Comparing inquiry-based and conventional science instructions in the Italian high schools

Confronto tra Inquiry-based Science Education ed insegnamento tradizionale delle Scienze in alcune scuole superiori italiane

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This study aims to evaluate if inquiry-based science education (IBSE) at the high school level allows the achievement of better learning objectives with respect to conventional science education (CSE). The findings would help to understand if, how, and why IBSE can be used as a successful teaching approach. The study included four high schools with different specialties, eight experienced science teachers and approximately 350 students, attending sixteen classes. Two biochemistry topics were taught by the same teacher in two classes. A two stage quasi-experimental, crossover design was adopted. The primary outcome compared the difference in the average pre-teaching and post-teaching test-scores, using a 3-multilevel analysis. On average, the outcome in terms of scores significantly improved by 4% with IBSE with respect to the CSE approach, demonstrating differences among the school specialties. In conclusion, our study indicates that IBSE is significantly more effective in enhancing skills.

Keywords: Teaching Methods Comparative study; Biochemistry education; Inquiry-based learning; Academic achievement; Hierarchical linear model.

Questo studio mira a valutare se l'approccio "Inquiry-based science education" (IBSE) consenta il raggiungimento di obiettivi di apprendimento, a livello di scuola superiore, in modo più efficace rispetto all'educazione scientifica convenzionale (CSE). I risultati possono aiutare a capire se, come e perché IBSE può essere utilizzato come approccio didattico di successo. Lo studio ha incluso quattro scuole superiori con diversi indirizzi, otto insegnanti di scienze con esperienza e circa 350 studenti, suddivisi in sedici classi. Due tematiche di biochimica sono state insegnate dallo stesso docente in due classi parallele. È stato adottato un disegno quasi sperimentale, crossover, a due fasi. Obiettivo primario è stato confrontare la differenza nei punteggi medi nei test prima e dopo le attività, utilizzando un'analisi gerarchica a 3 livelli. In media, il risultato in termini di punteggi è migliorato significativamente del 4% con IBSE rispetto all'approccio CSE, dimostrando differenze tra gli indirizzi scolastici. In conclusione, il nostro studio indica che IBSE è significativamente più efficace nel migliorare le competenze.

Parola chiave: Studio comparativo di metodi di insegnamento; Insegnamento della Biochimica; Apprendimento fondato sull'indagine; Rendimento scolastico; Modello lineare gerarchico.

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1. Introduction

The need for new active learning pedagogies is more urgent than ever, as the traditional approaches are not very effective with today's students (Osborne & Dillon, 2008). It has been suggested that instructional content needs to change to better prepare students to make connections between scientific concepts and the contexts in daily life (National Research Council, 2012).

Over the past few decades, inquiry-based science education (IBSE) is becoming one of the most prominent alternatives to traditional science education. A growing interest in IBSE was promoted by official European documents (e. g., Rocard, 2007; Strand et al., 2015). Furthermore, several European projects have been carried out (e. g., Fibonacci-project- Artigue et al., 2012; Ark of Inquiry-project – Pedaste et al., 2015). They aim to move the attention from "what" is learned to "how" it is learned, looking at different learning student-centered methods. Similar suggestions were also provided by the functional skills required in the OCSE-PISA surveys (Breakspear, 2012; OECD, 2013).

1.1. *IBSE and conceptual framework*

Inquiry-based learning comes from constructivist theories (Barrow, 2006). Its goals are to achieve a deep understanding of scientific content, while, at the same time, it makes students capable to be independent in their own research. The construction of knowledge occurs through active thinking of the learner (Cakir, 2008).

The conventional view of learning is the transmission model. The learner is like a container which information is passively transferred. Mostly, it is based on the lecture instruction. (Novak, 2010).

Inquiry-based learning/teaching has the following characteristics: (1) it is an instructional model aiming of addressing a particular problem or answering a central question by data analysis (Bell, Smetana & Binns, 2005); (2) it enhances students' abilities to reason, and to construct their own understanding through the reflection on their experiences, based on hands-on activities, focusing on both the contents and the processes of science (Bartos & Lederman, 2014); and (3) it simulates the work scientists conduct when performing research. In conclusion, inquiry-based science education (IBSE) shifts the focus on the acquisition of the skills and the higher levels of knowledge as defined in a constructivist educational approach.

Among several models of inquiry-based learning, one of the most successful is the 5 E learning cycle (Bybee, 2006). It includes the key elements of the inquiry-based learning. The model consists of five steps, called 5 E (Engage, Explore, Explain, Extend, Evaluate), in which the intuitive conceptions come out, including misconceptions that are difficult to be removed. Students have the opportunity to draw, to investigate, to make hands-on activities, to think about what they are doing and, finally, to learn correct scientific principles.

1.2. *Inquiry-based vs conventional science education*

Inquiry-based instruction has produced very encouraging results on both student cognitive and behavioral outcomes in science (Marshall, Smart & Alston, 2017). Among the advantages of using IBSE, it has been reported that a student's active involvement in the learning process enhances learning (Von Secker & Lissitz, 1999) and improves motivation and deeper knowledge (Minner, Levy & Century 2010). Moreover, active learning approaches, triggering the brain connections in the prefrontal cortex and moving memories from short-term to long-term, allow the acquiring of conceptual and metacognitive knowledge, crucial to replace misconceptions and to fix new knowledge (Csikszentmihalyi, 1990; Posner, Strike, Hewson & Gertzog, 1982). When the teacher shifts from passive strategies to more active learning pedagogies (Deters, 2005), students can achieve a higher order of cognitive skills (Tomperi, 2014).

On the other hand, the IBSE approach has been criticized because (1) it needs careful planning, measuring out and assessing cognitive load, without which it is less effective than a traditional approach (Sweller, 1988); (2) there is a narrowness of content that can be taught; and (3) the actual effectiveness is observed only when learners have sufficiently high prior knowledge that provide "internal" guidance (Kirschner, Sweller & Clark, 2006).

1.3. *IBSE in Italy*

The Programme for International Student Assessment (PISA) is a triennial international survey developed on the initiative of OECD and aimed to compare education systems worldwide through evaluation of the skills and knowledge of 15-year-old students. One of the most recent PISA survey, carried out in 2015 involving over half a million students 15-year-olds in 72 countries and economies, showed that Italian students' science literacy scores were lower than the OECD average, ranking 26th to 28th when only the OECD countries were considered and 32th to 36th for all the participant countries (Gurria, 2016). This justifies the need of high quality and modernization of education, particularly in the field of scientific education.

The Italian Ministry guidelines (DM 10/2015; DPR 87, 88, 89/2010), explicitly asked to move from teacher-centered to student-centered instruction. Teaching can be considered from two different complementary perspectives: i) the role of teachers as transmitters of knowledge providing the correct answer to the students and ii) the role of teachers as facilitators of the active student learning, that stimulates the development of problem-solving skills (Tammaro, Petrolicchio, & D'Alessio, 2017). The latter perspective and the Italian innovation in Education had its beginning in the mid-nineteenth century, but it was stopped by Gentile, Minister of Education in 1923, who was convinced that in teaching the contents of subjects were more effective than methodology. Due to several expressions of disagreement in the following years, actions were undertaken during the 20th century to add a professional touch to Education & Training (Betti, 2016).

There is a quali-quantitative correlation between the variable teaching and the variable learning, but in Italy this correlation is not considered by political decision makers (Domenici, 2019). Until the end of the nineties, in Italy, no training courses were planned for secondary school teachers. The legislative process led to the creation of the "Scuola di Specializzazione per l'Insegnamento Secondario" (SSIS), activated in the academic year 1999-2000 (over half a century later than in almost all European and OECD countries) and interrupted in 2009. Only from the academic year 2011-2012 a new training course named "Tirocinio Formativo Attivo (TFA)" was opened, but it was then changed again in the current system for initial teacher education called "Formazione Iniziale e Tirocinio (FIT)". At the present time, the proposed training path to become a teacher provides an annual initial training professional course, oriented to pedagogy, new methodology, and practical activities.

However, teaching has not yet changed in such a large extent in Italy (Berlinguer, 2008; Mayer, 2013), although many professional development programs have been activated and several teachers are known to move toward IBSE practice (Pascucci et al., 2013). There is a long road to actually innovate the school. Most teachers (OCSE TALIS, 2013) are still using traditional, didactic methods, as they are likely struggled with the shift to an approach that effectively make learners active builders of their knowledge (Anderson, 2002). Italian high school education objectively does not support the change since typically: (1) students have to manage with a large number of subjects, which are taught in lecture–based lessons, (2) each class includes a large number of students, so that teachers cannot look after their students in an effective way; (3) lab activities are not mandatory and a few number of students have the opportunity to learn by doing (it depends on the teacher's availability); (4) very few hours per week (from two in classic and modern languages classes, to three in scientific and technical) are dedicated to science programs, which is not enough for a solid science education by active learning approaches (the only exceptions are the "applied science" classes, that are few in numbers and not included in the sample of the current study).

Other than for these features, the Italian educational model, in the field of high school education, substantially differs from the Anglo-Saxon one. Peculiarities mainly regard: (1) duration of course (five years instead of four); (2) class structure (each class attends the same courses); (3) compulsory curricula (teachers cannot make variations); and (4) summative assessments (based on open questions or essays).

Finally, Italian educational system, concerning the secondary school, still suffers from the overly theoretical training of future teachers that substantially equates pedagogy of philosophy and experimental pedagogical research (Mayer, 2013). In addition, although educational research is crucial to develop proficient teacher training (Eurydice report, 2016), pedagogical research in the field of experimental science has almost completely disappeared from Italian Universities. The new system of initial training of the secondary school teachers, involves the universities in a challenge (Margiotta, 2019). Unfortunately, the worrying fracture among the three functions, teaching, research and innovation is the reason of the substantial absence of pedagogical research particularly in the field of experimental science. Indeed, in the Italian University system, "Science Education" is recognized as an independent discipline only for what concerns Mathematics and Physics, not for Natural Sciences, unlike in other countries.

Although inquiry-based learning cannot be considered a recent orientation in pedagogy, it still represents a challenge in Italy, because of all the Italian peculiarities. In these conditions, on the one hand our efforts should be addressed towards an education that is globally oriented, on the other hand they must take into account cultural differences concerning science education in each country (Rundgren, 2016). In several countries there are Ministerial recommendations in order to use student-centered methods in STEM such as the IBSE. Nevertheless, these methods do not actually take place. IBSE approach was introduced by law in France only for primary education; its practice is an experimental phase in other countries and in other levels and types of education. Various compared studies about science education in several countries demonstrated that the implementation of science inquiry is affected by some factors, such as curriculum, assessment, policy and teacher professional systems (Heinz et al., 2016). Every exploratory study could be helpful for collecting data and developing a common framework on IBSE, which took into consideration the specific features of each country. Then, although previous studies already offered evidence that inquiry-based learning improves educational efficacy of science in other countries (Abd-El-Khalick et al., 2004), we would verify if these results might be reproduced in Italy. It is important to outline that a real emergency in science education exists in Italy and this justifies the need of this study.

1.4. *Research focus*

The current study stems from an increasing interest in IBSE in Europe, while the use is still limited in Italy. The main goal was to measure and compare the effects of IBSE and conventional science education (CSE) on students' school achievement in four types of Italian high schools. Heterogeneity of these effects was explored among the students.

We expect that the results of the current study will contribute to the understanding if and how the IBSE approach affects scientific learning in the Italian setting. The results will serve as a means to make recommendations about IBSE and its impact on students' overall learning. These recommendations will contribute to define the basic aspects for using inquiry-based learning as a regular part of the classroom experience.

2. Materials and Methods

The current study involves quantitative methods to investigate the impact of the IBSE on students' academic success. According to similar comparative studies (Anderson, Mitchell & Osgood, 2005; Osman & Kaur, 2014), a quasi-experimental plan (i.e., a within student quasi-crossover design) and mixed hierarchical models were used (Maxwell, Mergendoller & Bellisimo, 2005; Tsai & Yang, 2015).

2.1. *Participants*

The study was designed on a hierarchical basis involving four high schools, eight teachers, sixteen classes and 358 students who were from 16 to 19 years old during the investigation period (2015/2016).

Teacher	Age	Gender	Years of experience teaching	Type of school at	Years of experience with IBSE	High School**
1*	59	F	> 30	classic	1-2	A (urban school)
2	55	F	> 30	classic	1-2	A (urban school)
3	46	M	20-30	classic and linguistic	1-2	B (urban school)
4*	56	F	20-30	linguistic	1-2	C (suburban school)
5	50	F	20-30	scientific	1-2	C (suburban school)
6	53	F	> 30	scientific	<1	C (suburban school)
7*	58	F	> 30	scientific	1-2	B (urban school)
8*	48	F	10-20	technical	> 3	D (small-town school)

Tab 1: Teacher Participants
Note: * member of ANISN (Associazione nazionale Insegnanti di Scienze Naturali)
**The four high schools involved in the project: A (only classic classes), B (classic, scientific and linguistic classes), C (scientific and linguistic classes), D (technical education).

Firstly, the teaching staff has been identified in order to apply the research design. Selection was based on the criteria of professionalism and practice acquired in the new methodology during specialized courses for which the complete program can be downloaded from the AmgenTeach website: http://www.amgenteach.eu/italy. The teaching staff voluntarily participated to the study, stimulated by a personal interest. Table 1 describes the characteristic of the teachers.

During these courses (25 hours), the teachers learned the basics of this innovative approach and experimented the methodology in a simulation of some modular activities. In addition, after the teacher selection the two new topics and the grade of the involved students were defined during an organizational meeting including teachers and researchers. Teachers agreed to teach in two parallel classes of the third, fourth or fifth year (i. e. 10th, 11th or 12th grade) of classic, scientific, linguistic (studies of modern languages) or technical Italian high schools.

During the IBSE implementation, the teachers were asked to apply what they learned about the IBSE approach through the new topics. On the other hand, the traditional curriculum regarding the two topics had been predefined by the Italian Ministerial program (M.I.U.R., 2015) and by the textbook adopted in the class (Sadava et al., 2015).

The four types of high schools have different specialization and curricula. Anyway, sciences are a common subject to all high schools and it is studied for all five years.

2.2. *Teaching Topics and approaches*

Each of the eight teachers was asked to teach two topics of biochemistry to the students of the two classes at which he/she was assigned (February/March 2016). The biochemistry teaching topics, inspired by the materials from the College Board and Cambridge Resources for the A and AS Level (AP® BIOLOGY, 2015; Bradfield et al., 2014), were guided by the following questions: How do enzymes work? Which are healthy fats?

Conventional teaching approach (CSE) was firstly used within each involved class according to the transmission model of education: lecture-based lessons, structured according to the sequence of chapters in the textbook, the use of the test-book, and formative assessments based on oral examination. Students are expected to read the textbook after lectures.

On the other hand, the inquiry activities (IBSE), given during the equivalent class time, were designed to challenge the critical thinking skills and, at the same time, to evoke the scientific processes of data discovery, data analysis, inference making, and hypothesis testing, so simulating what scientists do in their research (National Research Council, 2012; 2015). The activities were developed using the 5 E-learning cycle model (Bybee et al., 2006) and a mixed guided/structured level of inquiry (Bell et al., 2005). Learners think individually, then work in teams on the same inquiry problem, and then proceed with inquiry learning processes, sharing ideas and articulating their thoughts. They communicate to the whole class their hypothesis and research project, engaging in classroom discourse. Finally, they can realize their experimental project in the laboratory and then reflect on collected data.

For each IBSE activity, the teachers received the two lesson plans including objectives, cognitive and transversal skills, and also additional supporting information, such as notes for instructors and actual student handouts.

2.3. *Experimental design*

A two stage quasi-experimental, quasi-crossover design was adopted (Figure 1). At stage 1, each teacher used the CSE approach for teaching one biochemistry topic (e. g., "enzymes") to one of the two classes and the other topic (e. g., "fats") to the other class. At stage 2, the teacher used the IBSE approach, switching the topic between classes. As each student received both teaching approaches by the same teacher, the design allows comparison within-student performance of IBSE and CSE, thus taking into account heterogeneity sources of both teachers and students. Moreover, as both topics were taught with both teaching approaches, the design also allows comparison between topic performance of IBSE and CSE.

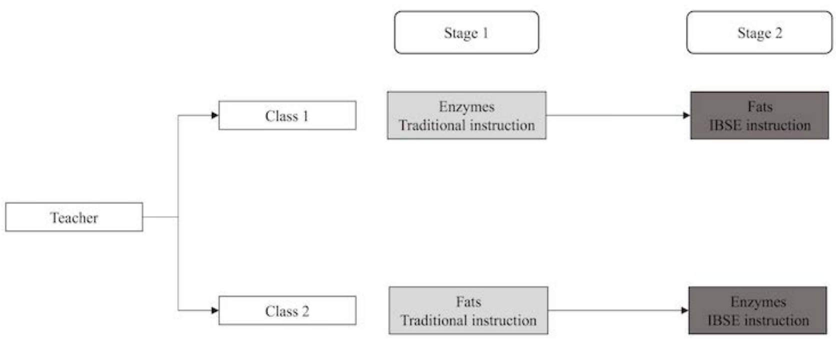


Fig 1: Synthetic flow of the study's design

2.4. *Carrying out the experiment*

After development of the CSE topic and before starting the IBSE one, students were given the opportunity to experience the new approach during an interactive seminar. This activity highlighted the methods of IBSE implementation to students who are accustomed only to lecture-based lessons.

Furthermore, a set of tools to measure student learning was developed and checked by some independent experienced teachers not involved in the project.

At the end of implementation of each topic, lasting six hours of class time, students were evaluated using the same summative assessment tools, by means of multiple-choice tests. The latter measured current knowledge in facts and concepts as well as reasoning and critical thinking skills. The framework of the assessment tools was provided in the textbooks used by the students (Sadava, et al., 2015).

This textbook suggests two different sectors of assessment, knowledge and abilities. According to this setting, the tests consisted of 34 multiple-choice questions, organized in two sections (knowledge and abilities) assessing different categories of learning, according to the latest Ministry guidelines (DM 10/2015; DPR 87, 88, 89/2010). Each item was defined according to the measured skill, in agreement with the revision of Bloom's Taxonomy (Krathwohl, 2002) as i) knowledge (low order thinking skills - LOTS -, such as remembering, understanding) and ii) ability (high order thinking skills - HOTS -, such as applying, analyzing, evaluating, creating). As there are not standardized tests in Italy, this test was developed by one of the authors and validated by independent experienced teachers absolutely not involved in the research project. Evaluating tests were submitted before starting the teaching experience (pre-teaching), and at the end (post-teaching) of each unit using the same assessment tools.

2.5. *Data collection and statistical issues*

A database was developed with relevant issues for each participating student. Fields of interest were: gender, kind of school attended (categorized as classic, scientific, linguistic and technical classes), grade (third, fourth or fifth year), marks in mid-term school report, and pretest and post-test scores obtained for each taught topic. The latter was used for computing the difference in the average pre-teaching and post-teaching scores obtained with IBSE and CSE approaches (i. e., the primary outcome of interest). Within the database, an identification code was assigned to each student by the teacher, so that the data analyst was blinded about student identities.

Among the 358 students included in the survey, 12 were eliminated because of their severe disabilities (4 students) or because they did not take either the pre-teaching nor the post-teaching test. The remaining 346 students, who were tested, showed the selected characteristics described in Table 2.

The sample size is justified for the primary outcome. Based on simulation tests, we found that a sample size of about 350 students would give a 77% chance of detecting a significant (one-sided 5% first-type error tolerated) gain of post-teaching from 0.20 (CSE) to 0.24 (IBSE). Means (and standard deviations, SD), t-test and its version for paired data were used where appropriate for univariate comparisons.

In order to take into account the multilevel data structure (i. e. students nested within classes and classes nested within teachers), a hierarchical linear regression model (Fitzmaurice, 2012) was fitted to estimate the effect of IBSE approach (Schwartz-Bloom & Halpin, 2003). The model is suitable when data is organized at more than one level because the random effects incorporated at each level provide the statistical dependency in the data. The levels in our setting were: (1) individual, (2) class and (3) teacher.

Adjustments were made for the above reported factors. Moreover, data were analyzed in order to evaluate the association between IBSE approach and the gain of knowledge and abilities scores according to the kind of school attended.

	N (%)
Gender	
Females	184 (53.2 %)
Males	162 (46.8 %)
Grade	
III (16-17 years old)	49 (14.1 %)
IV (17-18 years old)	31 (9.0 %)
V (18-19 years old)	266 (76.9 %)
High school type	
Classic academic high school	118 (34.1 %)
Linguistic academic high school	54 (15.6 %)
Scientific academic high school	143 (41.3 %)
Technical education	31 (9.0 %)
Marks in mid-term school report[a] mean (SD)	6.38 (1.25)
Disabilities	
Physical disabilities	2 (0.6 %)
Learning disorders	1 (0.3 %)
Dyslexia	3 (0.9 %)
Special educational needs	1 (0.3 %)
None	339 (97.9 %)

a) Score ranking from 1 to 10

Tab 2: Characteristics of the study sample

All analyses were performed using the Statistical Analysis System Software (version 9. 4; SAS Institute, Cary, NC; www. sas. com/en_gb/home. html). For all hypotheses tested, two-tailed p-values less than 0. 05 were considered to be significant.

3. Results and Discussion

Results from fitting hierarchical linear model are shown in Table 3.

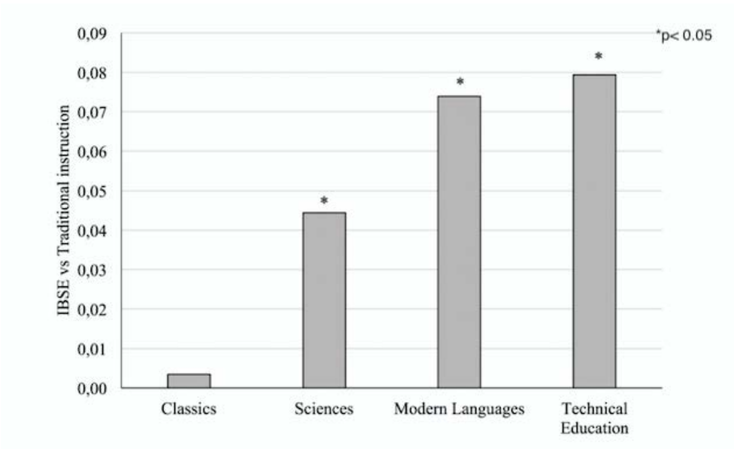
Consistently with others (Grabau & Xin Ma, 2017), a significant effect of IBSE was observed with an additional 4% gain than CSE. These results rise 7% and 8% respectively in scientific and linguistic classes. Among the other considered factors, only the type of high school significantly affected the gain in learning, since classic students have better performance than others. Gender was not a significant predictor of enhanced learning gains.

Intriguingly, the type of high school moderated the effect of the teaching approach in the improvement of learning. The smallest learning gain by IBSE was shown in the classic high school (0.4%); larger gains were achieved by students attending scientific (4%), linguistic (7%) and even more technical (8%) high schools (Graf.1). This finding is likely due to differences in baseline characteristics. For example, students attending classic high school are selected to be excellent in primary and middle schools, and already have the skills of deep study habits. Conversely, students attending other high schools usually are less well equipped to memorize content and learn concepts from a textbook.

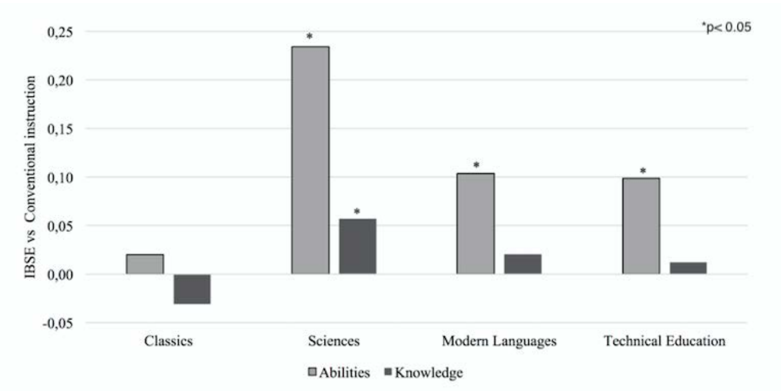
Effects	Estimate	P-value
Teaching approach		
CSE (reference)	0.00	<0.01
IBSE	0.04	
Topic		
Enzymes (reference)	0.00	0.53
Fats	0.01	
Marks in mid-term school report [a]	0.00	0.89
Gender		
Female (reference)	0.00	0.12
Male	-0.02	
High school type		
Scientific (reference)	0.00	
Classic	0.14	<0.01
Linguistic	0.05	0.23
Technical	-0.03	0.54

Tab 3. Effect of IBSE and other factors on the gain estimated by a hierarchical linear model

Graf. 2 shows that (1) IBSE better improved ability scores than knowledge scores among the students attending all the considered high schools; (2) knowledge scores were significantly improved by IBSE approach only among students attending the scientific high school; (3) abilities scores were significantly improved by IBSE approach among students attending scientific (23%), linguistic (10%) and technical (10%) high schools; (4) there was no evidence that the students attending classic high school had improved their knowledge with the IBSE approach more than with the CSE one; in addition they had no significant improvement in their abilities. These findings then confirm that the distinctive learning style for students attending classic schools, as well as their higher pre-teaching scores, limit the possibility of further improvement by modifying the teaching approach. Conversely, concept application, investigation and problem solving, i. e., the focus of IBSE learning, were better appropriate to students attending scientific, linguistic and technical classes. This latter finding is confirmed by previous studies (Bredderman, 1983; Shymansky, Kyle & Alport, 1983) that pointed out that IBSE was more effective on developing science process skills than on developing science content; in addition, the older the students the less the effectiveness is implemented.

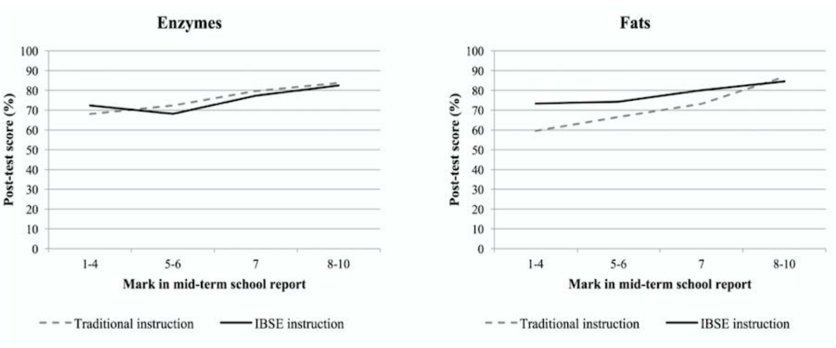


Graf 1: Effect of IBSE on the gain according to the kind of school attended



Graf. 2: Effect of IBSE on the knowledge and the abilities gain according to the kind of school attended.

Finally, in agreement with previous studies (Freeman et al., 2014), Graf. 3 offers further evidence that the IBSE approach had better post-teaching performance among students with less academic achievement (i. e., those who had lower scores in mid-term school report) mostly for the fats topic. In all the other settings, there was no evidence of differences between IBSE and CSE approaches.



Graf. 3: Comparing IBSE and CSE post-teaching scores along categories of mark in the mid-term school report for enzymes and fats topics.

This study has a number of potential limitations. Some of them derived from the fact that it was not designed as a true crossover. In fact, reasons related to school organization, made impossible to start the experiment by randomly assigning the exposure of interest (i. e., the teaching approach with CSE or IBSE) to each of the eight teachers, each involved twice. Rather, statistical units (students) differing by which of the two compared topics (enzymes or fats) were assigned first, always starting with CSE. In these conditions, we cannot exclude that the imposed sequence partially influenced the final results. For example, better performance might be systematically obtained at starting biochemical teaching, due to high enthusiasm and expectations by the students. If this was true, an underestimation of the IBSE effect with respect to CSE could have been obtained. On the other hand, students might give underperformances in IBSE approach, due to the traditional context where they are included.

Furthermore, we need to consider that in the Italian schools and especially in the kind of schools involved in the project, the usual tool of assessment is represented by oral examination and short open questions. The students are not familiar with multiple choice testing. This is also new for the CSE approach. Indeed, the ability of students to complete tests has little impact on the comparison.

4. Conclusion

The results of this study contribute to the understanding of the impact by the IBSE approach in the Italian model of schooling, which has some insights that deserve to be considered in the education context.

Results from this study indicate that the use of IBSE had an overall positive effect on students'learning, with considerable differences among groups.

On average, the use of IBSE significantly improved scores with respect to those achieved under the CSE approach, but with differences among the school specialties. Better performance in skills than in knowledge was also obtained by IBSE with respect to the CSE approach. These results are confirmed by previous research on IBSE, which has been implemented and evaluated across many different settings and with different populations, producing varied outcomes in regard to its effectiveness (Minner et al., 2010). In the review by Minner et al. (2010) it is reported that out of 138 inquiry analyzed studies, 71 had a positive impact, in terms of improved student learning. Actually, in our study, the quantitative analysis showed a significant increase in the students' learning associated with the IBSE approach. The hierarchical model allowed for the consideration of teachers, classes, students and approaches when the data was processed. The comparison gave us the opportunity to investigate and to identify the factors that contributed to the efficacy of each approach.

The students' scores improved significantly as a result of increased performance on questions requiring higher-order thinking, particularly among students attending technical (gain = 8%), linguistic (gain = 7%) and scientific (gain = 4%) high schools, as well as for students with histories of scholastic failure. This result is a confirmation of the positive impact of IBSE on students from disadvantaged backgrounds and supports work previously performed by other researchers (Anderson et al., 2005, Freeman et al., 2014). The role of IBSE as a facilitating agent for improving achievement, and as scaffolding for low performing students is demonstrated by its major efficacy in classes (technical, linguistic) that have a greater number of these kinds of students.

Indeed, type of high school and scholastic history, might be connected. In the Italian school context, those who attend classic classes are usually higher performing students, because of individual socio-economic background; they are less sensitive to the effects of IBSE approach in learning biochemistry topics, because they are also very successful under the CSE approach.

Undoubtedly there are many variables that were not considered in this study, which may potentially influence students' growth and improvement. A validated questionnaire, on students' perceptions and teachers' interviews, was administered. The responses, that show a clear student's preference for IBSE approach, will be presented in a future publication.

Our findings focus on issues that can help educators identifying strategies to better support and scaffold student reasoning; it is well known that there are many ways to learn and each student needs to find the approach that works better for himself. Helping students to improve their skills remains a challenge nearly everywhere and there are no easy answers.

Furthermore, in the sample of this study, most of the students attended the last year of high school (18-19 years old). This was one of the first applications of IBSE directly to high schools in Italy, in order to obtain a more rapid effect on the generation of students ready to attend University. It could be a model for other countries with similar conditions, where CSE is the prominent way to teach/learn and an experimental approach to IBSE would be required.

It is already known that Italian high-school is quite different from the Anglo-Saxon model for three significant reasons related to the duration of courses, the blocked composition of the class groups, that creates a prevalence of the group dynamics on the individual values, and the legal value of diploma, that is the legal constraint to the curricula approach. This study represents the first-generation of this kind of work in Italy, where the context is not favorable to this new learning approach, while traditional lecturing is widespread. Future studies should be conducted to understand the factors that inhibit change in pedagogy and content in science education, and how to meet the challenges.

We hope that these findings, when combined with the unstudied factors, propose insights for extending and deepening our understanding of what can and cannot be achieved by IBSE in order to design better environments and strategies that can work to enhance learning for all students.

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