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The long-term effects of introducing the 5E model of instruction on students' conceptual learning

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ABSTRACT

The effectiveness of the 5E model has been supported by research in schools in recent years, although its efficacy has rarely been assessed in the long term to avoid novelty effects and to consider the impact of the usual loss of fidelity that time entails. This study was designed to assess the long-term effects on students' conceptual learning as a consequence of an intervention that introduced the 5E model to their teachers five years earlier. Two questionnaires measuring the prevalence of alternative conceptions about the kinetic-molecular theory were performed over a five-year interval (pre-test in 2014 and post-test in 2019). 725 students participated, 371 in pre-test and 354 in post-test. In schools where the 5E model was introduced, statistically significant differences were observed in the percentage of correct answers between the pre- and post-test in both grades (p = 0.003 and 0.0028, respectively), with Cohen's d = 0.427 and 0.439, respectively, indicating a relevant effect size, while in control schools no statistically significant differences were reported in either grade. These results provide strong evidence regarding the long-term sustainability of interventions aiming to change teachers' practices in favor of active learning methods such as the 5E model and their positive effects on students' conceptual learning.

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Introduction

The concern over the prevalence and persistence of students' alternative conceptions has a long-standing history in science education. Research pioneered more than 40 years ago by the educational researcher Rosalind Driver laid the groundwork for hundreds of studies on students' ideas of major concepts in many scientific disciplines (Driver, 1985; Driver & Easley, 1978). A large body of research has examined students' alternative conceptions in a variety of areas in the sciences (Duit, 2009).

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Alternative conceptions have their origins in a diverse set of personal experiences, including direct observation, peer culture, and language, as well as in teachers' explanations and instructional materials (Coley & Tanner, 2012). These ideas are firmly entrenched and difficult to dispel with conventional teaching strategies (Wandersee et al., 1994). However, instructional approaches that facilitate conceptual change can be effective classroom tools (Duit & Treagust, 2003, 2012; Wandersee et al., 1994). When students hold alternative conceptions related to their educational objectives, learning requires triggering a conceptual change as learners' conceptual structures must be fundamentally restructured in order to allow them to understand the intended knowledge, that is, to acquire scientific concepts (diSessa, 1988, 1993, 2008; Smith et al., 1994; Vosniadou, 2012).

The broad consensus among researchers in the education field is that in order to promote conceptual change individuals should not be thought of as passive recipients of information during instruction, but rather as active learners that construct their own knowledge. In other words, for conceptual change to occur, students need to engage in active learning (Duit & Treagust, 2003, 2012; Posner et al., 1982; Scott et al., 1992; Vosniadou et al., 2001).

Over the last three decades, a great number of academic publications have focused on the subject of active learning, with strong evidence to support its benefits in leading to more meaningful learning (Felder & Brent, 2009; Freeman et al., 2014; Hsieh, 2013; Prince, 2004). Active learning can be defined as any instructional method that cognitively engages students in the learning process. In other words, this type of learning leads students to do activities which require them to think about what they are doing. Active learning is the opposite of passive learning, where students do not actively engage in the learning process. Students may nevertheless absorb some of the information presented during passive learning, usually without grasping its meaning. Examples of passive learning include attending a lecture, reading a textbook, or watching a video. All these activities could be active experiences, but they too easily become passive activities that require minimal thinking by students. Therefore, students should do more than just listening or reading. They need to be engaged in thinking about the information they receive. Research has shown that students learn more when they are exposed to active learning methods, which means that they are actively engaged in obtaining, sharing, discussing, creating, and applying knowledge, and when students use higher order thinking such as analysis, synthesis, reflection, and evaluation (Freeman et al., 2014; Hsieh, 2013; Mueller et al., 2015).

However, implementing active learning in the classroom is not an easy mission, especially when teachers do not have prior experience with this type of instructional approach. In order to be successful, teachers need specific training, clear guidelines, and comprehensive resources with specific, thoroughly designed activities to engage students in developing meaning (Auster & Wylie, 2006).

In science education, instructional models such as Atkin and Karplus Learning Cycle and the Science Curriculum Improvement Study (SCIS) Learning Cycle have consistently proved useful to help teachers change their conventional instructional methods to more active educational approaches (Abraham & Renner, 1986; Marek, 2009; Marek et al., 1990; Marfilinda & Indrawati, 2019; Scolavino, 2002). Among these systematic teaching approaches, the 5E model, developed in 1987 by the Biological Sciences Curriculum

Study (BSCS), is likely the most widespread and ubiquitous model (Bybee, 2015; Bybee et al., 2006; Duran & Duran, 2004). This approach builds on the work of other instructional models and its design is based upon sound cognitive science research (Bybee, 2015; Bybee et al., 2006). The model consists of five phases: engagement, exploration, explanation, elaboration, and evaluation (Table 1). Each phase has a specific function and contributes to helping the teacher provide coherent instruction and to the learner formulating a better understanding of scientific knowledge, attitudes, and skills. According to its creators, the five phases of the BSCS 5E Instructional Model are designed to facilitate the process of conceptual change (Bybee, 2015; Bybee et al., 2006).

Several connections can be made between the 5E Model of Instruction and the research literature on active learning (and conceptual change) which explain how this model helps learners to actively construct their own knowledge.

Firstly, in the *Engage* stage the teacher introduces a problem or a discrepant event in a familiar context that students cannot explain with their current ideas because it does not fit with their preconceptions. As a result of this, a cognitive conflict (which plays a relevant role in most theories of conceptual change, as stated by Duit et al., 2008) occurs. This conflict provides an opportunity to activate and elicit the students' prior knowledge and reveal their alternative conceptions. Research has found that encouraging students to recall relevant knowledge from previous courses or their own lives can facilitate the integration of new material (Peeck et al., 1982; Woloshyn et al., 1994). However, students may not spontaneously bring their prior knowledge to bear on new learning situations. Therefore, it is important to provide opportunities for students to activate their prior knowledge so they can build on it productively (Bransford & Johnson, 1972; Dooling & Lachman, 1971).

The *Engage* stage also plays a significant role in promoting student motivation, which is another key factor for achieving conceptual change (Pintrich et al., 1993; Sinatra & Pintrich, 2003). Specifically, the initial situation provides two kinds of engagement: a contextual engagement, which is based on the fact that students appreciate the real-life

Table 1. Description of the phases of the 5E model (from Bybee et al., 2006).

Phase	Description
Engage	The teacher or a curriculum task accesses the learners' prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organise students' thinking toward the learning outcomes of current activities.
Explore	Exploration experiences provide students with a common base of activities within which current concepts (i.e. alternative conceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation.
Explain	The explanation phase focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Learners explain their understanding of the concept. An explanation from the teacher or the curriculum may guide them toward a deeper understanding, which is a critical part of this phase.
Elaborate	Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities.
Evaluate	The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives.

implications of the posed situation (i.e. they recognise its instrumental value, as defined by Wigfield & Eccles, 2000), and a cognitive engagement, which is grounded in the curiosity that often arises when the students realise that their current ideas cannot satisfactorily explain an observation that puzzles them, which is a consequence of the cognitive conflict (Kang et al., 2004; Posner et al., 1982).

Secondly, the *Explore* stage consists of a guided inquiry activity that provides opportunities for students to address alternative conceptions and build new explanations that make sense to them (intelligible and plausible explanations, as suggested by Posner et al., 1982). In this activity, students investigate phenomena, discuss ideas, and make connections. The teacher becomes a facilitator who listens, observes, and guides students to their understanding. In this stage, which can be accomplished with the whole group or in small groups, the teachers' role is to make sure students help one another solve problems by building on each other's knowledge, by asking questions to clarify explanations, and by suggesting avenues that would move the group toward its goal (Brown & Campione, 1994). Both cooperation in problem solving (Newstead & Evans, 1995) and argumentation (Youniss & Damon, 1992) among students enhance cognitive development. Finally, the *Explore* stage provides students with opportunities to grapple with specific information relevant to the learning objectives, which is known to create a 'time for telling' that enables them to learn much more from an organised explanation which is given in the next stage (Schwartz & Bransford, 1998).

Thirdly, the concepts explored in the *Explore* stage are formalised in the *Explain* stage. This phase provides opportunities for teachers or the curriculum to directly and formally introduce those concepts and help students organise their new knowledge in ways that facilitate encoding and later retrieval. The way in which students organise knowledge influences how they learn and apply what they know (Ambrose et al., 2010). Research shows that when students are provided with an organisational structure in which to fit new knowledge, they learn more effectively and efficiently than when they are left to deduce this conceptual structure for themselves (Ausubel, 1960, 1978; Bower et al., 1969).

Fourthly, the *Elaborate* stage includes activities that require students to apply the concepts they have learned to solve new problems in new contexts. Here the new concepts prove to be 'fruitful', as Posner's model suggests. The activities in the *Elaborate* stage provide opportunities for students to transfer their new knowledge to a wide diversity of contexts. Exposing students to multiple contexts promotes deeper understanding since they are more likely to abstract the relevant features of concepts and to develop a flexible representation of knowledge (Gentner et al., 1993; Gick & Holyoak, 1983). Extended practice is essential if something new is to be learned, especially if the goal is for that new knowledge to be retained over time and transferred to new contexts (Healy et al., 1993; Martin et al., 2007).

Finally, in the *Evaluate* stage the knowledge acquired by each individual student is assessed through an activity that challenges their understanding. Measures of transfer play an important role in assessing the quality of students' learning experiences. Different kinds of learning experiences can look equivalent when tests of learning focus solely on remembering, but they can look quite different when tests of transfer are used (NRC, 2000).

The effectiveness of the 5E model has been supported by research conducted in schools in recent years. Different studies report evidence of a better conceptual understanding of scientific ideas and models, positive effects on general achievement in science, gains in students' self-expressed interest and confidence in science and in scientific careers, and positive attitudes toward science (Bybee, 2015; Bybee et al., 2006; Cardak et al., 2008; Hokkanen, 2011; Kilavuz, 2005). In addition, several studies have reported that the 5E model is superior compared to conventional methods in facilitating a conceptual change in understanding scientific concepts such as photosynthesis (Balci et al., 2006), states of matter and solubility (Ceylan & Geban, 2009), work, power, and energy (Hirça et al., 2011), heat and temperature (Turgut & Gürbüz, 2011), and force and motion (Feyzioğlu et al., 2012), among others.

However, most of this research has focused on short interventions followed by immediate testing and has not analyzed the long-term effects and sustainability. On the one hand, short interventions cannot dismiss novelty effects or even the Hawthorne effect (Paradis & Sutkin, 2017), so we cannot simply assume that the methods will have a long-term effect. On the other hand, one of the main problems of transferring research results into real settings is the loss of fidelity that the actual implementation of the evidence-based methods usually experiences with time, eventually making its effectiveness decrease or even disappear (Dede et al., 2005). Therefore, the evaluation of the long-term effects of interventions aiming to change teacher practices is of great interest for science education.

In this context, this study was designed to analyze the effects on students' conceptual learning five years after an intervention introduced their science teachers to the 5E Model of Instruction. The effect on student outcomes was measured as the decrease of the prevalence of students' alternative conceptions (in particular, concerning the kinetic-molecular model), with the experimental groups being compared to control groups where teachers did not learn about the 5E Model of Instruction and continued using conventional strategies focused on content delivery with standard textbooks as the main curriculum resource.

Methodology

Research questions

This study aims to answer the following questions: Can an intervention aiming to introduce an active learning methodology (the 5E Model of Instruction) be sustained and show a positive effect on the conceptual learning of students, in comparison to more conventional methodologies, when comparisons are made five years after the intervention was introduced to teachers? Is the 5E model more effective than conventional methods without the advantage of novelty? Is the effect of the 5E model on students' conceptual learning outcomes sustained a year after students received instruction for the last time (on a specific topic)?

Participants

The study included students in the 3rd and 4th year of secondary education (equivalent to 9th and 10th grade in the K-12 grade nomenclature) from four non-religious charter schools in Barcelona, Catalonia (Spain) which serve students with similar demographic characteristics. Two schools (1 and 2) were assigned to the experimental group, and the other two (3 and 4) were assigned to the control group. We compared the performance of the students who attended secondary school in 2014 (pre-test) versus the students who finished the school year in 2019 (post-test), which results in a 5-year interval between pre- and post-test.

All the teachers in the experimental group in the four levels of secondary education were involved in the intervention introducing the 5E model. On the other hand, none of the teachers in the control group received training in this regard and they continued to apply conventional methods for the entire experimental period. At the time of the pre-test (2014) (before the 5E model was implemented), none of the teachers involved in the study or their colleagues had applied active learning before in their classes. In the 5 years that elapsed between the pre-test and the post-test there were no reported changes to the teaching staff in the experimental or control groups.

Intervention

During the pre-test (2014), all students in the 3rd and 4th year in both the experimental and control groups answered the questionnaire on the kinetic-molecular model. After the pre-test (2014), each science teacher in the experimental schools received a two-hour training session on the 5E Model of Instruction. In this session teachers were presented with the basic paradigm of conceptual change and they learned how the 5E model helps in triggering conceptual change. Also, the types of activities in which teachers and students engage in each stage of the model were particularly highlighted. More importantly, teachers and students were also supplied with a curriculum resource fully based on the 5E model developed by the International Science Teaching Foundation (London, UK): Science Bits. This resource replaced traditional textbooks in the experimental schools that implemented the active learning model (schools 1 and 2) not only for the topic analyzed in this research (the kinetic-molecular model) but also for the entire syllabus. The 5E curriculum resource used in this study was aligned with the official Spanish curriculum, as were the textbooks used in the control schools. The new method and the resource were first used in the 2015–2016 school year.

In addition to 5E lessons aligned with official standards, the curriculum adopted by experimental groups included teacher guides to help teachers follow the 5E sequence for every topic in the syllabus. Teachers and students in the control schools (schools 3 and 4) continued as usual, which meant that traditional textbooks were used as the main teaching and learning resources. In all schools, as is typical in Spanish schools, students engaged in hands-on laboratory activities for one hour each week in a specific laboratory classroom. The rest of the science lessons (2 or 3 h per week depending on the grade) took place in standard classrooms. All schools invested the same amount of time, 3 weeks, to teaching the kinetic-molecular model in both the 2nd and 3rd grade of secondary education (equivalent to 8th and 9th grade according to the K-12 levels). This is the most basic model of the structure of matter, which allows for an explanation of physical changes such as changes of state or the formation of solutions, though it is not suitable for explaining chemical changes. We focused our analysis on this topic because it is related to many typical and persistent alternative conceptions regarding the nature of matter (Driver, 1985; Smith et al., 1985; Stavy & Stachel, 1985; Stavy, 1990a. 1990b).

In 2019, students in the 3rd and 4th year of secondary school (9th and 10th grade) answered the questionnaire (post-test). This means that the students who took the pre-test were not the same as those who took the post-test since we aimed to compare students who had been taught with conventional methods versus active methods throughout all secondary education grades, which in Spain is comprised of 4 grades (7th through 10th grade according to the K-12 nomenclature).

Teacher group discussions

Group discussions were conducted before the pre-test and after the post-test with most of the teachers involved in the study to collect information about their instructional practices. Before the pre-test, teachers in both the control and experimental groups were asked about the learning methods they commonly use and their prior knowledge regarding the 5E model or other active learning methods. After the post-test, the teachers in the control groups were required to report changes in their practices, if any, during the 5-year span of the study, and the teachers in the experimental groups were enquired about details regarding the introduction of the 5E model and the new curriculum resources in their classes.

Student questionnaires

The alternative conceptions that we targeted in this study are the most prevalent regarding the kinetic-molecular model of matter and physical changes (Driver, 1985; Smith et al., 1985; Stavy & Stachel, 1985; Stavy, 1990a, 1990b). These alternative conceptions include children's ideas about the relationship between mass and volume, the phenomenon of substance buoyancy and its relationship to density, the nature of gases, the conservation of matter in physical changes (such as changes of state and the formation of solutions), and the effects of thermal energy on substances. Several alternative conceptions about changes of state in water were also included, such as questions regarding the composition of clouds and the density of ice compared to liquid water. In order to reveal these alternative conceptions, we developed an online questionnaire with 26 questions (supplementary information). The questionnaire featured 18 multiple-choice questions with 3 possible answers, while 8 were open-ended questions that could be answered with a brief response. The pre-test and the post-test questionnaires were identical.

According to the official curriculum in force in Spain during this study, students learned about the kinetic-molecular model the year before they started secondary school and then in the 2nd and 3rd year of secondary school (8th and 9th grade) as a topic included in the subject called Physics and Chemistry. All alternative conceptions targeted in the questionnaires were related to phenomena and concepts that all teachers, both in the experimental and control groups, reported that they teach and evaluate in their classes. In addition, they were aligned with the syllabus and evaluation criteria of the official Spanish curriculum.

The same questionnaire was applied to different students and at different times. In order to ensure the traceability of the data, the results have been compiled into two large groups: students who received active learning (5E model) and those who received the conventional methodology focused on content delivery.

The open-ended questions in all tests were rated by the same person (a science teacher from a non-participating school) who was specifically hired to do this job. The information about the schools, classes, and students involved was replaced by codes, and tests were mixed randomly when supplied to the rater. A brief rubric with only two possible outcomes for each question (scientifically accurate or non-scientifically accurate) was provided.

Statistical analysis

A normality test was conducted on the data which confirmed that they followed a normal distribution. The students' performance in the alternative conceptions' questionnaires between the pre-test and the post-test condition was then compared by conducting a Student's t-test for independent samples. The performance in the pre-test was also compared between the two groups using the same type of statistical analysis. Where comparisons showed statistically significant differences, the size of the effect was measured using Cohen's d formula with pooled standard deviations (Cohen, 1988).

Results

A total of 725 students participated in this study, 371 during the 2014 academic year and 354 in 2019. A total of 391 students participated in the experimental group (schools 1 and 2) and 334 in the control group (schools 3 and 4). Table 2 shows the distribution of these students according to their group, grade, and school year.

The results obtained from the questionnaires were converted to the percentage of correct answers. Tables 3 and 4 show the mean results of each group both in the pre-test and the post-test.

Based on these results, a normality test was carried out for the sample, which confirmed that the sample follows a normal distribution. Therefore, a Student's t-test for independent samples was conducted comparing the performance of the experimental and control groups in each grade level before and after the intervention. The results in the pre-test were also compared by applying the same type of statistical analysis.

In schools where the 5E model was implemented (experimental group), statistically significant differences were observed in the percentage of correct answers before and after the implementation of the 5E model in both grades (3rd and 4th grade of secondary school), while in the control schools no statistically significant differences were reported in either grade (Tables 3 and 4, Figures 1 and 2).

As shown in Table 3 and Figure 1, statistically significant differences were observed in the 3rd grade after the implementation of the 5E model ($p = 0.003$), with a Cohen's d score of 0.427, thus indicating a medium effect size.

Similar results were observed in the 4th grade, with statistically significant differences in the experimental schools after the implementation of the 5E model ($p = 0.0028$) and with a Cohen's d score of 0.439, thus also indicating a medium effect size (Table 4, Figure 2).

Table 2. Distribution of students (n) by group, grade, and year.

	Experimental		Control		TOTAL
Grade	3rd	4th	3rd	4th	
2014	111	93	84	83	371
2019	90	97	87	80	354

No significant differences were found in the pre-test results when comparing the experimental and the control groups.

Regarding the teaching practices, the teachers in the control groups reported no substantial changes in their methods over the previous five years, while the teachers in the experimental group reported having adopted the new curriculum resources and methodology (the 5E model) as their new teaching standard. The teachers in the experimental groups agreed that the first and second stages of the 5Es (*Engage* and *Explore*) brought about the most important change in (and challenge to) their practices, particularly the activities aimed to elicit and discuss the students' prior conceptions (*Engage*) and the learning sequences where students explored alternative explanations through guided inquiry (*Explore*). Although at first teachers encountered some reluctance from students to engage in active learning, they agreed that most students had soon become familiar with the new method and the new curriculum resources and that they generally liked it more than other previous learning approaches. Finally, teachers reported that, in their opinion, the implementation of the 5E model had been hugely supported by the adopted curriculum, which included specific sequences of activities for each 5E stage and extensive teacher guides.

In summary, analysis of the students' questionnaires allowed us to answer the three research questions posed as they provided evidence of the levels of prevalence of students' alternative conceptions in several conditions. Also, analysis of the data from the teacher group discussions pointed to the sustainability of the intervention and the lack of changes in the teaching practices of the control groups.

Discussion

Since the late 1970s, largely thanks to the groundwork laid by Rosalind Driver and other researchers (Driver, 1985; Driver & Easley, 1978), many science educators have become aware of the fact that students bring alternative conceptions to the task of learning science that can be difficult to dispel and which impede the students from learning scientifically accurate concepts, theories, and models. The suggestion that learning science might require a focus on conceptual change was first noted by George Posner and his colleagues (Posner et al., 1982), who introduced what is known today as the classical approach to conceptual change. Indeed, this framework became the leading paradigm that guided research and instructional practices in science education for many years.

Although many researchers have offered new approaches to understanding conceptual change over the years, all of them have agreed on the fact that conventional methods of teaching usually fail to trigger this change, and that active learning methods are more likely to succeed (Duit & Treagust, 2012). Unfortunately, one of the major obstacles to implementing teaching methods that enhance conceptual change and hence help remediate persistent alternative conceptions is that teachers are frequently not well informed

Table 3. Percentage of correct answers of the pre- and post-test in 3rd grade students (experimental vs. control).

3rd grade, secondary school	Pre-test (2013–14)	Post-test (2018–19)	Difference	*p*-value	Cohen's d
5E model (experimental)	53.45% (*n*=111)	58.32% (*n*=90)	4.87%	0.0030	0.427
Conventional methods (control)	54.86% (*n*=84)	55.36% (*n*=87)	0.50%	0.7581	-

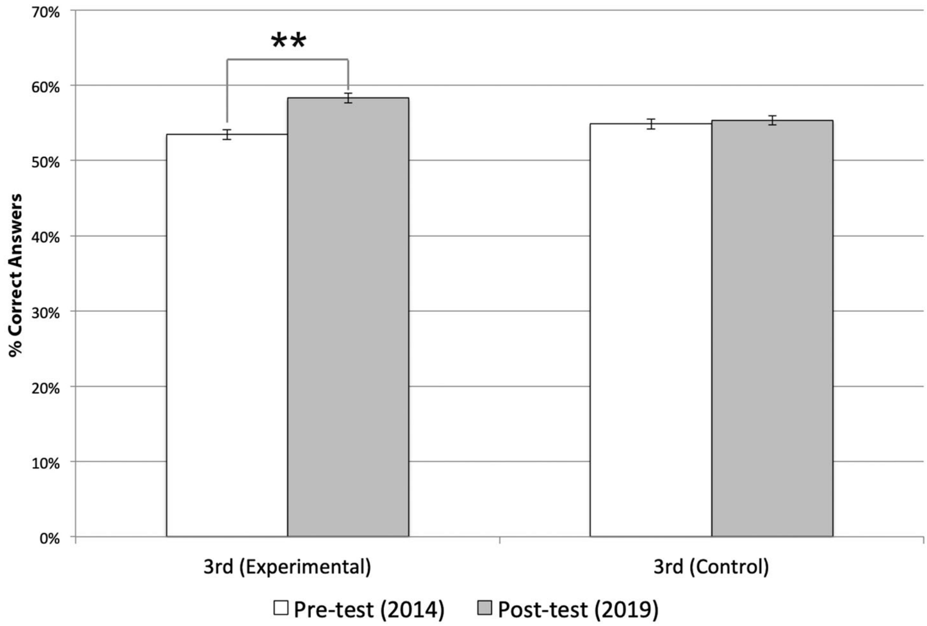

Figure 1. Percentage of correct answers of the pre- and post-test in 3rd grade students.

about the recent state of research on teaching and learning science, and many of them hold views of teaching and learning that are predominantly transmissive and not constructivist (Kotul'áková, 2020; Meschede et al., 2017).

In that regard, Lyons (2006) noted that students in three studies on students' school science experiences in England, Australia, and Sweden frequently described science teaching and learning as the transmission of content from expert sources to relatively passive recipients. Students were especially critical of this kind of teaching practice, which made them believe that science is merely a body of knowledge to be memorised. Although science teachers hold a wide variety of views on teaching, a large gap still remains between instructional design based on recent research findings and the normal practice in most classes observed. Therefore, it is essential to encourage science teachers to introduce active learning methodologies grounded in research into their classes.

However, educating teachers about conceptual change and training them on methods that are more efficient than traditional approaches in order to trigger this change does not guarantee that the teachers will implement the methods in their classrooms, that they will do it with sufficient fidelity, or that they will sustain these methods in the long term. Interventions on this subject need to be supported by clear and easy-to-

Table 4. Percentage of correct answers of the pre- and post-test in 4th grade students (experimental vs. control).

4th grade, secondary school	Pre-test (2013–14)	Post-test (2018–19)	Difference	*p*-value	Cohen's d
5E model (experimental)	56.81% (*n*=93)	61.77% (*n*=97)	4.96%	0.0028	0.439
Conventional methods (control)	56.53% (*n*=83)	53.89% (*n*=80)	−2.64%	0.1540	-

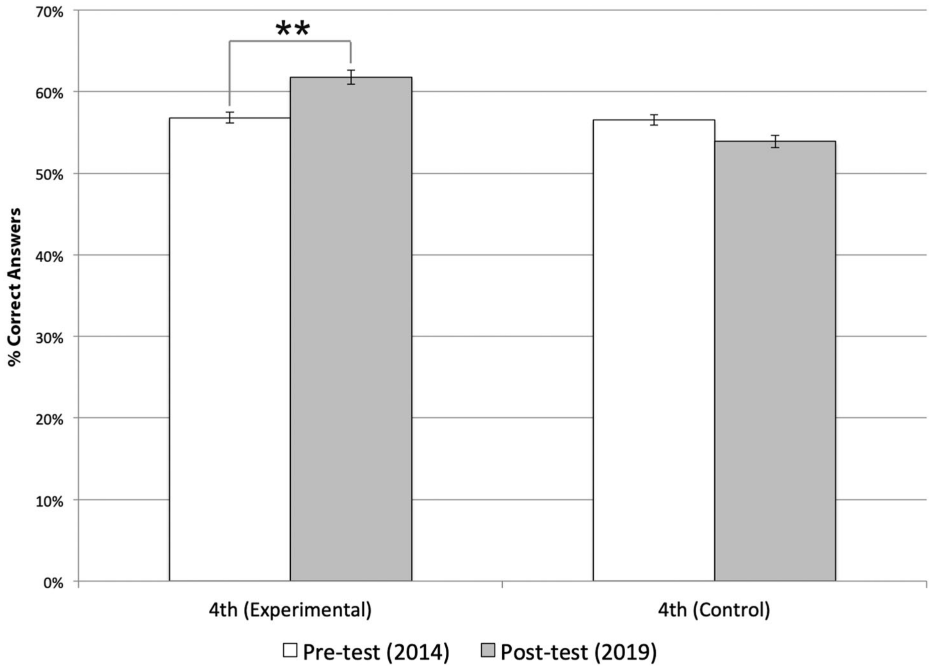

Figure 2. Percentage of correct answers of the pre- and post-test in 4th grade students.

handle models of instruction, such as the 5E model, and by comprehensive resources that provide specific activities and guidelines if the objective is to have a long-term impact. This study provides a successful example of this kind of intervention and evidence that supports its efficacy even five years after its deployment.

Specifically, this study has focused on revealing whether the introduction of the 5E model to teachers by means of a training session and a curriculum resource supported a change in teacher practices in the long term, which the data collected from the teacher group discussions confirmed, and whether that change had any effect on the students' learning outcomes, which we found out by directly testing the students' conceptual knowledge. In this regard, we assumed that a drop in the prevalence of alternative conceptions can be related to an improvement in conceptual learning, representing a successful conceptual change that favours scientific conceptions over unsophisticated ones (Mayer, 2010; Sesen & Tarhan, 2010). Therefore, we were not interested in the specific effect that the model had on each alternative conception but on the prevalence of such conceptions as a whole.

Among all possible topics to be evaluated, we selected the kinetic-molecular theory as an example of a scientific model that is relevant to both physics and chemistry and is also important for understanding biological processes along with important current global challenges such as climate change. The contents of this theory support the understanding of the basic properties of matter (such as mass, volume, and density, among others) and represent a simple model of the structure of matter that allows for the explanation of physical changes (changes of state and solutions, among others). Moreover, this theory and its applications offer the opportunity to introduce students to learning about models and their role in science (Prieto et al., 1996). In fact, different studies have shown the difficulties for 12–14 year-old students in understanding and correctly applying this model (Llorens de Molina, 1988; Prieto et al., 1996). To our knowledge, no previous studies have evaluated the efficacy of active learning approaches on this theory and only a few have assessed other models of matter (Sesen and Tarhan (2010) assessed active learning methods with acids and bases).

The most relevant finding of our study is the significant improvement observed five years after the intervention in the schools that were introduced to the 5E methodology compared to the control schools, with effect sizes measured by Cohen's d above 0.4, which can be regarded as relevant in accordance with typical effect sizes obtained in education and social science research (Kraft, 2019). This is especially remarkable considering the long-term nature of this study.

These results show that an intervention aimed at introducing an active methodology to teachers, in this case the 5E model, can effectively change teachers' instructional practices and support students' conceptual learning in the long term. In this regard, we think that the availability of curriculum resources with specific active learning sequences and teacher guides is a key factor in facilitating the adoption of active learning methods and maintaining their fidelity and hence their effectiveness in the long term.

The fact that this study was carried out over a five-year interval makes it especially relevant. Most of the previous research comparing the 5E model with more conventional instructional methods has focused on short interventions followed by immediate testing and has not analyzed their sustainability and long-term effects. On the one hand, the long-term nature of the present study implies that neither the Hawthorne effect (the observer effect) nor the novelty effect should have interfered with the results of the experimental groups. Indeed, students were already familiar with the 5E model when they reached 3rd and 4th grade of secondary school (9th and 10th grades) since they had used the model since 1st grade (7th grade). We can therefore assume that there was no effect of novelty related to the students' outcomes and that the 5E model was effective despite not being new to them. Also, since all students were only evaluated with the questionnaire once during the study, this clearly reduces the possible observation bias (Paradis & Sutkin, 2017). Consequently, the classical mechanisms of the Hawthorne effect, such as special treatment or attention given to subjects, awareness of being in an experiment, and a change in routine or novelty (Paradis & Sutkin, 2017) can be considered practically non-existent in this study. On the other hand, the evaluation of student outcomes five years after the intervention, together with teacher reports about their practices, allows us to evaluate the impact of the intervention in the long term, specifically its sustainability regarding teachers' practices and its possible loss of effectiveness with time, compared to conventional teaching methods.

It is also worth noting that the students in 4th level of secondary school (10th grade) were evaluated a year after they were taught about the topics related to the kinetic-molecular model for the last time. This means that the outcomes measured in this case were long-term in nature. In certain cases, alternative conceptions cannot be detected through immediate exams after the intervention since these alternative conceptions return after a time and persist in the future while the new concept the students have learned vanishes (Dunbar et al., 2007). For this reason, long-term studies are fundamental when analyzing the effects of educational interventions on the prevalence of alternative conceptions.

The results obtained in our study support the use of active learning methodologies not only in secondary education, but also in later years in high school and in university where, although active learning is recognised as a superior method of instruction, recent surveys reflect that teachers and professors frequently choose traditional teaching methods (Deslauriers et al., 2019; Kim et al., 2019). We must highlight that the present intervention did not involve more hands-on activities, but probably more of what we could call minds-on activities. Therefore, this study supports the claim that active learning methods can be useful as long as students are cognitively involved in the learning activities, regardless of their hands-on nature, as has already been reported (Yardley et al., 2012).

According to the teachers in the experimental groups, probably the most important changes they introduced in their classes when implementing the 5E model were (a) providing time and opportunities for students to elicit prior knowledge; and (b) engaging them in activities that promote reflection and make them think about what they are learning to make it meaningful. Therefore, the *Engage* and *Explore* stages of the 5E model could be critical in causing the differential effect on learning outcomes that it has usually been found between this instructional model and more conventional methods (Bybee, 2015). The caveat for teachers would be that they should seriously consider allowing students time to contrast their prior ideas with the new ones through the introduction of activities that promote discussion and reflection. Conceptual change requires more time than shallow learning, but if the aim is to promote meaningful, transferable, and long-term learning, then there are stages of the active instructional sequence that can't be underestimated.

Finally, as for additional strengths of this study when compared to previous studies, we have the large sample size utilised and the focus placed on secondary education. As for shortcomings, we think that future studies of the 5E Model should assess other variables such as students' attitudes and interests. This can be done by following the path of other studies that have evaluated new approaches to science teaching and learning (e.g. Savelsbergh et al., 2016). Also, qualitative studies might be more accurate in informing us of how faithful the teacher implementation was, identifying the specific actions in the 5E model responsible for better conceptual learning, and pinpointing the differential effects in each type of alternative conception. We think this would mitigate some of the limitations of our quantitative study. In addition, future research should also analyze the impact of active learning or the 5E Model of Instruction on other frequent and persistent groups of alternative conceptions such as those related to plant nutrition or the astronomical model of the seasons, for example.

In conclusion, the results of this study provide evidence for a significant reduction in the prevalence of students' alternative conceptions based on the responses to a questionnaire on the kinetic-molecular theory five years after an intervention was conducted in real settings that combined training and resources to help teachers implement an active learning strategy, in particular, the 5E model.

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