generated drawings, has proven particularly effective in promoting science learning, as emphasized by several studies (Chang et al., 2020; Düsing et al., 2019; Wang et al., 2023).

Laboratory activities were also carried out to actively engage students in the learning process. These activities, supported by the teacher and often organized in rotating pairs or small groups, took place in the classroom using easily accessible, everyday materials that required no special disposal procedures. Students had to fill in an observation sheet at the end of the activity.

Although the activities were generally feasible, their practical implementation entailed some problems, depending on the varying degrees of cooperation of the students and their willingness to engage. For example, sometimes chatting and moving chairs created a noisy environment. Moreover, most of the students did not complete the assigned homework, namely to answer a series of questions uploaded onto the class' online platform after each lesson. In agreement with the teacher, it was decided to substitute the homework with an observation sheet, developed in collaboration with her, to be completed during the class activities. This tool was proposed to the class, as it represents a key element of science education, reflecting an established and widely used practice in this field. Its value lies both in the ability to guide students' activities in the laboratory, facilitating the learning process, and in providing the teacher with a clear tool for communicating instructions, as highlighted by Tiberghien et al. (2001). Students were also asked to write down on the blackboard some key points, such as the materials used. The request to complete in the classroom the activity observation sheet proved useful also for keeping track of the progress of operations.

For the different operational research questions, different types of data were collected and analysed, as described in the following, with the methodologies and using the tools listed in Table 3.

Concepts emerging from students' output

Concepts emerging from students' outputs were analysed during IEP-2 activities. The first task was to read a short text describing the geological carbon cycle, illustrated by a diagram. The request was to identify the main processes and represent them graphically in an image accompanied by very brief captions.

These students' outputs were analysed by a group consisting of university researchers and upper secondary school teachers. For this purpose, a list of descriptors was created, organised in a spreadsheet, which each member of the group compiled individually. Our procedure for identifying descriptors was not imposed a priori on the data but emerged from a detailed analysis of the types of concepts that emerged (Grosslight et al., 1991). In the end, only those items on which all compilers agreed were considered (Bengtsson, 2016).

Pre- and post-tests for assessment of students' learning

The effectiveness of the three IEPs, covering Biology, Chemistry, and Geosciences, was evaluated through a pre/post-test consisting of 10 multiple-choice items, administered to the students before and after the instructional sequence. Each question included four response options, with only one correct answer. The test was reviewed and approved by the classroom teacher, who agreed to its delivery to the students.

The test related to IEP-2 is given as an example in Annexe 2. There, items 1, 3, and 5-10 were selected from the final chapters of textbooks commonly adopted in upper secondary school curricula. Items 2 and 4 were prepared for this work and underwent a process of revision to ensure:

- alignment with the learning objectives of the educational path;

- thematic relevance across the three disciplinary domains.

The results of the pre-post test were compared, and the significance of their differences was assessed with Wilcoxon's nonparametric test.

Questionnaire for students' perception of interdisciplinarity

To gain deeper insight into the perceived effectiveness of the three IEPs a self-assessment questionnaire was developed and administered to students upon completion of the educational activities. The instrument was designed to investigate key dimensions of the learning process, specifically its cognitive, relational, and metacognitive aspects (Annexe 3).

The questionnaire consisted of 19 statements, to which students responded using a six-point Likert scale, ranging from 0 (never) to 5 (always). The items addressed several areas, including:

- interest in the topics covered,
- perception of learning,
- organization of the work,
- group dynamics,
- interdisciplinary integration.

In this article we are considering only the students' perception of the interdisciplinary aspects.

All statements were initially formulated and later collaboratively reviewed with other researchers to ensure:

- clarity of expression,
- educational relevance,
- alignment with the pedagogical objectives of the project.

A final open-ended item allowed students to suggest improvements or modifications to the learning pathway.

The questionnaire was reviewed and approved by the subject teacher, who endorsed the objectives of the study and authorized the administration of the instrument within her classes.

Collection of teachers' reflections

At the end of the three IEPs, a structured reflection form was administered to the participating teacher in order to gather qualitative feedback on the instructional process, organizational strategies, and perceived strengths and weaknesses of the activity (Annexe 4).

The form included both closed and open-ended items addressing:

- classroom management approaches (whole-class, small-group, heterogeneous/homogeneous grouping);
- use of specific teaching materials and tools;
- alignment between the proposed content and the standard curriculum;
- student engagement indicators (interest, collaboration, group climate);
- appropriateness of the duration and complexity of activities;
- professional impressions and suggestions for improvement.

The goal was to collect qualitative evidence from the teacher, assessing both the professional impact of the experience and the overall effectiveness of the interdisciplinary pathway. Responses were analyzed to identify:

- enabling and limiting conditions;

- the replicability and scalability of the model;
- perceived effectiveness in teaching Earth sciences and related subjects.

TABLE 3

Types of data, collection tools and analysis methodologies for each operational research question

Operational research question	Type of data	Tools Used	Analysis Method
1. Which interdisciplinary concepts emerge from students' output?	Students' productions: students' artifacts and conceptual reworkings	Descriptor grid agreed upon by research team	Qualitative: emergent coding; concept frequency tracking
2. Does the approach used in the IEPs contribute to improving students' disciplinary learning?	Pre and post test administered in class before and after the IEPs	Closed-response questionnaire (administered pre/post)	Quantitative approach (Wilcoxon test) to assess the significance of the differences between the pre- and post- questionnaire
3. How do students' perceptions of their own active participation in teaching change?	Closed-response questionnaires and open reflection completed at the end after IEPs	Self-assessment sheet using 6-point Likert scale, 0 (never) to 5 (always), and open sentence.	Percentage: frequency of responses.
4. What elements emerge from the teachers' perspective?	Teachers' written reflections completed at the end of IEPs	Mixed format reflection form (open-ended + closed items)	Qualitative: analysis of responses

RESULTS

The results of this study are described following the operational research questions (Table 3).

ORQ1: Interdisciplinary concepts emerging from students' output

We evaluated the presence or absence of the main topics in the students' production during IEP2 activity. In the following we briefly listed them, reporting in parenthesis the percentage of students which included the topic in their drawing, Fig.1:

1. Volcanic activity contributes to CO_2 release (76%) and this geologic process has implications for chemistry and ecology.
2. In fact, atmospheric CO_2 contributes to the acidity of precipitation (32%).
3. The biological component emerges in carbon incorporated into the shells of marine organisms (12%) and sedimentation (4%).
4. The interaction between the atmosphere and hydrosphere emerges through the exchange of CO_2: transfer from the atmosphere to the hydrosphere is indicated (48%) and less frequently (12%) the reverse process.
5. Finally, the contribution of subduction to carbon recycling in the Earth's mantle, closing the geochemical cycle, emerges as 16%.
6. It is worth noting that students also introduced some elements not explicitly present in the material provided to them. Among the concepts that emerged, the name of solid phases of carbon (graphite, diamonds) or of the coal was reported by 8% of students. Moreover, even if photosynthesis was not explicitly named in the introductory lessons

on the geological carbon cycle, 33% of the students included it in the drawing. A significant aspect that emerged concerns CO_2 emissions due to human activities, indicated at a frequency of 50%.

ORQ2: Pre and post-test evidences of interdisciplinary learning

Pre and post-tests, for the three IEPs, show an increase in the number of correct student responses at the end of the IEP. In the 1st classes (14 years), the success rate increased from 37% to 47%. This difference is statistically significant. Wilcoxon's non-parametric test indicates that the null hypothesis, i.e., that the different activities performed are irrelevant to the results obtained in the post-activity test, can be rejected with an error probability of less than 1% (z-test score is -3.426, p-value is 0.0006 < 0.01).

The most pronounced increase is observed in the 2nd classes (15 years), where the percentage increases from 51% to 70%. Students in the 3rd-4th classes (ages 16-17) also show improved performance, with correct answers rising from 48% to 66%. Also, in these cases the significance of the improvement was assessed through the Wilcoxon test.

ORQ3: Students' perception of interdisciplinarity

In Table 4 the data provided represent an assessment of students' IEP in different classes and school years in relation to their ability to identify interdisciplinary connections, the impact on their knowledge, and the need to use skills acquired in other disciplines. In the 1st classes a small percentage (9%) of the students say that they have "always" identified interdisciplinary connections. This value increases significantly in the 2nd (16%) and 3rd-4th classes (25%), suggesting that more advanced students perceive better links between disciplines. As for the pathway's contribution to better understanding the topics covered in the different subjects involved in the 1st classes, 28% of students report that the course contributed "much" to understanding, with a peak of "enough" (37%). In the 2nd classes and in the 2nd biennium, the value of "much" and "always" is even more significant. For example, 42% for the 2nd biennium, indicating a greater impact for older students, and thus with greater awareness.

TABLE 4

Personal evaluation sheet of the student on the IEPs. Since filling in the tests and questionnaires was not compulsory, the numbers of answers do not coincide with the number of class members

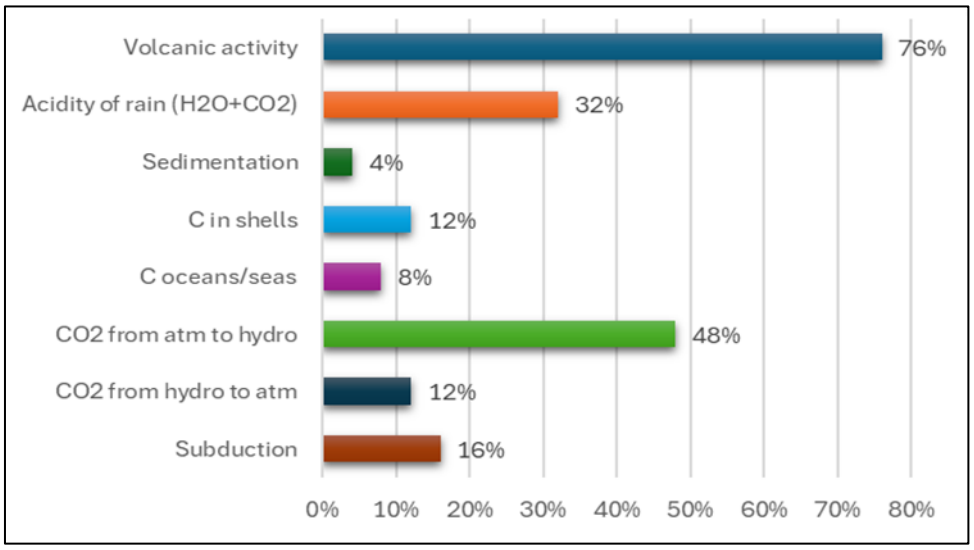
	I was able to identify connections among disciplines			The course helped me better understand the topics covered in the different subjects involved			To carry out the course, I had to use knowledge I had acquired in other disciplines		
Classes	1st	2nd	3rd-4th	1st	2nd	3rd-4th	1st	2nd	3rd-4th
Age	14-15	15-16	16-17 17-18	14-15	15-16	16-17 17-18	14-15	15-16	16-17 17-18
N	43	38	12	43	38	12	43	38	12
	%	%	%	%	%	%	%	%	%
Always	9	16	25	9	16	25	5	11	0

Much	23	32	50	28	21	42	24	26	25
Enough	37	48	25	37	45	25	38	45	58
A little	19	8	0	14	13	8	21	11	17
Very few	5	0	0	2	5	0	10	5	0
Never	7	0	0	9	0	0	2	3	0

ORQ4: Teachers' perspective

Three teachers were involved in the research project, and what emerged from the reflection sheets that the teachers filled in at the end of the IEPs represented useful qualitative results. The analysis of the teachers' reflection sheets indicated that the teacher retained that the approach adopted for the development of IEP-1 and IEP-2 fostered observation and inference skills in the students, enhancing group work with diversified returns. Dynamic and productive collaboration was stimulated, useful both for remedial schooling and for future in-depth study, as far as the first two paths are concerned. The possibility of more practical activities in the laboratory could further broaden the understanding of geological processes. Finally, the teachers retained that the approach adopted for the development of the IEP-3, the concept of geodiversity, approached with interactive methodologies, aroused curiosity and interest, offering interdisciplinary insights linking geosciences, biology and chemistry, demonstrating the importance of a global approach in understanding ecosystems.

FIGURE 1



Concepts emerged from students

DISCUSSION

As regards the students' output, we discuss here the results for the IEP-2, namely the interdisciplinary path about the carbon cycle.

In Figure 1 the predominance of the concept of "volcanic activity" (76%) indicates that this aspect related to the carbon cycle has been successfully identified by students. This may indicate a good understanding of geological interactions. The lower degree of identification of processes such as "sedimentation" (4%), "occurrence of carbon in oceans/seas" (8%) and "subduction" (16%) agrees with the lower visibility of these geological phenomena in our daily life, as well as in the background of the students' knowledge. It may request to deepen these themes through more targeted activities or with more effective teaching aids.

Some concepts emerge that are not included in the material received by the students. It is significant that over 50% of the students contribute ideas related to "anthropogenic carbon". This points to a good ability to link interdisciplinary concepts to current issues. The notable presence of the concept of "carbon from photosynthetic activity" (33.3%) confirms that students are spontaneously making connections with biology, whereas the percentages of "carbon in coal" and "graphite/diamonds" (both 8.3%) indicate curiosity and possibly connections to chemistry.

It may be useful to reflect on why some concepts have received less attention, in order to improve the interdisciplinary education path. A more varied teaching approach or exercises that stimulate wider reflection could be useful. Finally, the ability of students to propose new concepts shows that interdisciplinary pathways stimulate critical thinking and innovation.

In general, the overall positive results of the pre and post-tests underscores the effectiveness of the proposed interdisciplinary activities. As concerns students aged 14, the results show less improvement than the others. This could be related to the fact that a different approach from the one they are familiar with may initially require a period of adjustment, during which students become comfortable with the new tools. This can make progress less apparent. Younger students, in fact, might be less familiar with collaborative learning strategies compared to older students. In general, progress in the groups indicates that the interdisciplinary approach works well, but perhaps it would be useful to refine strategies to better involve students. Additional teaching support or more introductory activities for their level could be considered.

As can be seen from Table 4 regarding students' perceptions of interdisciplinary links, they recognize various levels of connection among subjects. A substantial percentage, on the other hand, claims to have found such connections "enough" or "much", indicating a positive impact of the path, but with margins for improvement to make these connections even more evident. The IEPs contributed to interdisciplinary understanding, stimulating integration with other subjects. Classes with older students benefited more from the course, demonstrating a better ability to identify and apply interdisciplinary connections.

This interdisciplinary method offers teachers the chance to engage with topics beyond their specialization and supports a broader understanding of knowledge.

Finally, the results of this experience revealed both the strengths and weaknesses of an interdisciplinary approach, highlighting how it can enrich the learning process and at the same time present challenges. On the one hand, interdisciplinarity helps students approach problems with different perspectives, broadening their view of reality. For teachers, it is an opportunity to explore topics beyond their own expertise. Therefore, the development of interdisciplinary skills through targeted training is essential. In general, it fosters a holistic understanding of knowledge. On the other hand, this type of approach requires that the teachers have a high level of competence and preparation (Watanabe & Huntley, 1998) while, at present, most of them are not trained to teach in an integrated manner (Shen et al., 2015; Sinelnikov & Zharkovskaya, 2018). Sound training is essential to avoid a superficial approach, which would undermine both the educational value of interdisciplinarity and the quality of Geosciences teaching. Teachers should develop interdisciplinary skills through targeted training courses to meet the challenges and enhance this method. However, the reported data support the implementation of IEPs and highlights two main benefits: 1) making learning more active by using experiences that help

students understand the value of the subject, to make links with other aspects of their knowledge and provide multiple perspectives (Bransford et al., 1994); and 2) the use of Geosciences enables the acquisition of knowledge useful for interpreting processes and issues, highlighting the discipline's contribution to finding solutions (Zoback, 2001). Their global importance and the essential role of geoscientists in contemporary society are fundamental (Gosselin et al., 2013).

It is important to be aware that there are relevant differences among Geosciences, Biology and Chemistry, both in methodological, historical and epistemological aspects, and that to respect the disciplinary specificities is essential to maintain the richness of each field of knowledge. Moreover, it presently appears hard to imagine a fully integrated curriculum, since no one is competent in everything. However, through a balanced approach, it is possible to plan and implement opportunities for interdisciplinary connections that enrich the natural science learning process.

DATA REPOSITORY

Annexes can be accessed at OSF repository: https://osf.io/x92dc/files/osfstorage/6888f32c213b3cda1323412a

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