Application of Design Research Methodology to a Contex-Sensitive Study in Engineering Education

Rémy Crepon
Faculty of Education
Universidad Complutense Madrid (UCM)
Madrid, Spain
rcrepon@ucm.es

***Abstract*— In this paper, we describe and analyze how design research methodology has been implemented in one research project in engineering education. In a first part, we describe the research project in engineering education, we explain why we decided to apply the design-based methodology and how we did it. In a second part, we consider the methodology itself, and in the particular context of the study. First, we analyze the interactions between the instructors, the teachers, the students, the researcher, the designer and the object of design. We argue that a theoretical framework is necessary to inform the logic of the study. Second, we discuss how design research can be used to generate instructional design methods that are sensitive to the context. Third, whereas design methodology is dealing with purposive and small scale sampling, we consider phenomenography research to be an appropriate continuation of the design research, rather than statistical generalization.**

Keywords—engineering education research; research methodologies; design-based research; educational design research

I. THE RESEARCH PROJECT IN ENGINEERING EDUCATION

Although Higher Education Institutions (HEI) and companies have different objectives, organizations, and cultures, they hold similar learning and development necessities to grow engineering minds. They both aim to develop people's problem-solving capacities from authentic material, while keeping learners' motivation high and facilitating the career guidance of engineers [1]. New practical initiatives can be implemented in order to foster University-Business Collaboration (UBC) in Engineering Education (EE). The collaborative design of digital Learning Resources (LR) between university and business is deemed able to initiate and organize the exchanges between teachers and instructors and to set goals oriented towards the entire population of learners in initial and continuing education in engineering.

A. The purpose of the research

The research project under study is aiming to make explicit the assumptions and decisions for the design of digital learning resources that would support blended learning in both academia and industry. The specificity of the research project comes from the fact that it was improbable to find an existing project matching the conditions that would allow investigating the subject in the particular context of engineering education. Previous research work resulted too global and abstract to be useful in the particular UBC context. Indeed, we had to investigate a new and innovative teaching practice, with no prior example in mind. Consequently, we decided to set innovative educational practices and to study them at the same time. The epistemological positioning of our research is naturalistic and post-positivist as we would rather consider the subjective dimension of the design process of LR and its contextualization within real-life systems of thought, people and action. As a consequence, the research methodology had to enable qualitative, exploratory and descriptive research in a complex and changing environment as we try to understand particular situations or experiences rather than validate them. Besides, our research methodology would allow reporting with fidelity the multiple perspectives and the dynamics between the key decision makers in the educational system.

B. The Design-Based Research methodology

Design Based Research (DBR), firstly called "design experiments" by Brown [2] and Collins [3], then "development research" [4] or "formative experiment" [5], is a genre of inquiry [6] especially useful to design and study an innovative solution to educational problems at the same time [6,7]. DBR methodology is flexible, aims to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners, in real-world settings, and yields contextually-sensitive design principles and theories that can inform the work of others [5,8]. It particularly fits with our research objectives to account for decisions related to the design of LR which are sensitive to the context of academia and industry. DBR advances design, research and practice concurrently. A research methodology describes why and how particular methods are selected to reach the desired outcomes [10]. Considering DBR, it involves mixed research methods, both quantitative & qualitative, to gather and analyze data from real environments with a multitude of context-specific and context-dependent variables. In addition, DRM usually involves purposive and non-probability sampling.

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C. *The application of DBR methodology in the research project*

In the context of our research project, the researcher did set innovative practices that wouldn't be implemented in current educational and organizational settings. Indeed, there are few incentives given to teachers and instructors to design common LR across university and companies. Using DBR, we engineered an e-learning module in geostatistics, in real world settings and in collaboration with instructors from industry and teachers from university. The module, a self-paced tutorial, is aimed to be completed by learners before traditional class at university and before training in the company (Fig. 1). The module has been refined iteratively along the design process (Fig. 2). The research is conducted on interventions, that is to say directly on the methods we used to design the educational resource [6] (Fig. 3).

During the DBR, the researcher has a singular role: he is the researcher and the designer at the same time. As a researcher, he defines the investigation settings in authentic environments to reach the research outcomes. In our case, we decided to design a pilot module first, with an instructor from a multi-national company. The choices of the discipline matter and of the company have been done considering the gain of using blended learning in that particular field and also the later potential to gain interest of more stakeholders in other institutions. The course was new in that company. Its structure and the associated learning material had to be designed and developed from the beginning. Besides, the researcher initiated further contacts with other practitioners in companies and teachers in engineering schools. He got familiarized with the people, the resources, and the organizational constraints, and tried to lessen his obstructiveness in the learning environment [9]. As a designer, the researcher was also in charge of developing the LR along with addressing the specific issues that rose during the design and development phase. He made retrospective analysis with the practitioners in order to identify the strengths and weaknesses of the original design and he designed refinement to reach intermediate and ultimate design goals. He also tried to minimize the bias of being the single designer, and of external influences.

II. ANALYSIS OF THE METHODOLOGY

In this part, we conduct an analysis of the DBR methodology as it is implemented in this research project in engineering education.

A. *Interactions and inspiration*

First, we analyze the interactions between the instructors, the teachers, the students, the researcher, the designer and the object of design.

As we said previously, in the research project under scrutiny, the researcher role and the designer role are held by the same person. It corresponds to the "interventionist" dimension of DBR [6].

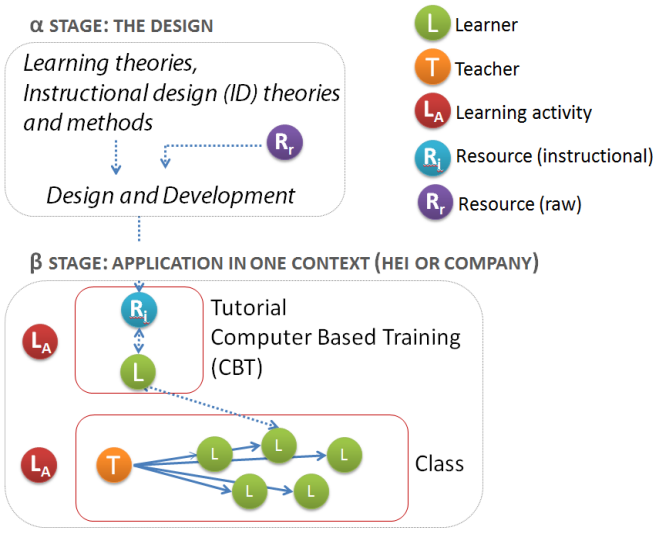

Fig. 1. The research study: learning resources design for blended learning at HEI and company

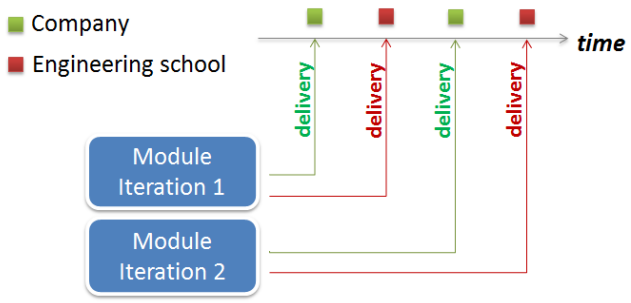

Fig. 2. The e-learning design process: an iterative approach

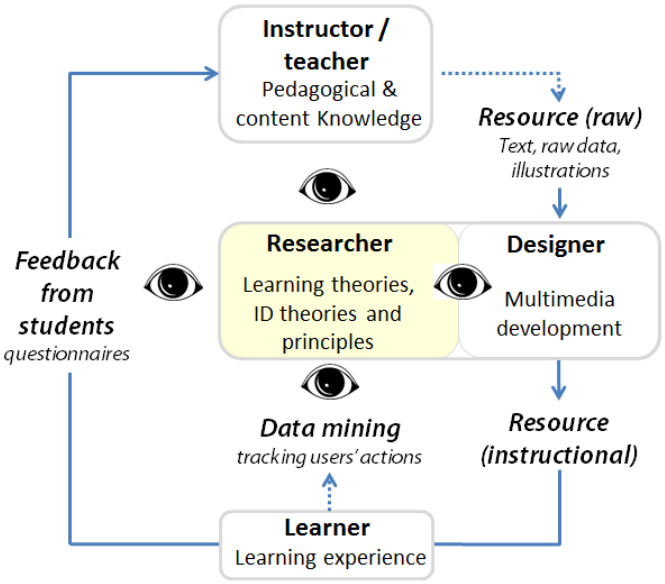

Fig. 3. The research is conducted on interventions

The research and design activities are retroactively analyzed by the same person but from different standpoints. As a researcher, the main goal is to guarantee the scientific value of the study, the rigor of the research and link theory with practice in education. One major task in DBR is to check results' confirmability, that is to say "the assurance that researcher findings are rooted in contexts and persons apart from the researcher, and that they did not merely arise in the researcher's imagination" [10]. As a designer, the considerations are rather technical. Designers neither adopt their clients' values nor impose their own. They rather act as facilitators and they adapt to their clients' perspectives, beliefs, and strategies while aligning and extending the design processes [9]. The iterative nature of DBR gives milestones and time to reflect at the end of each phase, both for research and design purpose. After the implementation of the first design at the company and at the engineering school, the decisions, the opinion of instructors, teachers and students have been analyzed from a pedagogical perspective, feeding the research and leading to design improvements.

Along the study, the researcher developed and maintained contact with instructors in companies and with teachers in engineering schools. It represents the "collaborative dimension" of DBR [6]. The exchanges include meetings, phone and web conferencing. For the pilot design, the instructor has been interviewed first. Then, the discussions were mainly focusing on the structure of the course, on the teaching matter itself, on the main concepts and principles of the discipline, on the representations to use and on the design of self-assessing tools through short practices by the mean of interactive exercises or quizzes. Later, the exchanges with the teachers in the engineering schools and the instructors consisted in adapting the design to the course structure when necessary and making small adjustments. In addition to these activities, similar to project management practices, instructors and teachers were requested to fill out a questionnaire aiming to collect their opinion and beliefs on e-learning, their feedback on the e-learning module and their recommendations. Another questionnaire was sent and filled out by the learners during the last day of the course.

We argue that the exchanges between the researcher, the instructors and the teachers are not random. A theoretical framework is necessary to inform the logic of the study. This is the "theoretical" orientation of DBR [6]. Theories in learning and educational sciences are used to frame the research, its methodology and also the logic and criteria of the design itself [5,9]. In our case, the research project follows an approach consistent with its epistemological positioning. Indeed, we follow socio-constructivist theories and the principles of situated cognition.

Socio-constructivist approaches assume that all knowledge is constructed from social interactions and from the learner's previous knowledge [11], might it be true or false [12]. It is important to recognize that a teacher is a former student who developed advanced understanding and expertise in one particular field. Consequently, we collected information on people's experience in order to understand how the nature of instructors' and teachers' accumulated knowledge would influence their prescriptive design of the LR. Another example of socio-constructivist influence in the research is DBR itself. As we previously said, DBR is an iterative process, making it a constructivist approach by nature. In fact, cyclic implementation and analysis are necessary to construct understanding on what works and what doesn't.

According to situated cognition, every learning experience is embedded within a natural, social and material context. Therefore, the role of tools is important to be well understood, especially for learning activities [7]. Engineers are surrounded by technical equipment and computing systems. As a way of example, the necessity to use scientific tools often makes demonstrations, measurements and examples for teaching purpose a lengthy process. E-learning can help to remove some material and time constraints. In addition, from the perspective of situated learning, the cognitive process exploits available structure in the natural and social environment [13]. It is called the "embedding thesis". Therefore, in the context of the study, we particularly get interested in understanding the "complex transactions between embodied minds and the embedding world". In particular, we consider the use of technology as a powerful way to improve efficiency and to extend learners' epistemic reach while it allows off-loading cognitive work onto the environment [13].

B. A context-sensitive approach

At any time of the research, the researcher finds and creates the conditions to achieve his research goals. In real world settings, it implies to constantly adjust to many dynamic variables and also to external influences. It is the reason why DBR is said to be "flexible" [6]. This unique flexibility for a research methodology gives DBR the possibility to generate instructional design methods that are sensitive to the context. Actually, natural and disruptive changes in the organization of the study can turn out to be opportunities to generate context sensitive principles and to extend the research reach. The first example is the pilot module, also called "iteration 1". It showed so much interest that we kept it as the object of study for the entire DBR. In addition, whereas the pilot module was hosted outside the company's Learning Management System (LMS) for the first training, we later get the chance to host the resource directly on the company's LMS for a formal corporate blended course. This allowed us to lower the influence of the delivery method on learning, which is not the primary focus of the research. One other example of unpredicted change has been the arrival of a new teacher at the engineering school making possible to reconsider the course structure in geostatistics and to integrate the e-learning module as a course activity in its own right. Finally, the corporate training had once been postponed of two months. It has been the opportunity to collect specialists' opinion about the questionnaires and we finally had time to use the reviewed questionnaires for the corporate training.

DBR is a "multilevel" inquiry [6]. In contrast with laboratory experiments where controlled variables are measured, the real-world settings expose us to factors that are not directly related to the study. As a consequence, the general orientation of the research in education can easily be in tension with administrative, political, financial or technical considerations. The risk to deviate from the desired research

trajectory is proportional to the number of systems in interaction (institutions, people…). As a result, the researcher should facilitate the adoption of the object of design to make the study happen. A high level of effort can be put in administrative or technical tasks while it won't necessarily be reflected in the research results. Doors have to be opened to get the research done, and sometimes it needs the active support of decision makers such as the teachers, the instructors and in some cases the program directors, the pedagogical advisers and the managers. As far as we can judge, these hurdles partially explain why DBR is demanding in order to study real world phenomenon and even more across the public and private sectors. Anyhow, the main value of DBR is precisely to account for practices and determine factors which will promote or prevent the success of the design in real-life contexts. This characteristic is prevailing for the construction of theoretical frameworks or principles which will guide the design of digital LR for blended learning in engineering within the HE and corporate contexts.

III. CONCLUSIONS

In the context of the research project described in this paper, DBR has emerged as the most appropriate research methodology in order to set innovative educational practices and to study them at the same time, and in real world settings. DBR implies working in high uncertainty environments because many external variables are at play. However, these external factors do represent the natural embedding environments for which the object of design has to be engineered. Consequently, if the researcher is reactive and creative enough, he can leverage on unpredicted changes in order to obtain context specific results.

The DBR is a genre of inquiry where reference theories are necessary to inform the research decisions, to build and use relevant research tools. Critical tasks of the researcher are to guarantee the feasibility of the interventions, to minimize the bias of being the single designer and to build a collaborative working environment while lowering research obtrusiveness. DBR is not a strictly scientific research method as it is neither designed to validate hypotheses under controlled conditions, nor to validate cause-and-effect relationships, nor to predict phenomenon. However, it is a good research methodology to generate induced theories and principles from observation of innovative practices in real world environments.

IV. FUTURE ORIENTATIONS

Whereas DBR, implemented in real world environments, has a high ecological and external validity [6], we have to remind that it is dealing with purposive and small scale sampling. Therefore, the range of contexts for the application of the research is limited; it concerns the design of LR for blended learning, in engineering education, and for HEI and companies. This considerably limits the size of the population most likely to use the object of design (the tutorial module). Consequently, we don't consider using statistical generalizability for the purpose of this research [10].

Actually, once the object of design is refined and available, it can be implemented in similar contexts than the one of the study. Indeed, we contemplate applying the e-learning tutorial to other academic or corporate institutions in order to capture the variation of how the users, might they be learners or teachers, experience it. Phenomenography research [14] methodology appears to be an appropriate continuation for the design research. Phenomenography is a research method for categorizing the totality of qualitatively different ways in which people experience, conceptualize, perceive, and understand various aspects of an object of interest (phenomena) [9,14]. Our purpose would be to learn how teachers, instructors and learners describe the LR and try to make categories in order to capture the variation. We are interested in understanding if certain perceptions are more prevalent in one group or culture than in another [15]. More interestingly, we would like to understand how the differences in approach are related to the different contexts (HEI and companies). Therefore, we would rather try to determine which theoretical insights and/or practical interventions of the study can be transferred to other contexts [6].

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