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Is it possible to reach a sustainable change in Science Teaching at primary schools? A plan for achieving it

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Abstract. One of the great challenges of recent decades, which has been the subject of much debate and research, is how to bridge the gap between science education research and school practice. To address this issue, we have reviewed and analysed in depth the characteristics that in-service teacher training programmes should have in order to be effective and of high quality. In this paper, we present a professional development programme to achieve the desired didactic change in science teaching at schools. This programme is organized into phases that can be evaluated by measurable indicators to determine its success or failure. In addition, in order to assess the sustainability of change in a school (or group of teachers), we have incorporated the theory of critical mass in social change, which has received recent empirical support.

1. Introduction
There is a shared interest in enhancing science education at the primary stage [1, 2, 3], and a broad consensus that it should be developed using an inquiry approach, where classroom activity is organized by posing conceptually rich questions or problems, the resolution of which is developed in an environment that favours scientific practices and the (co-)construction of meanings [4, 5]. This orientation is reflected in recommendations and curricula of the European Union organisms [6] and the United States of America [7, 8].

However, as trainers of future teachers and tutors of practicums, we do know that divergence between current research and usual practice is huge. In most cases (fortunately not all), in Spain, paraphrased textbook reading by the teacher remains the method used to teach science. In this sense, the only thing that teachers do to prepare their science lessons is to temporally arrange and use the ideas presented in textbooks throughout the school year [9]. This way of teaching science is what we call “usual teaching” from now on. Even some classes that are claimed to be "active” usually consist of a sum of animation techniques and repetitive learning, which clearly does not represent any educative innovation. In this situation, it is not surprising that the director of education of the OECD, responsible for the PISA tests, states that teachers in Spain “are as if they were working in a factory, in a chain of production” and that some Spanish authors, such as Porlan [10] state that it is almost impossible that inquiry-based science teaching becomes the usual way of teaching science in schools, since teachers can individually decide to keep on using only textbooks during their lessons. .

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Despite acknowledging the fact that changing the way physics is taught at schools is a difficult problem, the issue is scarcely researched in Spain and Europe. There is a lot of research involving preservice teachers, but little on how to get in-service teachers to carry out successful and in a sustainable way, inquiry-based science teaching (IBST). Given the scant time devoted to science education in preservice programs at the university (between 5 and 7.5% in Spain) and the influence of the context on how science is taught in schools, it is unlikely that the initial training received has a significant influence on professional practice. Therefore, the authors believe that we should rather consider how to support "professional practice" and leverage its influence on initial training. In other words, we believe that it is a priority to train teachers that could act as examples for future teachers, creating learning communities where pre-service teachers can be trained.

So we have focused on finding out how to make inquiry-based teaching the "normal practice". Because this is a complex problem, with many external and internal obstacles to teachers [see 11, 12, 13], in order to learn and draw conclusions, it is necessary to focus research on the analysis of cases (i.e., the study of a school or a group of teachers whose characteristics, conditioning factors and actions can be tracked) and to define very well, in an operative way: a) what we want to achieve; b) the plan foreseen for its achievement, ordered in phases that can be analysed; c) how to assess the development of the plan; and d) when it can be considered that an effective and sustainable didactic change has been achieved in a school.

Our answer to "a)" is that through collaboration between our team and the teachers and principal team of a primary school we want to achieve teaching of physics based on the model of teaching by inquiry. Then, our research questions are: Can we devise a plan for IBST to become the normal way to teach physics (or science in general) at a primary school? How can we evaluate the effectiveness of the plan so that we can learn for future training at other schools?

To this end, we have carried out an in-depth review of the didactic literature to identify features of effective professional development programs to achieve didactic/professional change and we have ordered them into phases that can be analyzed by empirical indicators to determine its success or failure. Also, in order to assess whether a school (or a group of teachers) has undergone irreversible change in their teaching practice, we have incorporated the theory of critical mass for changing social conventions that has received recent empirical support [14]. Therefore, in this study we present a plan to try to achieve this teaching change in an effective way, describing the different phases together with the criteria to evaluate them. The plan has been developed three times, in three different Spanish schools, in a longitudinal study that involved the authors of this paper for more than 4 years [15]. The successive implementation of the plan in these schools has been useful for us to improve it. The results of the first tests of the plan have been published [15], so we know that the implementation of this plan, whenever possible, leads towards the ambitious didactic change proposed by the curricula recommendations of the European Union and the United States.

2. A plan for achieving the science teaching change

In order to analyse and draw conclusions from a process of intervention/collaboration between two teams (that of the teachers of a school and that of the university) with the aim of changing conventional science teaching into IBST, we have divided it into the following general phases: 1) initial contact and generation of positive expectations towards change; 2) first implementation of the innovation by teachers; 3) evaluation and reinforcement: second implementation by teachers; 4) sustainability and extension of the teaching change.

2.1. Phase 1: Initial contact and generation of positive expectations toward change

While the how of initiating professional development activities is a scarcely or not at all researched topic, yet, it seems to be important to setting the basis for the didactic change [16]. Our previous experience in training courses for teachers had been good in terms of our intervention (according to the assessment by participants), but negative in terms of implementation in their classes. The diverse origin (it was difficult to find several assistants from the same school), their different motivations or the scarce control over the school curricula (to be able to decide what contents to deal with, when and how to do it) of attenders, were some of the obstacles for the innovations to reach the practice. Under these conditions it is difficult to form groups of people with the "strong bonds" and shared objectives that are required for the propagation of complex behaviours [17] such as the science teaching change that we propose. In this way, we decided to focus our research on how to achieve the teaching change in groups of teachers belonging to the same school.

In this first stage, we aimed to achieve: (1) a positive climate of trust and collaboration; (2) to show that change is desirable and possible by sharing knowledge about content and how to teach it in an integrated and pragmatic way; (3) to obtain information on teachers' concerns to implement the innovation (to solve them in the future), and (4) to obtain the commitment of some of them to initiate it in their classrooms.

In their review of the characteristics and quality of professional development programs, van Driel, Meirink, van Veen and Zwart [18] considered essential that, in any program, teachers understand how their students learn, as they distrust about the feasibility of certain general innovation proposals. Teachers need examples of sequences of activities which could be applied in their classrooms. Consequently, we designed a training course to improve teachers' knowledge (both conceptual and methodological), addressing the same inquiry-based science teaching sequences of activities (IBSTs) that their students will develop (as primary teachers will finally be the ones to implement innovation in their classrooms) [19, 20, 21]. Of course, the course took place in a problematized environment in which teaching sequences started from questions or problems that make sense to children at a certain schooling level and which, at the same time, represent a progressive advance in the science core problem or idea chosen, ranging from first to six grades (in Spain, sixth grade belongs to primary school, not middle school) [21]. Teachers, organized in small groups, had opportunities to "live in the flesh" the learning environment generated by IBST. The small groups faced the teaching sequences of activities led by one research team member. During the discussion of the activities with teachers, there were reiterated opportunities for the ideas to emerge, which were tested to gain knowledge on the core problem or question set at the beginning. This discussion was also usually used for didactic reflection based on the experience of the teachers and on previous interventions with primary pupils of the research team. The objective was simultaneously to improve conceptual and methodological knowledge but, also, attitudinal involvement, so they could put into practice in their classes, for the first time, some of the developed sequences. At the end of this course, teachers were more aware of what is required to carry out an IBSTs, so this seemed to be a good moment to collect their needs and concerns (e.g. lack of content and methodological knowledge or lack of time to design and prepare inquiry-based science activities) with the aim to help them to put some of the sequences developed in the course into practice [21]. The approximate duration of the training course was 40 hours (the course took place in non-teaching hours, in July - a non-teaching period in Spain).

We assessed the success of this phase based on the following indicators:

- Positive evaluation of the training course obtained by means of an anonymous and individual questionnaire at the end of the course.
- Obtaining information "in the field" on the difficulties and needs teachers may have to be able to carry out the innovation. We did obtain this information through a questionnaire after the training course (when teachers had a more defined idea of what the intended innovation entails). As van Driel [18] point out, the problems or obstacles we observe during the process cannot be overlooked if we want the program to last over time. One of our objectives was to learn from failures so that we can foresee them for future interventions. Our team's reflection on these aspects was a key piece of our learning to foster the didactic change and was carried out throughout all phases.
- Commitment of some teachers to put into practice some of the developed teaching sequences, with an approximate duration of ten teaching hours.

2.2. Phase 2: First implementation of innovation by teachers

The decision to implement one of the IBSTs is the responsibility of teachers and principals, whose role is important in driving and encouraging teaching change (in Spain, the principal or/and teachers can decide the methodology they use to teach science or other subjects) [22, 23]. However, getting to action is not easy. It is necessarily a process of "ownership" that requires personal work to prepare the teaching sequences. Achieving didactic change has less to do with convincing people that the idea is good than with the challenge of getting them to do the extra work required to put it into practice [17, p. 137). Indeed, Elliot [24] state that to face this change for the first time, teachers need a lot of support, and Opfer and Pedder [25] draw similar conclusions in their review of teacher training literature: teachers need support, time, and feeling comfortable and confident in the face of change.

In this phase, our team offered unconditional assistance, in the form of: a) mentoring sessions to review the IBSTs with teachers who volunteer, reflecting on them again and helping to prepare the material for students (collaborative planning); b) attendance as assistants during all classes of their intervention, which were recorded for further reflection on practice [26]; and c) measuring change in students' learning outcomes and attitudes. At this point, we informed teachers that the measurement of results on content knowledge (using pretest/postest questionnaires) will only serve to document the process and that they would be only used for internal analysis for further improvement. Measurement will only be reliable when they have owned the sequence, which, as a reasonable rule is usually achieved after the second time, at least, once it is carried out.

Obviously, we did not start from scratch: the IBSTs had been elaborated by the research team [27, 28] and tested in primary groups, and these represented a coherent and progressive teaching itinerary in the development of some of the big ideas (or problems) of science that are included in the official curricula. Our intention was that teachers could adapt and modify them, if they considered it necessary, once they have put them into practice. This phase started once the principal and teachers' team participated in the training course, and they agreed to work together with our team, on improving science teaching. Therefore, this phase started at the beginning of the school year (in September in Spain) and finished at the end of the school year (end of June). In the schools where we have worked, the university team has invested more than 100 hours of work during this phase.

The indicators for assessing the success of this second phase rely on one of the most cited models in professional development [29]:

- Some teachers carry out the sequences generating a dynamic of inquiry (they call it "domain of practice and consequence") and their performance serves, in addition, for other colleagues to learn from them. We did not expect every teacher in the school to carry out sequences by inquiry, but rather some of them to initiate that process. This is a crucial indicator: if no teacher is willing to initiate innovation in the classroom, the collaboration ends.
- If teachers who carry out the inquiry sequences for the first time feel comfortable and secure in the face of change, and express positive attitudes and a "desire for more" ("personal domain"). To assess this aspect, we conducted semi-structured interviews.
- Finally, we tried to "assess" the satisfaction of families and principals with the change. To assess this aspect, we used questionnaires and interviews. As we have previously stated, we identified factors that, in a given school, facilitate or hinder the teaching change. We made notes in the field notebook and considered the reflections of the research team ("external domain").

2.3. Phase 3: Reflection on the practice and reinforcement: second implementation by teachers

In the two previous phases, teachers and members of our team developed several IBSTs with primary children. An itinerary of increasingly complex sequences will be available from first to sixth grade about one of the core ideas contained in the science curricula. We had the first results of the students' records of classroom activity and interviews with the teachers involved about content knowledge achievements. After this first implementation, we gained knowledge on how to improve the IBSTs for a second implementation. To do this, we developed seminars (two hours per week for three months) to revise the sequences and collectively analysed selected class video clips to reflect on the activity of students and the intervention of teachers. We hoped that teachers of different grades will participate in these seminars (every teacher who teaches science should know, at least, the storyline of the sequences and what is done in the years before and after with their students) and that seminars will facilitate the teachers to put into practice (some of them for the second time) the corresponding sequence with a greater conceptual and methodological mastery, that is, with greater self-confidence [21]. This should also serve to help introduce new colleagues who have not participated in the previous phases into the innovation. These seminars were scheduled to take place at the beginning of the next school year (September), with a duration of 30 hours. Our objective was that, in this phase, IBSTs were carried out within the same storyline in each of the primary courses in a coherent way, with increasing and coordinated complexity. In both this phase and the previous one, changes are required in the organization of the school: IBST require time and continuity, not two fifty-minute classes a week. The role of the principal is (and was) decisive in this phase. In this phase, the work of the university team involved more than 50 hours of collaboration with the team of teachers.

The indicators of success in this phase were:

- Willingness to make organizational changes that favour innovation.
- Positive appraisal of the usefulness of the seminar sessions by the participants and the research team. To assess this aspect, we conducted semi-structured interviews and annotations in the field notebook of the researcher leading the seminar.
- Analysis of classroom dynamics. To assess this aspect, we checked that some indicators of working by inquiry during several classes are fulfilled.
- Self-evaluation of the teacher involved through a semi-structured interview.
- Learning outcomes of students of the teachers who performed a sequence for the second time. To evaluate this aspect, we used pretest/postest questionnaires and comparison with control groups that had dealt with the same content.

2.4. Phase 4: Sustainability and Extension

We understand this phase as a situation in which some teachers have incorporated the IBSTs of approximately ten hours in their classes (they have put it into practice for two or three times, with the organizational and methodological changes it entails) and they demand training on new sequences (to initiate another "storyline" on another core idea of science). There will be enough teachers involved so that the students at school can receive an investigative teaching with continuity and progression throughout the primary education, about this core idea of science.

However, what would be the minimum number of teachers committed to teaching science by inquiry so that we can consider the teaching change in the schools as consolidated? Will the resistance to change of some reverse what has been achieved in the group of teachers committed with the change? Will the group of committed teachers be able over time to ensure that this innovation is considered as the "desirable way" of teaching science at their school? These questions enter fully into the objective of the theoretical models of change in social conventions being used by mathematicians, economists and sociologists. These models have shown that if, a minority group committed to one cause reaches a certain percentage of the population (called “tipping point” or “critical mass”), dynamics of social change are generated that lead to the adoption by the majority of a new social convention, even contrary to the behaviour previously established. The size of the critical mass (in percentage of the population) can vary according to the behaviour to be changed (and the way of teaching science is a very complex behaviour) and the characteristics of the social group. Centola and colleagues [14] in the empirical proofs of their theoretical model, find a tipping point of 25% and he asserts the following: “Our results suggest that in organizational contexts - where population boundaries are relatively well defined and there is a clear desire and rewards for peer-to-peer coordination - processes of change in social conventions adjust quite well to critical mass dynamics” [17, p. 1118]. This study extends to processes in which initially the majority have a clear preference for the established convention (this is called “entrenchment”, and in our case, they are the teachers using “usual” science teaching). In this case, these authors show that if the “gain” received by the minority committed with the change (in our case, with IBST) exceeds that received by the majority, the breaking point remains close to 25%.

The above ideas justify our hypothesis that if in a school a critical mass of teachers who teach science by inquiry is reached, and coordination among equals is favoured, the change will eventually extend to a large majority of teachers who teach science. Of course, the involvement of the principal of the school in fostering “rewards” towards inquiry-based science teaching will be necessary to do the breaking point affordable, especially if there is “entrenchment” in “usual” teaching. What can “rewards” be for committed teachers? Why should the principal promote IBST rather than conventional teaching? What might be the value of the “tipping point”? In our plan, teachers committed to change will feel personally and socially reinforced, “rewarded”, if a substantial part of the situations in different domains listed in Table 1 take place.

Table 1. Aspects (“rewards”) that favour the attainment and consolidation of a critical mass of teachers who have made a didactic change in a school (towards inquiry-based science teaching).

DOMAINS	
PERSONAL SATISFACTION WITH OWN WORK	Improved learning and attitudinal outcomes in their students and family satisfaction More creative self-perception of their teaching work Feel part of a coherent and progressive teaching plan, and of a team that is working on the same as him or her (knowledge of the science storylines throughout the primary schooling; knowing what his or her classmates are doing)
SCHOOL ORGANIZATION AND EDUCATIONAL AUTHORITIES	Their work is valued by principal/s The principal facilitates organizational changes (modification of timetables and/or spaces; assignment of the teaching of the science subject to the committed teachers) Resources are provided for acquiring the necessary materials for inquiry science teaching Time is included in teachers' schedules for meetings and seminars (Spanish teachers can reduce/allocate teaching hours for the preparation of the project) School inspection supports innovation Favours the autonomy of the school in the development of educational innovations Favours the professional projection of the involved teachers and of the school
PROFESSIONAL DEVELOPMENT AND PROJECTION	Participation in workshops and conferences presenting what they made in their classrooms Transfer their experience to other colleagues and especially to future teachers Tutoring practicum students especially motivated by inquiry-based science teaching

The evidence of good learning outcomes and motivation in pupils, teachers and parents should motivate the principal/s and the education inspectorate support. In these conditions, bearing in mind that didactic change is a complex change in behaviour, we adopted the conservative criterion of considering one third of teachers who can teach science as the critical mass (in schools of Spain, there are specialists in music, foreign language and sports; a generalist teacher teaches Spanish, Mathematics, Social studies, Sciences and Arts&Craft).

Thus, our plan for didactic change would be successful if 33% of the teachers were able to carry out IBSTs during two or more school years, using at least 20% of the total hours of the science subject (60), and a good part of the aspects in the three domains described in Table 1 were observed. In addition, if the change has been successful, it will produce that teachers involved and the principal wish to extend collaboration with the research team by dealing with new sequences that complete the science curricula. In this new process, it is possible to incorporate another school to take advantage of the experience acquired by teachers of the first school. In summary, this has been the plan that we have developed over four years.

3. Conclusions
In this paper, we have presented and justified a plan to achieve a change in the way science is taught at the primary schools, based on a collaboration between a research team at the university and the teachers/principal team of schools. To identify characteristics for designing a successful plan, we reviewed the literature on didactic change, as discussed in the previous sections of this paper. A characteristic of this plan is the operational definition of success indicators in each phase to facilitate research on how to achieve "real" didactic change or, if not achieved, to identify the causes. We have managed to achieve the change in two schools. The key aspects that enabled the success of the plan were: the readiness of the school management; the initial commitment of a critical mass of teachers; overcoming the tension of the first implementation (being videotaped); the follow-up and improvement seminars (with analysis of video clips of the teachers themselves); and the results of the pupils after the second implementation. The welcome from parents, and the promotion of professional development supported by the management and inspectorate, also contributed to the consolidation of change. Now, we are working in translating the experience acquired in the "arena" to online materials, to reduce the real intervention time of our team at schools, so the impact of the plan could be extended, contributing to reducing the gap between research and practice.

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