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Addressing the implementation problem in university teaching education: the case of study and research paths

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After more than fifteen years of research about study and research paths within the Anthropological Theory of the Didactic, we address the implementation problem of how to disseminate this inquiry-based instructional proposal to different university settings in first-year courses of statistics for engineering degrees. We adapt the methodology of didactic engineering as implementation strategy to create the didactic and pedagogical infrastructure that we consider necessary for carrying out an SRP by lecturers non-expert in didactics research. We present the first steps of the strategy that corresponds to a “proof of concept” project in process. The discussion raises new questions about how implementation problems can in turn nourish research in didactics.

Keywords: training of university mathematics teacher, novel approaches to teaching, implementation, study and research path, didactic engineering, infrastructure and superstructure.

INTRODUCTION

Study and research paths (SRPs) are inquiry processes proposed within the Anthropological Theory of the Didactic (ATD) that can be conceived as both instructional proposals and general models of inquiry (Bosch, 2018; Chevallard, 2015). The first SRP at university level was devoted to population dynamics and addressed to first-year students of a technical engineering degree. It was performed from 2005/06 to 2009/10 (Barquero et al., 2013). Since then, numerous implementations of SRPs occurred at several universities and following various modalities, as is recalled by Barquero et al. (2020, 2021).

In this context, a long-term investigative effort has been devoted to understanding the *ecology* of SRPs, that is, the conditions and constraints either favouring or hindering their implementation and successful dissemination, a critical dimension to address the implementation problem (Artigue, 2021). Given the importance of the teacher’s role in development of study processes, SRPs were also developed to train future teachers, giving rise to what is called *study and research paths for teacher education* (SRPs-TE, Barquero et al., 2018). Along a third line of research, connected to the two previous ones, the process of implementing an SRP became more and more explicitly modelled as a piece of didactic engineering (DE). DE is an experimental methodology to validate and develop knowledge models in instructional settings for the analysis of didactic phenomena (Artigue, 2020).

Until recently, SRPs have always been implemented by teams of teachers including at least a researcher in didactics, expert in the ATD. From 2018, lecturers non experts in didactics began implementing SRPs in engineering, business administration, and management university degrees. Nowadays, their long-term dissemination and self-sustainability are questioned: *how to implement SRPs in university education, beyond the controlled conditions established by researchers? What conditions are needed? How to train lecturers to implement inquiry-based teaching through SRPs?* First experiences were described in (Florensa et al., 2018; Fernández et al., 2024), but many questions remain open.

This type of questioning can be located in the new field of research about the implementation of results in mathematics education, to which has been devoted a thematic working group in CERME since 2017 and the recently created journal *Implementation and Replication Studies in Mathematics Education* (Jankvist et al., 2021, Koichu et al. 2021). Different approaches are used in such studies, especially design-based research. As Artigue (2021) suggests, the ecological perspective and the proposal of SRPs (both linked to the ATD) might also be used as “internal theoretical resources for this field of study” (p. 33). The aim of the research presented in this paper is to progress in this direction, by considering the specific case of the dissemination of research findings about SRPs in university mathematics education. Our study can be linked to the issues opened by the last INDRUM2022 panel about innovation in university teaching based on research (Florensa et al., 2023).

The research strategy we propose, based itself on the *didactic engineering methodology*, focuses on creating conditions for the dissemination, from research in didactics to the teachers’ practice, of the *didactic and mathematical praxeologies* (Bosch & Gascón, 2006) supporting SRPs. Our research questions are:

RQ1: How to model the conditions and constraints weighing on the dissemination of the pedagogical paradigm attached to SRPs?

RQ2: How to model the dissemination process in terms of didactic engineering, while including the necessary collaboration between researchers and lecturers?

FORMULATING THE IMPLEMENTATION PROBLEM WITHIN THE ATD

The dialectics between infrastructure and superstructure

When theorizing about SRPs, questions regarding both mathematical and didactical *infrastructure* and *superstructure* emerge quite naturally. Indeed, an SRP may be seen (schematically) as a process of inquiry that a group of students will undertake, aided by a (group of) teachers. This process is generated by a genuine question to which teachers and students must provide an answer. On the road to addressing this question, students will encounter and study already existing works and answers, searching through various pieces of media (books, articles, the Internet, experts, etc.). We can use the notions of infra- and superstructure to analyse the conditions needed to carry out the inquiry process:

In ATD, a technique can be described as the association of a device and “gestures”; in particular, a *praxeological infrastructure* comprises devices, large and small, which are works, and which enable *superstructural activities* to be developed—the execution of a given technique being based on this infrastructure. (Chevallard, 2009, p. 40)

For instance, searching for information on the Internet requires to carry out specific gestures (that is, a superstructural activity) on a given infrastructure, the web itself. A classroom in a school is also a necessary infrastructure to support teaching and learning processes (the superstructural activity), even if it can be replaced by other infrastructures, for example when online instruction becomes necessary. In the mathematical context, the infrastructures also exist in the form of a set of works prepared in the long run. For instance, in order to find the new coordinates of a point on the plane after a rotation by a given angle, complex numbers will prove to be an efficient infrastructure (by carrying out a superstructural activity based on calculations in \mathbb{C}).

The main value of the notions of infrastructures and superstructures is to point out that “there is a strong tendency, among individuals and institutions, to ‘forget’ infrastructure as a problem, while routinely exploiting it as a means. What prevails here is what we might call the ‘silence of infrastructure’” (Chevallard, 2009, p. 41). Therefore, setting up a study process goes along with the preparation of an appropriate infrastructure. For instance, a learning management system such as Moodle may form part of such an infrastructure. However, and quite clearly, this cannot work without a matching superstructure on the students’ side, closely related to their *praxeological equipment* (knowledge and know-how). The latter may either be already there or provided by the teacher. In any case, both the platform and a praxeological equipment would be needed, for students to perform a superstructural activity. In this respect, the ecological analyses may be seen as the study of the available pieces of infrastructure and the quest for potential sources to provide the missing elements:

Health is when infrastructure is forgotten; it is when the superstructural illusion prevails, pushing aside the question of the infrastructural conditions and constraints of superstructural activities. (Chevallard, 2009, p. 41)

In the rest of this section, we will develop this model in the particular case of the dissemination of the SRP pedagogy. The thickness of the veil provided by this “superstructural illusion” should then appear even more clearly.

Implementation methodology and didactic engineering

As mentioned before, the dissemination methodology we rely on is that of didactic engineering (DE). As Artigue (2020) explains, the DE methodology was introduced in the Theory of Didactic Situations as an experimental epistemology of mathematics. We are considering here the format and phases proposed by Barquero and Bosch (2015) to address the problem of the conditions for disseminating SRPs to university lecturers. However, instead of using DE for the design, implementation, and analysis of an SRP (as it is usually done), it is here used to guide and analyse both the design,

the implementation and the analysis of the dissemination of SRPs beyond the original designers. This strategy can also be interpreted as a second-generation DE (Perrin-Glorian, 2011), in so far as the result of a DE process (an SRP) becomes the centre of another DE supported by a collaborative process between researchers and teachers.

In this context, the four phases of didactic engineering may be seen as: (1) a preliminary analysis which aims at the delimitation of a didactic phenomenon, considering the ecology of SPRs and the consequent difficulties for their dissemination due to a lack of didactic and pedagogical infrastructures; (2) an *a priori* analysis of the dissemination strategy hinging on the design and use of appropriate infrastructures; (3) an *in vivo* analysis during the implementation of the dissemination strategy; (4) an *a posteriori* analysis of the strategy and its effects on the didactic phenomenon at stake. In this paper, we only address parts (1) and (2).

Infrastructure and superstructure of a dissemination process

Disseminating the pedagogy of SRPs using the methodology of DE puts at play three sets of infrastructural and superstructural elements, which we represent as layers:

The *outer layer* (*didactic* infrastructure) relates to a lecturer not expert in didactics teaching an SRP. Her students will develop a superstructural activity (an inquiry process based on an SRP) which will rely on a didactic infrastructure that the lecturer may arrange to some extent. However, the lecturer's gestures, in turn, rely on other infrastructures, which need to be accessible for the instructional process to take place.

The *principal layer* (*dissemination* infrastructure) relates to the dissemination process *per se*, which we address using the categories of DE (preliminary, *a priori*, *in vivo* and *a posteriori* analyses). That is, lecturers will develop the superstructural activity consisting in implementing their learning process to get acquainted with the pedagogy of SRPs. This should happen thanks to a disseminating infrastructure provided by us, the disseminators. It may include physical facilities (e.g. a website), but also immaterial ones (e.g. student-lecturers' personal heuristics on teaching and learning). As always, elements of this infrastructure will be out of our reach as disseminators. The description, justification and limits for this infrastructure is the object of investigation in the subsequent sections.

The *inner layer* (*scientific* infrastructure) regards the superstructural activity performed by researchers to create elements that would become parts of the previous infrastructure. This activity includes our theoretical framework, the ATD, and research results about SRPs' ecology and management (Barquero et al., 2021).

THE STRATEGY OF LABINQUIRY

To address the issues we identified, we consider the case of a dissemination project in process, LABINQUIRY, developed within the framework of the ATD. Results derived from previous projects have shown that SRPs have a strong transformative character and a positive impact on both students and teachers' performance and satisfaction (González-Martín et al., 2022). However, it is also observed that they are

only viable and sustainable under regular university conditions as long as the teacher leading the inquiry is an ATD researcher or works in close collaboration with a team of researchers. The analysis of the ecology of the SRPs' brought to light specific types of institutional constraints that originated from the prevalence of the *paradigm of visiting works* in current university education (Bosch, 2018; Barquero et al., 2021; Jessen et al., 2019). These constraints explain the difficulties for teachers to manage inquiry-based instructional proposals and the barriers found to disseminating them beyond research-controlled settings (Dorier & García, 2013; Shpeizer, 2019).

On the bases of these results, the main aim of the project LABINQUIRY is to create two related prototypes for the transfer of SRPs to secondary schools and universities. The first prototype is composed of an online platform (Moodle or Google Classroom) to support the design, implementation, and management of inquiry-based teaching proposals specific to the paradigm of questioning the world. Its main objective is to create good conditions for teachers "launching" SRPs thanks to a didactic infrastructure that provides them with controlled conditions that are resilient to the institutional constraints identified. The second prototype is LABINQUIRY-Community, an online social network for teachers and researchers to manage the interactions generated by LABINQUIRY. It aims at generating insights from the interactions and use them to integrate teachers into a community of practice to share experiences, pool data and resources from the instructional processes, receive live advice from other colleagues and researchers, and even implement inter-school and inter-university SRPs. The community of teachers is decisive for the dissemination and implementation of inquiry-based teaching proposals on a large scale and under different institutional conditions.

The choice of using a pilot SRP

We identified two main difficulties when it comes to implementing an SRP in ordinary teaching conditions: its *a priori* preparation and its *in vivo* monitoring. The preparation includes a quite thorough epistemological analysis, including the design of a generating question and its analysis in terms of a questions-answers dialectic, and the study of its conformity with the official curriculum. To make the implementation easier, we decided to provide lecturers with a proposal of such an analysis, which already implies many pieces of knowledge and know-how (see next section). Concretely, we chose a "pilot SRP", which we experimented for the past four years, to make sure its epistemological basis and pedagogical design are sound. This SRP has been taught by a lecturer in statistics, non-specialist in the ATD, and is generated by a question about air quality in given Low Emission Zones around Barcelona (Fernández et al., 2024; Verbisck et al., this issue). It was improved throughout the years, until its current state of development which contains the following innovations. First, there are well-identified phases of the inquiry process and introduction of labels to refer to them. Secondly, there is an explicit role of the questions-answers dialectics. Third, there exist an external instance who presents the generating question of the SRP and to whom its answer will be addressed. Fourth, a

more stable methodology for the students' logbooks (diaries) and intermediate reports is used, which are structured in a standardised way. Last but not least, there is a clearer organisation to report and debate on partial or temporary results and a more precise frame for their discussions in the classroom.

Preparing the SRP to be implemented so extensively might favour the dissemination process for several reasons. First, it is a fully developed example of what the pedagogy of SRPs looks like. Second, it can precisely arouse questioning about this early stage of the process, and so incite lecturers to try it by themselves on another topic. Finally, it allows the lecturer to focus on the in-class SRP's management, which is an inescapable stage of the whole procedure, and which itself poses numerous difficulties, some of which we will now further develop.

***A PRIORI* ANALYSIS OF THE DISSEMINATION PROCESS**

Elements of the ecological analysis

As mentioned before, numerous studies discussed the ecology of SRPs in experimental conditions. However, we must now consider the ecology of the dissemination of SRPs, which could be a whole other story. The last implementations with lecturers who are non-experts in the ATD show that, among the main constraints limiting the implementation of SRPs, the workload they suppose for lecturers is one of the most important ones. Since Spanish degrees in Engineering are mainly organised according to the European Higher Education Area (EHEA), SRPs are totally aligned with the guidelines promoting a student-centred and competence-based instruction. Even if this significantly reduces the curriculum constraint, the pedagogical changes it supposes remain almost under the sole responsibility of the lecturers. The lack of appropriate pedagogical and didactic infrastructures leads to overwork for lecturers, especially in time and dedication. So, we might face rather strong constraints at this level of organisation of teaching duties.

The ecological problem is then formulated in terms of how to create the missing didactic infrastructure and how to make it available to lecturers. Significant conditions and constraints will arise given the kind of teaching and learning practices which already exist in the academic institution: we need new superstructures to put the new infrastructures into play. On the one hand, the very idea of didactic training for lecturers is not shared in the academic world, as may be seen through the pervasive absence of training to teach at the university level in many European universities. This is another symptom of the historical discredit of teaching, still regarded as a *semiprofession* rather than a "true" profession (Etzioni, 1969). On the positive side, and to the difference of many secondary school teachers, university lecturers are more familiar to the paradigm of questioning the world due to their research experience. Indeed, it is closer to their daily practice to manage a study process whose only *raison d'être* is a research question, carry it out through a dialectics of questions and answers, or search for books and study new works.

A praxeological model for the pedagogy of SRPs

The construction of our reference model for the practice of teachers in the SRP's pedagogy can be supported by its praxeological analysis, that is, a description of the know-hows (sets of tasks performed using given techniques) backed by pieces of knowledge of a more theoretical kind (be they heuristic or scientifically grounded). To build such a praxeological model, we relied on two sets of sources. First, a theoretical characterisation of the SRP's pedagogy (Bosch, 2018; Chevallard, 2015). Then, a substantially developed practice of reference taking place within our research team, whose members design and teach SRPs since 2005.

Without going too much into details, let us simply say that we model partial or full praxeological organisations attached to didactic tasks of the kind: "proposing a generating question to the students", "generating a questioning process in the classroom", "discussing the relevance of a set of derived questions", "organising the search for already available answers and their validation", "summarising the students' proposals of intermediate questions and partial results", "organising and defending the final answer of the class". The types of tasks described are the ones considered the most helpful to monitor the inquiry process. All in all, the ecological and praxeological analyses provide us with a clearer view of both the existing infrastructure and the superstructural activity which should take place within it. Based on both, we inferred the specifications of the infrastructure we needed to develop to strengthen (or merely make possible) the implementation process.

An infrastructure congruous with the superstructural activity to be developed

As most universities today use online learning management systems, it appeared natural to transfer the content and material of the pilot SRP to lecturers as a Moodle or Google Classroom page. In addition, this might help teachers not to be overloaded with the design of the SRP, concentrate on its managing and, if necessary, adapting parts of it. Such a Moodle page can then play the role of an online infrastructure to support students' superstructural inquiry activities.

However, the course management of an SRP does not go without a body of know and know-how on the part of the lecturer. This is why the Moodle platform will come together with a website providing numerous texts, videos, research papers, etc. for lecturers to get acquainted with the theory and practice of SRPs. If we might formulate a generating question for lecturers learning how to implement SRPs, this could be: "How to teach the pilot SRP given in Moodle in my particular institutional context?". Consequently, the structure of the website should anticipate possible derived questions from this generating question, provide partial answers (or at least, offer a self-sustained media) to facilitate a rich and shared *milieu* between lecturers, researchers, and educators. That is, the dialectics of crucial questions and praxeologies is at the core of the construction of the proper infrastructure, for the implementation process to take place. Nevertheless, the infrastructure cannot solely consist in a website and a Moodle platform, as they would rapidly become too short

to cover each aspect of the forthcoming dialectics of questions and answers. This is why these two pieces of material infrastructure go together with the LABINQUIRY-Community. The latter's purpose is to provide an interacting community for lecturers to share, confront and validate their practice in the making. From a scientific perspective, the community will also be a valuable vantage point on the conditions and constraints concerning the dissemination of the pedagogy of study and research paths. The creation of this community can be considered as part of the paradidactic infrastructure supporting the dissemination process (Miyakawa & Winsløw, 2013).

CONCLUSIONS

Using the notions of infrastructures and superstructures opens the way to approach the study of the conditions and constraints weighing on the dissemination problem (RQ1), with the proposal of considering several layers: a didactic, a dissemination and a scientific infrastructure. This is a way to take the infrastructural problem into account, avoiding the “superstructural illusion”. The first aim of LABINQUIRY is to provide a didactic infrastructure to help lecturers implement SRPs starting from a pilot case rooted in an online teaching platform. To disseminate the didactic gestures of the corresponding superstructure, a disseminating infrastructure is developed following the stages of the DE (RQ2). The DE concerns both the infrastructure and the personal activity of lecturers, which then collectively learn about the pedagogy of SRPs thanks to the companion community. This infrastructure is based on previous results from the designed SRPs and from the analysis of their ecology and the didactic praxeologies needed to manage them.

Last but not least, the study of this LABINQUIRY SRP case also illustrates how the elaboration of such an infrastructure can only provide a limited part of the “total” infrastructure for the paradigm of questioning the world to disseminate at the university. A project like LABINQUIRY may contribute to develop our scientific knowledge on research dissemination. Moreover, this type of implementation project is also crucial for the data it provides to further develop scientific knowledge about didactic phenomena, which is the ultimate infrastructure of our research activity.

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