Teaching Experiments within Design Research

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Abstract
Design research is a methodological paradigm, mainly qualitative, that is currently being intensely applied and developed in educational research. In this work we briefly describe this methodology and, within it, we focus our attention on a specific type of studies: teaching experiments. After describing the main characteristics of these studies, we present some conclusions that have been obtained in two teaching experiments developed by the authors. This information may contribute, directly or by promoting reflection and discussion, to the development of this methodology and to its application.

Keywords
Design Research, Educational Research, Qualitative Methodology, Teaching Experiments

Design research or research based on design is a methodological paradigm that is being intensely applied and developed in educational research in the last decade (Kelly, 2003). This type of methodology, mainly qualitative, has been developed within the *Learning Sciences*: a multidisciplinary field which studies learning and teaching processes and includes, among other fields, anthropology, educative psychology, sociology, neurosciences, science education and mathematics education (Confrey, 2006; Sawyer, 2006).

In this work we briefly describe this methodology, and within it, we focus our attention on a specific type of studies: teaching experiments. After describing the main characteristics of these studies, we present some remarks and conclusions obtained from our experience in applying this methodology in two related research studies (Molina, 2003, 2006; Molina and Ambrose, in press). This information may contribute, directly or by promoting reflection and discussion, to the development of this methodology. It also aims to inform researches about important issues to consider when applying this methodology.

Generally speaking, design research can be defined as a set of methodological approaches in which *instructional design* and *research* are interdependent. On the one hand, the design of learning situations serves as a context for research. On the other, continuous analyses and a final retrospective analysis provide information to develop and improve the design (Cobb and Gravemeijer, in press). This paradigm aims to analyze learning in its context by designing and systematically studying particular forms of learning, strategies and educative tools in a way that is sensitive to the systemic nature of learning, education and evaluation. Design is considered to have the potential to promote learning, to create useful knowledge, and to make the theories of learning and teaching progress in complex settings (Cobb, Confrey, diSessa, Lehrer and Schauble, 2003; DBRC, 2003).

Ideally design research leads to a greater understanding of learning contexts by the design of its elements and the anticipation of how they are going to jointly work, to promote learning. Beyond creating effective designs for some learning, design studies explain why the design works and suggest ways in which it can be adapted to new circumstances (Cobb et al, 2003). This type of research includes theoretical foundations on education and learning and reflects a commitment to understand the existing relations between educative theory, practice and artefacts. The objective is to produce knowledge supported by practical evidence that guides instructional decision making, to improve students´ learning.

In order to clarify this description we comment below on the main characteristics of these studies.

Characteristics of Design Studies

1. Design studies are centred in the characterization of a learning/teaching situation in all its complexity, most of which is not well-known initially. The classrooms or learning/teaching settings are considered complex and conditional. So, an ample range of measures is needed to capture the learning process that takes place, as well as the students´ final cognitive state. These studies involve multiple variables, many of which cannot be controlled (Collins, Joseph and Bielaczyc, 2004). Because of this complexity, it is essential to distinguish between the elements or variables to be studied and those others that are considered accidental or are assumed as surrounding conditions (Barab and Squire, 2004; Cobb et al., 2003).
2. They usually involve different types of participants, being necessary that if a person acts as a teacher, he or she is completely involved in the research process. The different participants will contribute with their different experiences to the collection and analysis of the data (Barab and Squire, 2004).
3. They happen in real life contexts where usually some type of learning takes place. Therefore, the type of situations considered are plenty: a team of researchers working with a small group of students; a group of researchers working in a classroom in collaboration with a teacher; a group of researchers, teachers trainers and teachers jointly promoting the development of a professional community; a team of researchers collaborating with teachers and other educative agents in studies that involve several schools... (Barab and Squire, 2004; Cobb et al., 2003). The multiplicity of contexts in which these studies can take place and the type of people involved are some of the factors that cause the existence of very diverse types of design studies. Among them, we focus on teaching experiments, as defined by Lesh and Kelly (2000) and Steffe and Thompson (2000), which we describe later in this paper.
4. The theories developed within design studies are humble because they are specific of a learning domain and explanatory of the activity of the

design. These studies have an intermediate theoretical reach (Cobb et al., 2003). diSessa and Cobb (2004) emphasize the utility of these studies for the development of useful theoretical constructs to detect order, regularities and patterns in the complex contexts in which they are developed.

5. These studies are characterized by a *progressive refinement* since the design is constantly reviewed by considering the evidences obtained along the research process (Collins et al., 2004). Continuous cycles of design, application of the design (intervention), data-analysis and redesign are performed. The researchers that use this methodology, test make and refine conjectures about the learning trajectory by considering the evidences obtained. They collaborate or act as teachers and gather extensive records about what the students, the teachers and the researchers learn throughout the process (DBRC, 2003).
6. Design studies include two types of data analysis: a preliminary analysis which is performed after each cycle of the research process, and a final prospective analysis which involves all the data obtained along the data collection.

Teaching Experiments

As we previously mentioned, teaching experiments are a special type of design studies. Generally speaking a teaching experiment consists of a sequence of teaching episodes in which the participants are usually a researcher-teacher, one or more students and a researcher-observer (Steffe and Thompson, 2000). The time of duration can be variable (e.g. hours, an academic year). The atmosphere to observe can be from small room-laboratory for interviews, to complete classes or even bigger learning settings.

The main characteristic of these studies is the rupture of the differentiation between teachers and researchers, due to the researchers´ interest of experiencing students´ learning and reasoning in first person. Researchers become an integral part of the system they are studying by interacting with it. This leads to complex interactions that break the habitual distinction between researchers, teachers and students.

Unlike classroom based-research, in teaching experiments one of the researchers takes the role of the teacher unless the official teacher becomes completely involved in the research process. In addition, in the in-class interventions, the research objectives are valued over what may be better for the students (Kelly and Lesh, 2000; Steffe and Thompson, 2000).

Objectives

The general objective of teaching experiment is to study the development of the ideas, tools or models in which students and teachers are contained, not to generalize about them. The focus can be on the students´ or teachers´ development or on the evolution of the teaching settings and activities, among

other elements (Kelly and Lesh, 2000). According to these authors, these studies are centred on the study of the development of complex, self-organized, adaptable and in-interaction systems, whose evolution is often extremely sensible to small changes in their conditions.

Teaching experiments are made to test and generate hypothesis and conjectures during each teaching episode as well as in the global research process. Some hypothesis or conjectures may be formulated or abandoned after the analysis of one or various episodes and new hypothesis or conjectures will condition the design of the next in-class interventions. Researchers need to continuously postulate the meaning that underlies the students´ language and actions. In this way students guide the researchers (Steffe and Thompson, 2000).

Progressive Refinement

As we previously mentioned the "progressive refinement" is an important characteristic of design studies and, therefore, of teaching experiments. This characteristic refers, in this case, to the recurrent cycle formed by the formulation of hypothesis and conjectures, the design of an in-class intervention, the experimentation in the classroom, the analysis of the data collected, the reconstruction of the hypotheses and conjectures and the design of a new intervention.

Researchers initiate the study with a preliminary model of the phenomena they want to study, which is based on their theoretical assumptions and their previous experience. Throughout the interaction with the students, the collected data allow confirming or rejecting the initial hypotheses and conjectures and suggest new forms of experimentation that can lead to the development of a firm model of the students' mental activity. Then the cycle begins again.

In this process, there are two opposed objectives. On one hand, researches want to find out if the model remains viable when considering the data collected. On the other, they are willing to modify the model, at any moment, if some unexpected observations are obtained (Confrey, 2006; Steffe and Thompson, 2000).

In the in-class interventions, the researcher-teacher must be centred in exploring the forms in which the students act and give meaning to the concepts in use, leaving aside his/her own hypotheses or conjectures. Initially he/she will act in an intuitive and responsible way in the attempt to explore the students´ thinking and reasoning, trying to anticipate the students´ possible answers or reactions to the proposed activities. This type of interventions allows generating hypothesis. As the experiment advances, and the researcher-teacher acquires more experience with the students, often he/she will take an analytical position instead. Analytical actions will be directed to test previous defined hypothesis or conjectures.

Data Collection

The collection of data that accompanies these studies is exhaustive to be able to precisely describe the in-class interactions, the students´ performance and its evolution, the researchers´ reflections and decisions taken along the research

process and the students´ work between the sessions. It is necessary to collect information about everything that happens in the classroom.

Multiple methods of data collection (including video recordings and note taking) as well the participation of a team of researchers are recommended. The participation of various researchers allows having continuous discussions about the design of the in-class interventions, the data collection and the possible interpretations of the data, which enrich and increase the quality of the research process.

Data Analysis

As previously mentioned, two types of data analysis are performed which take place at different moments in the research process. The preliminary analysis, which consists of the analysis of the data after each in-class intervention, leads to making decision about future interventions and facilitates the revision and the development of the researchers´ hypothesis and conjectures. The final retrospective analysis, which is the analysis of all the data gathered during the research process, leads to the construction of a coherent history of the evolution of the researchers´ conjectures and the evolution of the students´ behaviour, thinking and performance throughout the in-class interventions.

A detailed description of the research process, with justifications of all the decisions taken, is necessary so that a suitable valuation of the research work can be made and its quality can be guarantied. In the final analysis, the methods to use will depend on the type of data collected as well as on the research objectives.

The researchers´ aim is to elaborate a model of the changes that are considered learning or development throughout the teaching experiment, considering them as caused by the in-class interventions. This model, which has the potential to connect research and teaching practice, is based, not only on the conceptual analysis of the students´ language and actions, but also on the theoretical constructs established in previous conceptual analysis. The obtained model will be of use as long as it emerges again in other similar interventions with students (Steffe and Thompson, 2000).

An Example: Two Teaching Experiments about Third Graders´ Strategies for Solving Number Sentences

Having described this methodological approach, we now briefly comment on the two teaching experiments we have recently developed. They were directed to study third grade students´ ways of approaching solving number sentences which are based on arithmetic properties (Molina, 2003, 2006; Molina and Ambrose, in press, Molina, Castro and Ambrose, 2005). Both experiments were developed with a third grade class of 18 and 26 students, respectively. We worked with the students in their regular classroom, during six or five sessions over a period of one year. This timeline was chosen intentionally (except from vacation periods) because we wanted (a) our intervention to have a longer effect, (b) to diminish the probability of assessing a memory-based learning and (c) to have enough time

between sessions to analyze the data of the previous session and take decisions about the next one.

In these in-class interventions one of the authors of this paper acted as a teacher, while the official teacher stayed in the class to keep the students´ behaviour under control. Another researcher participated in the rest of the research process, while several (external) researchers collaborated at different times by questioning and discussing the design of the interventions as well as the analysis and interpretation of the data.

The design and planning of the interventions were specified along the process as it is common in these research studies. Before initiating the in-class interventions we chose the teaching approach we would follow, we decided the type of tasks we would use, and we roughly planned the order and way in which we would address each of the research objectives. These decisions were made after having developed a deep revision of literature about mathematics education which was related to our research interest.

Our first objective was to analyse the students´ initial understanding of the proposed tasks as well as to detect the strategies used by the students to solve the number sentences. The first session was also directed to get students used to the researcher as a teacher, and vice versa, as well as to the presence of the video-camera in the classroom. Later sessions aimed to help students to develop their understanding of the sentences, to promote the use of multiple strategies to solve them and to analyse both processes.

The tasks used were number sentences, mostly true/false number sentences, based on some arithmetic property or principle (e.g., commutative property, inverse relation of addition and subtraction, compensation relation), which were proposed to the students, in the context of whole class activities, written tasks, discussions and interviews (see concrete tasks in Molina, 2003, 2006).

The data were collected by video-recording the sessions, audio-recording or video-recording the interviews and collecting the students´ worksheets. In this way, we gathered an exhaustive collection of data about the students´ thinking while solving the proposed number sentences. We also collected data of the thinking and decisions taken by the participant researchers at different stages of the research process, especially in the meetings about the design of each session and the analysis of the data of previous sessions.

In both studies the data analysis was qualitative as the purpose of this study was to describe in great detail students´ thinking, not aiming to provide generalizations but rich descriptions of students´ performance and evolution in relation with our research objective. Further details of the data analysis are presented on the next part of the paper where, using our experience with the methodology of teaching experiments within the design research paradigm, we present some remarks referring to detected weaknesses and difficulties and recommend possible ways of approaching them.

Lessons Learned from Our Experience: Weaknesses and Difficulties of Teaching Experiments

About the Design of the Study

One of the recommendations given for the application of this methodology is the participation, in the research process, of various researchers due to the huge amount of data that is usually generated and to the interest of contrasting different perspectives about the studied phenomena and the obtained data. This may be an important limitation as often research studies, at least in Mathematics Education in Spain, are made by a low number of researchers, frequently one, two or three.

In our study we have alleviated this requirement by a) limiting the research focus, which has reduced the elements of study in the diverse and big amount of data collected and b) having frequent discussions about the research process and the data and results obtained, with various researchers related in different ways to the study (or even not related at all). These exchanges have contributed and enriched the data analysis and the overall development of the research study as well as helped to guarantee the quality of the research process.

Reducing the research focus also helps to tackle a possible limitation of this methodology mentioned by Dede (2004): that the arguments and results obtained may proceed from a low percentage of the data collected.

About the Data Collection

On another hand, we observe that the exploratory character of these type of studies cause that not all variables of the in-class intervention of interest to the study can be known beforehand. Some of them area appreciated as relevant when doing the retrospective analysis, once the data collection has ended. Because of this fact, we suggest the realization of a very varied and complete data collection and recommend video recording the interventions. In this way, all the activity happened in the class can be explored afterwards and new elements of interest can be detected. Some data collected may be left aside if they don't provide relevant information.

As these studies includes several in-class interventions, it is necessary to collect information about the students´ mathematical activity between the sessions. It is important to know which contents are being worked to detect possible influences to consider when interpreting the data. This can be a source of weaknesses in the research study depending on the reliability of the information obtained in this regard.

Another difficulty comes from the intervention of a researcher as teacher. This double role of the researcher-teacher causes a tension as both roles need to be jointly articulated in the in-class intervention. In this sense, it is necessary to specify very clearly which are the objectives of each intervention before going into the classroom, and the researcher-teacher must stick to them. In addition, the researcher-teacher's teaching experience is an influence in the in-class interventions.

About the Data Analysis and Results

Regarding the data analysis, we want to highlight the complexity of the retrospective analysis due to a) the huge amount of data which is generated in this type of studies and b) that the data from each in-class intervention have to be analysed in a different way although the research objectives and the elements of analysis are the same. We also highlight the necessity to make a radical break between the preliminary analysis and the prospective analysis in order to be able to deepen in the phenomena of interest. Both analyses are substantially different. During the preliminary analysis, which needs to be quick, only a partial vision of the experiment and a preliminary version of the research conjectures and hypothesis are available. On the other hand, the retrospective analysis is calmer and is based on a complete vision of the teaching experiment. It requires deepening in the understanding of the teaching/learning situation. Transcriptions of the recording were only used for the retrospective analysis.

Because of these reasons, the results obtained from each of these analyses are significantly different, not only in its deepness. For example, in our study, the classification of the students´ performance when solving number sentences done during the preliminary analysis does not coincide with their classification in the retrospective analysis. From our point of view, this is one of the most important difficulties we have experienced in the use of this methodology: to distance yourself from the results obtained in the preliminary analysis done during the data collection as well as from the initial conjectures and the foundation of the design of each in-class intervention, in order to rigorously and objectively perform the analysis of the total data collected.

In the retrospective analysis, it is initially necessary to explore the whole information collected to identify the conceptual path followed by the group as well as the main elements and changes that can be appreciated. It is important to pay attention to the introduction of new strategies, actions or language forms. Some extreme cases allow identifying nuances between the students´ answers or behaviours. The possible interpretations for a given response allow appreciating a range of possibilities to deepen in by contrasting with other data. The process of analysis is a continuous dialectic between the data and the conjectures which are elaborated. It is important to ask oneself in which way the proposed tasks as well the specific interventions of the researcher-teacher contributed to the perceived changes and developments.

A final difficulty to mention, related to the presentation and justification of the results, is to delimit the origin of the knowledge which the researchers acquire along the research process, because of the continuous dialectic between the theory and the practice that occurred.

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