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THEDRE's Framework: Empowering PhD Candidates to Efficiently Implement Design-Based Research

Nadine Mandran · Mathieu Vermeulen · Estelle Prior

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Abstract This article presents a method to help PhD candidates in the implementation of Design-Based Research (DBR). It focuses on a process and a set of guides designed to accompany doctoral candidates in the different stages of their thesis. It also proposes a tenth principle concerning the definition of indicators used to drive the thesis. Evaluation is driven using a qualitative approach. Training programmes were conducted with 57 PhD students and 47 supervisors in 2019 and 2020. Participants in these sessions used the guides in the context of their thesis topic, then evaluated them. The results obtained show that the guides allow doctoral students to structure their reflections and better manage their thesis work. They also enhance the relationship between PhD students and their supervisor because they offer a means by which to collaborate regarding the thesis subject and research tasks.

Keywords empowerment · Design-Based Research · PhD candidate · tools · iterative method · THEDRE

1 Introduction

The world of computer research is full of enquiry today when confronted with the problematic of repeatability^{1,2}. The problem is even more blatant with regards Human-Centred Computing Research (HCCR) which requires human

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¹ <https://www.nature.com/news/2011/111005/full/478026a.html>

² <https://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.0020124>

involvement, for example in order to modelize and empower human activities such as teaching. It is true that HCCR is often applied in real situations (*e.g.* classrooms), creating the problem of repeatability. Results are hard to repeat from one teaching environment to another. However, it is necessary to be able to report on the quality of fieldwork that contributes to the creation of scientific knowledge. For this, frameworks and tools are required which show how research is conducted in this domain. They must precisely describe the experiments and data produced, and guarantee the traceability of this field. In the case of Technology Enhanced Learning (TEL) research, one of the most frequently quoted methods is that of Design-Based Research (DBR) (Collective, 2003; Collins, 1992; McKenney & Reeves, 2018; Reeves et al., 2005; Wang & Hannafin, 2005). This method lays down principles and properties but remains subject to a wide variety of interpretations due to an absence of tools and the fact that the implementation processes aren't described. Researchers in this domain often remark on this, as was the case of a colleague in 2019: "We all do DBR because we mix data production methods, work in situ, do iterations and integrate users. But apart from that?..." In our opinion, this method is important because it falls within in a systemic and pragmatic approach that supports the implementation conditions of HCCR, and therefore TEL. Thus, concerning the difficulty of setting up DBR, the problematic we have to solve is: which tools and which processes can we include in TEL research to facilitate things? This problem is all the more difficult for doctoral students having not yet acquired HCCR skills (Lebis et al., 2020). They often have trouble designing and performing experiments to validate their scientific contribution (Mandran & Dupuy-Chessa, 2017). The first of these concerns work production; they have trouble determining what their final production will be. The second concerns computer scientists' lack of training with regards to methods of production and data analysis in HSS (Humanities and Social Sciences) permitting the human factor to be integrated in a rigorous way in design and evaluation. Concerning the difficulties met by doctoral students when setting up DBR, we ask the following question:

How to empower DBR to facilitate research work of doctoral students as well as their collaboration with supervisors?

Otherwise, in the field of System Information (SI) research, a model of methodological research conduct named THEDRE provides a language for the design of research conduct methods in keeping with the different work situations faced by researchers in the field of HCCR (Mandran & Dupuy-Chessa, 2017). Using this model, researchers can create their own traceable research conduct model while adapting it to context. In this article we propose an instantiation of the THEDRE model to guide and trace research performed as part of DBR. Our aim is to provide a research conduct method for TEL adaptable to each researcher while respecting, at the same time, the concepts and properties of DBR. The method and tools proposed were created during work to accompany doctoral students and their supervisors at the LIG (*Laboratoire d'Informatique de Grenoble*) from 2009 to 2017 (more than 30 theses). Subsequent to this,

the tools were evaluated during training with doctoral students and researchers (57 PhDs and 47 supervisors, from 2019 to 2020) via three iterations. Having explained the epistemological and methodological framework relative to our work, we describe the properties of DBR and analyse how it was used in recent research articles. Next, we propose a number of guidelines adapted to THEDRE tools then associate the principles of DBR with these. Thirdly, we explain how we evaluated our proposition within the THEDRE training program and, last of all, give results concerning these evaluations before concluding with the contribution of THEDRE for DBR and opening a perspective on two principles of DBR difficult to implement as part of a doctoral work.

2 Scoping our work

The multidisciplinary aspect of HCCR makes necessary a language and shared principles understandable by all actors of this type of research. This is why, in order to grasp the concepts associated with our problematic, it seems useful to explain the notions and vocabulary used in this article. In this section we begin to speak of the theoretical framework of TEL research. Lastly, we explain the importance of the epistemological posture for this type of research.

As we address the problem of research guidance and traceability of its production, we need to specify which research productions are present in TEL. To define them in a formal way, and to refer to a theoretical framework, we use the work of Herbert A. Simon (Simon, 1962)³, “The Sciences of the Artificial”. The construction of “artificial objects” (Simon, 1962) is required for the elaboration of this research. He remarks, “Analysis should be accompanied by a lot of experimental work”. Thus, “artificial objects” should be constructed with users and context in mind. Next they must be tested with the same user. The design of “artificial objects” makes it necessary to consider several elements: “The intention, the characteristics of the artificial object and the environment in which it will be implemented”. The principles concerning the boundaries of the sciences of the artificial (Simon & Le Moigne, 2004, p31) can be applied to TEL research:

1. The final version of the object isn't always known at the outset of the construction process, the different steps modifying its state and causing it to evolve in keeping with users and context.
2. This vision being not necessarily clear, the object's construction requires several feedback sequences which take into account its evolution. The experimental phases are iterative.
3. It is constructed to reply to an intention.
4. In order to be operational, this object attempts to comply with users' needs.
5. The object may be similar to a natural object in that it replaces certain human tasks.

³ The book “The Sciences of the Artificial” was translated into French by J.L. Le Moigne in 2004. We have used this translation. (Simon & Le Moigne, 2004)

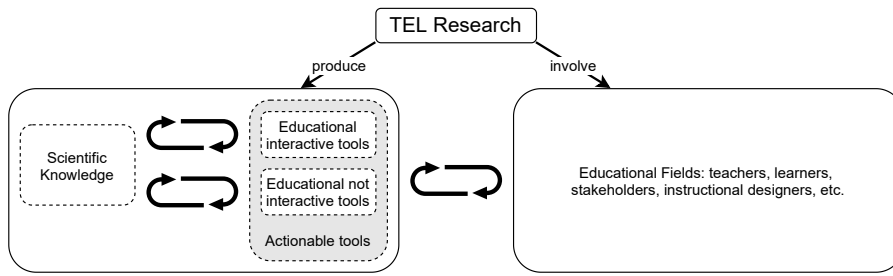


Fig. 1 Context and positioning of TEL research in the sciences of the artificial

We postulate that TEL research is a science of the artificial in that it gives rise to scientific knowledge associated interdependently with tools created for and by humans. Figure 1 illustrates our position. “Artificial tools” are often named artefacts. But an artefact can be a tool or a “corruption of results” from an experiment due to the technical/experimental process. So we use the concept of “actionable tool”. These tools are said to be actionable because they are activated by the user.

Proposing a research conduct method makes it necessary to take position from an epistemological posture. “Methodology without epistemology is the ruin of reflection” (Avenier & Thomas, 2015). General principles must be laid down to guide the constitution of scientific knowledge and its validation; in other words, the moral framework deliberately chosen by the researcher to elaborate valid scientific knowledge.

Referring to Piaget’s definition of epistemology as “the study of valuable knowledge constitution”, we define an epistemological framework as a conception of knowledge relying on a set of mutually consistent founding assumptions relative to the subjects that epistemology addresses. Hence, these assumptions concern the origin and nature of knowledge (epistemic assumptions), how it is elaborated (methodological assumptions), and how it is justified. Most epistemological frameworks also rely on founding assumptions that concern what exists (ontological assumptions) (Avenier & Thomas, 2015).

In order to generate scientific knowledge in the field of TEL, we chose the epistemological posture known as “pragmatic constructivism” (Avenier & Thomas, 2015). In this posture, the research process contributes to the generalization and refinement of scientific knowledge. It is based on five hypotheses: H1) Representations of the real exist. H2) Humans express their knowledge of the world. H3) The construction of the scientific contribution and tools is incremental. H4) Tools have a finality in a given context. H5) The research question can evolve in accordance with academic, technical and societal context and field results. The validity of the scientific contribution reposes on three aspects: 1- The multiplicity of data, 2- Reliability of data, 3- Documentation (Avenier & Thomas, 2015). The hypotheses proposed by pragmatic constructivism allow scientific knowledge based on reality to be constituted and to

place it in a context. This position also allows research to be conducted with tools designed on the basis of theoretical models and to include humans in the construction and evaluation of these tools. These aspects correspond to the way TEL research is conducted.

3 State of the art

To assist TEL research, Design-Based Research (DBR) is a possible method of research conduct (Wang & Hannafin, 2005). DBR provides a framework for research that produces tools humans can use, applied in a real context. However, this method is employed differently depending on the author. This point is positive because it is a method that can be adapted to different research contexts, but this poses a problem concerning comparability of research conducted using DBR. To solve the difficulty of setting up DBR, Reeves et al. (2005) proposes an explanatory diagram. This diagram (Figure 2) is often quoted in the literature. McKenney and Reeves (2018) propose to divide the DBR process and guiding tools. In this section we present the foundations and principles of DBR before going on to study, by means of fifteen recent publications, how it is applied in the field.

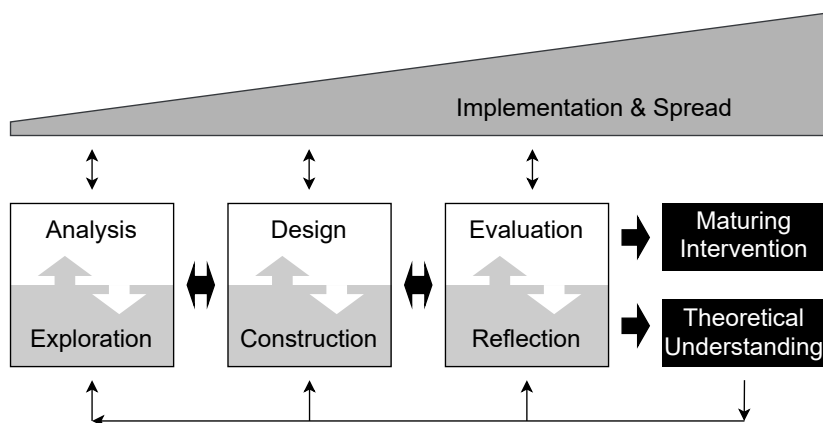


Fig. 2 Generic model for conducting design research in education proposed by (McKenney & Reeves, 2018)

3.1 Foundations of Design-Based Research

The research conduct method referred to as Design-Based Research (DBR) owes its origin to the writings of (Collective, 2003; Collins, 1992). Collins

(1992), in studies at the Center for Technology in Education (New York), performs a synthesis of technological research present in education and proposes to develop a conduct method appropriate for experiments in a classroom situation, in the presence of pupils, to assess whether new technologies can be of use to learning. According to Collective (2003), “Design-Based Research can help create and extend knowledge about developing, enacting and sustaining innovative learning environments”.

3.2 Principles of Design-Based Research

In 2005, Wang and Hannafin (2005) proposed nine principles applicable to research in this field on the basis of experiments conducted as part of TEL. These principles concern research organization; the involvement of actors and consideration of the field; the production and analysis of data; documentation and generalization. Table 1 presents a list of these principles. Three principles are given concerning organization: “The design of tools must be supported by research from the start” (P1). The idea is to identify pertinent resources for the needs of the project by way of the literature and different design examples. The second principle is, “Practical goals must be established to develop the theory and propose an initial plan” (P2). This step serves to identify what is produced with whom and in accordance with which planning. And lastly, the third principle, “The scientific contribution and actionable tools must be reconsidered regularly” (P3). In this respect, DBR is an iterative method allowing scientific contribution, the actionable tools and research questions to progress in the course of the process. In order to monitor the advancement of the work Collins (1992) proposes to add goal indicators. This proposition wasn’t included in the description of the DBR and, as far as we know, wasn’t used. This said, identifying indicators allows goals to be fixed and decisions to be made at certain moments of the process and also to launch a new cycle. Regarding experiments, a grounding in the field is one of DBR’s strong points. “Research should be conducted in conditions representative of the real world” (P4). The idea is to construct and evaluate tools and devices in the field, in an ecological situation. In this way, “Field actors are included as collaborators in the research” (P5). To permit production and analysis of data, one of the principles is “The systematic and targeted implementation of research methods” (P6). Here, “research conduct method” refers to methods used to produce fieldwork data to answer the research question. The authors recommend use of several data production methods whether they be qualitative or quantitative. Mixing methods is prescribed by other authors (Creswell, 2013). In DBR, “Data analysis should be done soon after production” (P7). Thus, continuous data analysis helps prevent a loss of relevance between the research question, the field and the results obtained.

One strong principle relies on “Documentation of the process, goals, production, analysis of data and results to testify to the work accomplished” (P8). Documentation of the research process is central in DBR, it guaran-

tees the quality of work as well as scientific transparency. The last principle of DBR concerns the generalization of research work (P9). For Wang and Hannafin, "Researchers should optimize local design without losing sight of generalization". This is necessary to construct tools or local models that can be generalized (*e.g.* by confronting them with several contexts).

3.3 Design-Based Research Process and guidelines

Over and above these principles, some propositions were made to structure a TEL research conduct process, as evoked previously by Reeves et al. (2005) who proposed a diagram (figure 2) . McKenney and Reeves (2018) propose a structuring of DBR and guidance via tools rooted in a project conducted over a period of four years to study the impact of a computer to sustain the teaching of sciences and mathematics, the programme known as CASCADE-SEA (McKenney & Van den Akker, 2005). This project was recorded, "Carefully documenting the iterative process of analysis, prototype design, evaluation, and revision". The research subject included technical and human aspects. "We sought insight into the characteristics of a valid and practical computer-based tool that possesses the potential to affect the performance of its users". This project was also an opportunity to question the research process, "Furthermore, this research has contributed to the articulation of design principles and related developmental research methods". McKenney and Van den Akker (2005) proposed several facilitating guides to improve collaboration and traceability. While these processes describe the main steps of research conduct work, they remain schematic. Also, the guides proposed do not cover the whole research process. What is more, they are akin to project management tools and not necessarily formative for doctoral students.

3.4 Design-Based Research implementation

We looked at research conducted with DBR tools in order to study how it was set up. To select research using DBR, we used the electronic documentary resources gateway Bibcnrs ⁴ to extract articles from between April 2015 and April 2020 whose keywords included the terms "design-based research" or "design based research". We selected specialized reviews associating education and computer science identified as reference material. The publications chosen were "Computer & Education", "Education Technology Research and Development" and "Journal of Educational & Technology Society". We adopted the hypothesis that if the keywords included these two terms they must be important for their authors and be used as management tools. We found 15 articles in which we analysed the implementation of DBR in accordance with the principles announced earlier. We subsequently abandoned two articles whose authors mention DBR but whose work does not allow study of how DBRs were

⁴ <https://bib.cnrs.fr/>

applied. In the article of Blackburn (2017), the author presents the results of a study without describing its overall context. In an article by Valentine and Kopcha (2016), the experimental approach and methods of data production and analysis are not sufficiently described to allow it to be known if the principles of DBR were implemented. We analysed the thirteen other articles while noting whether the nine principles of DBR had been applied. In accordance with principle (P1), “The design of tools must be supported by research”, the authors of the fifteen articles describe the tool they are to study in the field as being a tool designed on the basis of research results. In these articles the context of application is often amply described, in only one case is it not very precise (Ozverir et al., 2017). The iterative aspect is to be found in all articles (P3). Malinverni et al. (2016) also proposes the term “continuous improvement” which corresponds with a grounding in a quality approach. The number of iterations is variable: only one (Hirumi et al., 2016; Minshew et al., 2017), between two (Chiu & Churchill, 2015; Gresalfi & Barnes, 2016; Ozverir et al., 2017; Yu-Ju Lan et al., 2018) and three (Kim et al., 2015; Li & Chu, 2018; Zydneyn et al., 2020), and up to five (Vanderhoven et al., 2016). In accordance with the principle that determines the identification of goals and primary planning (P2), the authors describe their objectives and graphs are proposed to map the progress of research and experimentation. That of Reeves et al. (2005) is used in two of these articles (Ozverir et al., 2017; Vanderhoven et al., 2016). On the other hand, there is no mention of work planning, or of indicators to follow the work. Regarding grounding in the real world (P4 and P5), the authors work in an educational context. In the field, the number of participants varies between 4 and 122 (teachers and learners). A research project with four learners studies handicapped students (Yu-Ju Lan et al., 2018), which may explain the low number of participants. Another article concerns tests in laboratories (10 children) without mentioning an extension in a real situation (Cakiroğlu & Gökoğlu, 2019). For the two principles concerning the production and analysis of data (P6 and P7), the methods used to produce data, and the justification of these methods, are given in all the articles. With the exception of one article (Cakiroğlu & Gökoğlu, 2019), they all mention several data sources and data production methods to define the research question. This need for diversity of methods seems to incite the authors to use DBR. However, the immediacy of analysis to avoid loss of relevance is only present in two articles (Vanderhoven et al., 2016; Yu-Ju Lan et al., 2018). With regards documentation (P8), a key principle of DBR, the data production methods, results and analysis are amply reported in all articles. The steps of pre-processing, processing and validation are not presented in the articles and therefore not documented. Nonetheless, these steps seem to us fundamental to explain how results are constructed (*e.g.* unusable interviews, absurd data, etc.). One of the founding principles of DBR is the collaboration between all the field actors contributing to research (P5). This principle is difficult to apply notably because those concerned can have diverging obligations and interests. In the thirteen articles that were extracted, five mentioned this collaboration (Chiu & Churchill, 2015; Gresalfi & Barnes, 2016; Minshew et al., 2017; Yu-Ju Lan et al., 2018; Zydneyn et al., 2020). The

number of actors collaborating remains low (between 3 and 4 persons). The article by Minshew et al. (2017) mentions three roles: a teacher, a researcher and a methodologist. The last principle of DBR is related to generalization (P9): "Researchers must optimize local design without losing sight of generalization". Not all the articles propose generalization of a model; only a few do so (Novakovich et al., 2017; Vanderhoven et al., 2016; Zydney et al., 2020). On the other hand, the articles always present results concerning the tool developed or its impact without evoking, despite this, a generalization of results. This last principle (P9) appears to have been neglected in the use of DBR. In the articles analysed authors who chose the DBR method followed certain principles: they began with research to design a tool, research was conducted in an iterative manner; they used several complimentary data production methods and documented the process. However, the collaboration, an important principle of DBR with regards the co-conception of the research question and actionable tools, is absent from all the articles. When described, the authors don't say how it was implemented and what the advantages and disadvantages were. The principles that were least used or described were the a priori planning of research work and the documentation of data pre-processing and processing. The immediacy of data analysis to improve tools is not indicated. In addition, the finality of certain articles isn't always a generalization but the result of a study or the production of a tool. Table 1 makes clear which DBR principle is addressed in each article.

3.5 Advantages and limits of DBR

The advantages of DBR concern the nine basic principles which justify iterative field research conducted in collaboration with the different actors. These principles are of interest because they set down the milestones of a research epistemology rooted in pragmatic constructivism. Nonetheless, the criteria of value and validity used to create an epistemological framework (Avenier & Thomas, 2015) are not mentioned. Moreover, DBR isn't presented as a process, rendering its implementation difficult. To solve this problem, descriptions of the research conduct process and tools to document the latter were proposed (McKenney & Reeves, 2018; McKenney & Van den Akker, 2005). However, in our view, these documents remain imprecise, do not provide a process modelization language, and do not descend to the level of tasks to be accomplished. Furthermore, they resemble project management tools, not necessarily formative for doctoral students. For example, principle P9, concerning the question of genericity, seems to us difficult to deal with as part of a doctoral work. Not only this, there is no adaptable process allowing work with DBR to be monitored, and, more specifically, for young researchers. What is more, the iterative principle of DBR is pertinent to the independent progression of knowledge, and tools, but, despite the proposition made by Collins (1992), does not advocate use of indicators to follow the iterative cycles. To address these shortcomings, we propose to outline the research conduct method named THEDRE

Table 1 Summary of the content of the articles according to the principles of the DBR (x: principle used, -: not specified).

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
(Ozverir et al., 2017)		Goal Plan	2	x		x		x		no
(Malinverni et al., 2016)	x	Goal	-	x		x		x		no
(Hirumi et al., 2016)	x	Goal	1	x		x		x		no
(Minshew et al., 2017)	x	Goal	1	x	x	x		x		no
(Chiu & Churchill, 2015)	x	Goal	2	x	x	x		x		no
(Gresalfi & Barnes (2016)	x	Goal	2	x	x	x		x		no
(Yu-Ju Lan et al., 2018)	x	Goal	2	x	x	x	x	x		no
(Kim et al., 2015)	x	Goal	3	x		x		x		no
(Li & Chu, 2018)	x	Goal	3	x		x		x		no
(Zydney et al., 2020)	x	Goal	3	x	x	x		x	x	no
(Vanderhoven et al., 2016)	x	Goal Plan	5	x		x	x	x	x	no
(Çakiroğlu & Gökoğlu, 2019)	x	Goal	-	x				x		no
(Novakovich et al., 2017)	x	Goal	-	x		x		x	x	no

(Traceable Human Experiment Design REsearch) and its guides designed to help doctoral students lead research in accordance with the principles of DBR (Mandran & Dupuy-Chessa, 2017).

4 THEDRE, a method to empower DBR

Our contribution will involve proposing a new principle for DBR as well as a set of guidelines to conduct TEL (Technology Enhanced Learning) research as part of DBR and to provide doctoral students with markers. First of all, we briefly present the method. Next, we describe six of THEDRE's guides. As many versions of these tools exist and are easily accessible via Internet, we only present those specific to THEDRE. We give a description for each of these and indicate in what way they reply to the principles of DBR. Before describing the THEDRE method, we propose to add a new DBR principle, namely "set up goal indicators to drive the research process" (P10). Wang and Hannafin (2005) propose that goals be fixed and an initial plan with principle 2. However, in the implementations of DBR no goal indicator was identified.

This is why we wish to add a principle to organize research work and drive it. The idea is to “set up goal indicators to drive the research process”. Table 2 presents, according to category, the nine initial DBR principles plus the new principle (P10).

Table 2 Five categories to organize the ten principles of DBR

Activity categories	Principles
Organize research	P1: Identify pertinent resources for the needs of the project by means of existing literature and the different examples of design P2: Establish practical goals to develop theory and propose an initial plan P3: The scientific contribution and actionable tools must be reconsidered regularly P10: Setting up goal indicators to drive the process
Include actors and consideration of the field	P4: Research should be conducted in conditions representative of the real world P5: Field actors are included as collaborators in the research
Produce and analyse data	P6: The systematic and targeted implementation of research methods P7: Data analysis which should be done quickly after production
Document	P8: Documentation of the process, goals, production, analysis of data and results to testify to the work accomplished
Optimize local design vs generalization	P9: Researchers should optimize local design without losing sight of generalization

4.1 Presentation of the method

THEDRE is a method model used to conduct, guide and trace HCCR (Mandran, 2018; Mandran & Dupuy-Chessa, 2017). THEDRE was created to facilitate the research work of doctoral students and, more particularly, to help them design experiments involving humans. This method also aims to improve communication between students and their supervisors. Technically speaking, THEDRE belongs in a quality approach called “continuous improvement”. The research process is structured according to the four actions of the DEMING cycle: Plan-Do-Check-Act (Deming, 1993). To follow the cycles, goal indicators are established to monitor the work performed. The THEDRE method also recommends a user-centred approach to be adopted (ISO 9241, 2010) which allows the user to be integrated, or not, as the case may be, into the different design steps of a digital tool. As research involving humans in a real context is hard to repeat, the THEDRE method proposes to trace the research activity. This said, tracing everything, documenting everything, poses a problem

of data profusion and time loss. In order to minimize these problems, guides are proposed which permit the essential part of the work to be documented, only prominent and useful elements are conserved. Moreover, these guides can come in useful when writing certain sections of a thesis (*e.g.* state of the art). Given that THEDRE is a method model, all the guides are adaptable to different domains or contexts. We can therefore propose them to perform research within the framework of DBR.

4.2 THEDRE and the principles of Design-Based Research

In what follows, we explain how the THEDRE method and its guides reply to the principles of DBR. Globally, the documentation principle of DBR (P8) is covered by all the guides which aim to accompany doctoral students, to keep tabs on their work, the evolution of their propositions, and to document the research process. At each iteration, the scientific contribution, the tools and the research questions can be adjusted. Such is the iterative principle (P3) of DBR. In the next part of this section, we present six guides specific to the THEDRE method. (Note: the names of the guides have sometimes evolved during the iterations, as participants have suggested new names).

4.2.1 Guide 1: Iterative method, tasks and alerts: PDCASE

The guide “Create your iterative research conduct method” allows doctoral students to be informed of the steps and activities they will be forced to deal with during the entire course of their research work. It is based on an augmented and adapted version of the Deming cycle. It includes six sub-processes. The first of these (Plan), “Install a scientific, technical and societal framework. Propose a contribution”, corresponds to the definition of the problematic and its management over time. The second (Do), “Test, evaluate the contribution and/or actionable tool”, corresponds to the experimental period required to produce data in association with users. The third (Check), “Analysis and interpretation of data produced during experiments”, corresponds to the result production step needed to reply to the research question by means of data produced and, also, to calculate the process’s goal indicators. The fourth (Act), “Conclude by experiments. Improve the contribution and/or actionable tool”, makes it possible to “build scientific knowledge while identifying the contribution through experiments then to decide whether or not to launch a new cycle”. At this point the researcher can chose to initiate a new cycle or to communicate. THEDRE proposes a fifth sub-process (Submit), “Communicate results to the scientific community”. The sixth sub-process (Exit) corresponds to the last step of the work. This step includes tasks related to archiving of documents and therefore to backup of process documentation. Figure 3 presents a schematic version of the THEDRE cycle. In each of these sub-processes, doctoral students and their supervisors are asked to identify the tasks required to conduct the thesis work. THEDRE proposes 65 research activity tasks. Thus,

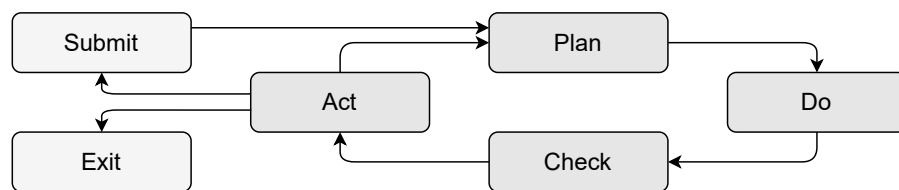


Fig. 3 THEDRE cycle with six steps

the supervisor presents and explain the tasks to the doctoral candidates. They are then incorporated into THEDRE's six sub-processes in such a way as to let the student know when to perform the activities. As far as the adaptability of the method, tasks can be added or suppressed; the sub-processes can be restructured or renamed. Some tasks proposed cover several DBR principles. Those related to research organization are, among other things, supported by the tasks "Identify the precise domain in the scientific literature" (P1) and "Develop goal indicators and the associated risks" (P10). The two principles of DBR linked to the question of the field and the actors are made obvious by several tasks including "Choose and describe the field of study and users concerned" (P4) and "Give the reasons why users will be involved (explore, co-construct, evaluate...)" (P5). Principles related to production and analysis of data are, among other things, supported by the tasks "Chose and justify the data production methods" (P6), "Identify experimental errors", "Validate data" and "Analyse data" (P7). Participants read the tasks and place them in a sub-process. Each person is free to create their own research conduct method by placing the tasks in the process that suits them. The idea here is not to follow the method rigorously but to initiate doctoral students into the iterative side of a research process and have them discover the researcher's job.

The six guides presented in the next part of this section are structured in an identical way. They consist of item boxes in which questions are asked that aid reflection. Hence, students are guided in structuring their reflections for one thing, and, secondly, questioned regarding sometimes uncommon elements they will use to lead research work. Two of these guides are presented in the core of this article (*i.e.* guide 4 and guide 5), the others can be found in the appendix of the present document. They are also available on the website <https://thedre.imag.fr>.

4.2.2 Guide 2: "Specify the scientific contribution and actionable tools"

Guide 2 allows one to "specify the scientific contribution and actionable tools" produced during doctoral work. At the beginning of a thesis students often have trouble identifying what constitutes a scientific contribution and actionable tools. This guide helps the supervisor make clear what he expects from the student (P2); it facilitates collaboration between them. It actually permits the notions of scientific contribution and the actionable tools to be explained to the student. It takes the form of a table with four item boxes: describe the sci-

entific contribution, describe the actionable tools, the state of these tools and the necessity to mobilize users or not (P4). This guide covers two principles; it allows practical objectives to be fixed to develop the theory and propose an initial plan (P2); it makes it possible to stipulate which “field actors are involved and for what” (P5). In addition, the information given in this guide is revised and updated throughout the entire thesis work, thus the contribution and the tool evolve as research advances (P3).

4.2.3 Guide 3: “Identify indicators and experimental measurements”

Guide 3, “Identify indicators and experimental measurements”, replies to the proposition of (Collins, 1992) concerning the implementation of goal indicators and the need for criteria permitting it to be known whether the process should be iterative or not. This guide is composed of a set of questions whose role, for one, is to create activity indicators. The latter chart the work carried out during the thesis. In addition, it allows goal indicators to be created. Their creation as part of research work is not common but in the case of an iterative research process they are essential to the decision to communicate results if the latter are sufficiently advanced or perform another research cycle (P10). The guide also incites the student to deepen the definition of measurements taken during experiments and also to refine the experimental protocol and document it (P6 and P8).

4.2.4 Guide 4: “Beginning thesis work in the right way, building one’s problematic”

Guide 4 “Beginning thesis work in the right way, building one’s problematic” facilitates the elaboration and follow-up of the problematic and contributes to the writing of a thesis introduction. It is comprised of questions distributed between the eight item boxes, presented in Table 3. The principles of DBR are given in parenthesis. The items “Problematic”, “Academic work” and “Technical work” help doctoral students rally existing work in order to build their problematic. They reply to principle 1 of DBR concerning the identification of pertinent resources to lead research work. The item “Activity and goal indicators” covers principle 10. The item “Description of the context and domain” assists students in the explicitation of the “real world” in which they will develop their scientific contribution. It replies to principles 4 and 5 used to describe involvement of actors as well as the context. In the item “Method used to build and evaluate work”, the idea is to review the literature from the angle of methods used by the community, then choose the adequate ones to reply to the problematic. These questions guide students in their choices and in the application of systematic and targeted methods (P6). The questions draw attention to points that are often neglected at the beginning of a thesis, but which can turn out to be crucial later on (*e.g.* an element of the literature). The item in question contributes to awareness of the real research context (*e.g.* questions about societal and ethical aspects) (P4). It can also

Table 3 Questions and items for Guide 4 “Beginning thesis work in the right way, building one’s problematic”

Item	Questions
Describe the problematic (P1)	What is the problem? Can you illustrate the problem? Why is it important to solve it? Why is it difficult to solve it? Which questions do you wish to answer?
Academic work (P1)	Who are the reference authors in this domain? What are the related works? What answers do these provide in relation to your question? What work remains to be done?
Technical work (P1)	What tools were developed to tackle this problem? What is the state of advancement of companies with respect to this question?
Social and ethical impact (P1, P9)	Why attempt to solve this problem in relation to the expectations of society? Are there any governmental directives that deal with the problem? What are the ethical questions raised by this problematic?
Description of the context and domain (P4, P5)	What is the context of the research? Which fields should be used? Which actors/users should be involved?
Method used to build and evaluate work (P1, P6)	What are the research conduct methods found in existing publications? Who are the authors? How were the construction, the evaluation of the scientific contribution and the tools produced? Which methods of data production and analysis were presented in the publications? Who are the authors? What are the measurement tools described in the literature that you can use? How will you build and evaluate your contribution and, if applicable, the actionable tools?
Activity and goal indicators (P10)	This item uses the elements described in Guide 3 concerning activity and goal indicators.
Contribution	After having examined the literature, what are the perspectives indicated by the authors of the articles you read? In your opinion, what are the perspectives of solving the problem you are working on? On which perspectives will you concentrate your work? How will these results be useful to you? And to whom? Which contributions do you hope to provide? Which tools will be built? Finally, what “added value” do you hope to bring to the scientific community?

partially contribute to the principle of generalization (P9) by helping doctoral students experience a larger vision of the impact of their work and its generic value.

4.2.5 Guide 5: “Writing up an experimental protocol”

Guide 5, “Writing up an experimental protocol” serves to describe the experimental protocol; in other words, the data production protocol. It consists of seven items, presented here, in Table 4. This guide documents the experimental protocol; it contributes to the experiment’s traceability and data produced

Table 4 Items and questions found in Guide 5 “Writing up an experimental protocol”

Item	Questions
Experimental objectives	What is the point of these experiments? Which questions will they reply to?
Contributions and tools concerned by the experiments	What are the contributions concerned by the experiments? What progress will be gained thanks to the latter?
Questions, research hypotheses and indicators	Which questions do the experiments attempt to answer? Which hypotheses are formulated to answer these questions? Which indicators are necessary to reply to these questions?
Data to be collected	Which data, already available in the field, is useful to reply to these questions? What data should be produced? Which collection tools are required (interview guides, questionnaires, etc.).
Description of tools	What are the actionable tools that will be used during these experiments? What is the state of these tools?
Description of people participating in experiments (P4, P5)	Why are users involved? What do you know about the users? Which activities will be performed by participants? How many will there be ? When and where will they be consulted?
Data production method (P6)	Which methods will be used? Why? By means of which data production tools (<i>e.g.</i> interview guides, questionnaires, digital traces, etc.)? Which data will be produced? Using which technical materials?
Data analysis methods (P6)	Which methods and tools have been foreseen to analyse data? Which processes will be conducted to validate data?

to answer the research questions. Often, doctoral students have trouble filling out this document but, dealt with beforehand, it guarantees the neutrality of data collected. It covers both the principles related to the involvement of actors in the research (P4 and P5) and the description of data production methods (P6 and P7).

4.2.6 Guide 6: “Assessing experiments”

Guide 6 “Assessing experiments” gives a table in which to make note of the strong and weak points of an experiment. Filled out after the experiment (immediately), it corresponds with a first level of data analysis. The idea behind the drafting of this document is to facilitate data processing and the interpretation of results. In this respect, it covers principle 7 of DBR concerning the necessity for immediate analysis of data. Several items must be filled out: the description of interactions between participants and events that occurred, elaboration of a summary of the experiment, identification of innovative elements, deficiencies and areas of improvement concerning both the tool and the contribution.

4.2.7 Guide 7: "Correctly analysing and capitalizing data"

Guide 7 "Correctly analysing and capitalizing data" is a follow-on from the guide "Writing up an experimental protocol" and the guide "Assessing experiments". It allows the data processing and analysis phases to be handled and documented (P8). It includes seven items: the processing objectives, data analysis methods provided by the literature, pre-processing of data, processing, analysis, results and limits of data processing. It documents how data from an experiment is validated, pre-processed and processed. This document accompanies doctoral students when they begin processing data. It helps them write up the data processing phase and the results of their thesis manuscript or the results given in a research article. As well as replying to the need for documentation (P8), this guide covers principles 6 and 7 regarding data production and analysis.

4.2.8 Synthesis of Guides and Principles of DBR

Table 5 Table providing a synthesis of the guides analysed in keeping with the DBR principles (Grey column refers to new principle) (Grey lines refer to guides studied in the results)

	Organization				Actors and field		Data		Documentation	Local/ Generalization
Principle	1	2	3	10	4	5	6	7	8	9
Guide 1	x	x	x	x	x	x	x	x		x
Guide 2	x	x	x		x				x	
Guide 3			x	x			x		x	x
Guide 4	x	x	x	x	x	x	x		x	x
Guide 5			x		x	x	x		x	
Guide 6			x					x	x	
Guide 7			x				x	x	x	

5 Evaluation of THEDRE method guides for DBR

In this section, we explain how the THEDRE method guidelines used as a support for DBR were evaluated then give the results of this evaluation.

The aim of experiments is to evaluate the THEDRE method and its guides and to find ways of improving support for doctoral students during their thesis. The hypothesis advanced is that the method and guides proposed facilitate acquaintance with the principles of DBR. The latter are complex and can be perceived as such, and for this reason appear difficult to use for doctoral students. This is why we chose not to present them too explicitly to students participating in training. On the other hand, the guides, as explained earlier, help students grasp the principles of DBR. It is a good idea, therefore, to examine whether this method and guides are practical, and whether they facilitate

the work of doctoral students. Thus, we can decide whether they encourage the use of DBR. Our experiments aim to reply to two questions:

Question 1: Are the THEDRE method guidelines an aid to reflection and in the different steps of research construction?

Question 2: Do the THEDRE method guides help organization of doctoral students' work? Are they of use to do their thesis work?

To reply to these questions, we measure : 1- prior to training, the needs and expectations of participants; 2- during training, the usability of the guides and the level of participant satisfaction; 3- three months after training, the appropriation of the method and eventual shortfalls.

During the university year 2019-2020, seven training programmes using the THEDRE method and its guides took place, as well as a number of seminars. In all, 57 doctoral students and 47 supervisors took part. The version of the guides proposed came from the work of (Mandran, 2018). The evaluations were mainly performed during training lasting 12 hours. During this training, some time was reserved to gather the comments of participants concerning the tools proposed and their suggestions for their improvement. At the end of each training course the data collected underwent analysis. The results allowed us to improve the guides between courses (iterative principle and evolution of tools). During the seminars we also collected the comments of participants with a view to improving the guides. By their involvement all the participants contributed to the improvement of the guides (collaborative principle of DBR). Table 6 describes the different training courses.

Table 6 Training for the THEDRE method with guides (DS: Doctoral School)

Type	Training	Training	Seminar	Seminar	Training	Training	Training
Version	V1	V2	V2	V3	V3	V3	V4
Place	CAPTE, Lille	LIUM, Laval	LIP6, Paris	LIG, Grenoble	DS, Grenoble	DS, Lille	Virtual workshop
Date	2019/07	2019/11	2019/11	2020/01	2020/01	2020/02	2020/06
Duration	12 h	12 h	2 h	2 h	12 h	12 h	3 h
PhD student		6	3	3	10	11	24
Supervisor	12*	7	8	9			11
Number of guides	14	12	3	2	12	12	4

The four 12-hour training courses were conducted as though they were focus groups used to evaluate a product. This method makes it possible to invite participants to an exchange, to confront different opinions and to encourage the emergence of new ideas. Training began by a presentation of the concepts of THEDRE and its terminology. Participants interacted with the facilitator during the presentation. When this was over, an exchange between participants was staged. Next, the guides were presented one after the other, tested and evaluated. At the end of the testing, questions connected to the level

of comprehension were asked by the facilitator. The usability of the guides was measured using the system usability scale (SUS) (Brooke, 1996; Lallemand et al., 2015). An open question allowed remarks and suggestions to be collected. At the end of the course participants answered a satisfaction questionnaire on the subject of the method and the course itself. Three months later, interviews were conducted to evaluate how the guides were being used as well as their appropriation.

Data analysis was performed on the basis of qualitative data from exchanges during training, responses to open questions, quantitative data produced by the responses, SUS questionnaires and post-training interviews. For the qualitative analysis we used a thematic analysis (Paille & Mucchielli, 2011). The responses in the usability questionnaire were processed in accordance with the method of Bangor et al. (2008). The SUS score obtained was interpreted in the following way: "Worst imaginable", from 0% to 25%; "Bad", from 26% to 39%; "Acceptable", from 40% to 52%; "Good", from 53% to 74%; "Excellent", from 73% to 86%; "Best imaginable", higher than 86%. When the score exceeds 69% the tool is considered useable.

6 Results

This section presents the results obtained on the basis of data collected during training courses in Laval (A), Lille (L), Grenoble (G) and post-interviews (E). The verbatim taken from participants' oral feedback are noted in """; a code consisting of the initial of the place plus a number is attributed to each participant.

6.1 Question 1: Do the THEDRE method guidelines allow reflection and the different steps of the research's construction to be steered?

Thanks to these guidelines the THEDRE method appears to help doctoral students in their job as researchers; they are an aid to the identification of productions required in a thesis work: "(...) I would have liked to have done this course at the beginning of my thesis, it would have helped me later, in particular when writing up protocols or identifying scientific contribution which isn't always obvious" (G8). It helps "overall organization of a thesis and scientific rigour" (E2). This method allows a personal research conduct method to be thought out: "It could be used to elaborate the research conduct method that suits our work, (...) or imagine the method we want to follow in a particular context" (E1). It makes it obvious which tasks are to be performed: "We see the tasks to be accomplished in a thesis and this is perhaps something we're not aware of when we start out as a doctoral student" (E2). For Guide 1, the two tools that comprise it (board and tasks) were rated with the SUS. More than half the participants attributed an SUS score corresponding to good or excellent with regards to both parts of the guide (board: n=6 "good" and

n=7 “excellent”; tasks: n=9 “good” and n=4 “excellent”) (G4). According to the interviews organized one month after the course, some participants added other positive points to this guide, use with their doctoral students for instance: “I would use the diagram if some new doctoral students arrived tomorrow” (E5), in particular at the beginning of the thesis. The iterative aspect of the guide emphasizes the thesis circuit which is no longer seen as linear. Guide 1 gives the doctoral student, “a macro-planning with a global vision which integrates the necessary steps” (L10); “a definition of the action perimeter of the doctorate and pertinent actions” (G4); tools for “integration of the user into research” (L4); “a highlighting of the importance of publications and the dissemination of knowledge” (G4). In addition, one participant (E3) presented this guide to his colleagues: “I presented my map of the iterative method. There followed an exchange (...). They realized there were lots of things they hadn’t thought of”. One point concerning the use of this guide which requires vigilance is the number of tasks: “The sheer number of tasks can discourage doctoral students” (L4). If this is the case, a simplified list can be proposed depending on the advancement of their thesis. Participants would like to “prioritize tasks”. With the THEDRE method an organization of tasks is provided in keeping with three levels: one task compels other tasks, tasks are performed in parallel and tasks are compelled by other tasks. This was not used, however, during these training courses. The tool allows supervisors to ground, position themselves and familiarize doctoral students with this approach: “There is less need to argue in favour of the iterative approach. The principles presented allow the work of explanation to be reduced because they have been made familiar with the approach (...). They are not familiar with the principles that aim to test a scientific hypothesis. Here, there is a point of attachment” (A2).

6.2 Question 2: Do the guides derived from the THEDRE method facilitate doctoral students’ organization of their research work? Are these guides useful to their thesis work?

We focalize our results on three guides: those which aid doctoral students most in the explicitation of thesis objectives and their problematic; they cover all the principles of DBR. Guide 2, “Specify the scientific contribution and actionable tools” is, at first sight, difficult to use because it broaches the problem of research by production, which is inhabitual. The duality of this production, knowledge and tool, accentuates difficulties further. The usability score is globally low (SUS score n=4 “bad”, n=7 “acceptable”). On the other hand, it allows users to work on the notion of scientific knowledge and tools, and to establish objectives regarding what will be produced. “It allows the perception of a thesis to be broken down into comprehensible elements” (L11). “I think that really consolidated the fact that the contribution wasn’t the technical tool, not the prototype (...). Here, because they were presented as a table with a column dedicated to scientific contribution, the scientific contribution

was made clear. It's really the methods and the models published that are important" (L8). It helps the work of explicitation. "While filling it out, I got the impression that it helped me to elucidate things that perhaps hadn't been expressed in this form" (E1); and helps guidance: "These were things I wasn't attentive to (...) decomposition into actionable components (...) it allows you to see where you're going" (E3). Because this guide deals with the contribution of the user to construct and evaluate the tool, doctoral students can understand the necessity to involve users. "I think it was very end-user-centred, be it the tool or the component (...). This is always a good idea because we forget this quickly and it allows you to validate, in certain types of research, when you need to obtain validation of end-users, or to have them take part in design, not to forget them" (E1). This guide serves as a support for work between the supervisor and the doctoral student. "I found it very useful, in addition I discovered it just after an important meeting with my doctoral student to formalise those exact elements. It came as a kind of reminder. I left him to it and he did what was needed. I told myself, good, he's twigged what I wanted to say" (E2). Despite obtaining a better usability score (n=5 "good" and n=3 "excellent"), students found Guide 3, designed to identify goal indicators and experimental measurements, difficult to use. "It's difficult but that's because the question raised is difficult" (G8). Imagining goal indicators isn't common. "Stating evaluation metrics at the beginning is essential. In practice, this isn't often done" (E4). This work nonetheless helps the user to adopt an experimental logic, to anticipate and construct experiments. "It allows things to be thought out beforehand, to simplify and to make what follows clearer. It allows us to define what we are to evaluate and to construct the protocol with that in mind. (...). The metric allows us to define what will be measured and how" (E4). Two other students stress the fact that the guide is difficult to use: "It's difficult but that's because the question raised is difficult" (G8). Another would like more help defining objectives: "Add a system in the manner of a funnel to help define goal indicators. For example, start with a subject then deconstruct it then add calibrated indicators" (G1). Guide 4 obtains a usability score higher than the average reference score (*i.e.* 71 versus 68; SUS n=8 "excellent" and n=4 "good"). For participants it replies to the objectives demanded; that is, drafting an introduction to the manuscript while providing a synthetic and complete plan. Doctoral students seem to agree on the fact that this guide presents no obvious incoherencies but were forced to ask questions in order to use it. Among other things, it allows one "to think clearly" (G8), has a "synthetic and complete" appearance (L11), and allows certain aspects of the thesis to be apprehended more deeply: "It was interesting to ask oneself questions regarding a number of precise aspects, this allows you to reflect differently and to see the need to look deeper at certain points" (G5). Moreover, this guide facilitates work with the supervisor: "Practical and maybe easier to present to one's thesis director for a work period together" (G4). However, the guide is doubtless easier to use after several months of thesis work. G9 points out that it is easier to use if used towards the end of one's thesis: "A bit too simple when we're already in the third year, but I think it's good for those who

are just beginning their thesis”. “If I’d had it at the beginning of my thesis I think things would have been simpler” (L6). During the training courses, participants asked a lot of questions concerning the item boxes. One participant proposed some examples. Another proposition was to add a vocabulary and definition item box for thesis work: “Having said this, I think vocabulary should be defined in all introductions, no space appears to have been allotted to this task” (L8). These three guides, stemming from the THEDRE method, facilitate the research work of doctoral students and therefore contribute to the application of DBR principles.

7 Conclusions and perspectives

As this work provided an opportunity to accompany the implementation of the principles of DBR, we wish to open the door concerning this method and reconsider two principles: integration of all actors (P6) and generalization within a doctoral work limited in time (P9). To improve DBR, we proposed a new principle concerning the identification of goal indicators as well as a guide to create these. While perceived as being difficult, this task turned out to be helpful to both doctoral students and supervisors. It also heightened their awareness of “experimental logic”, indispensable to all research work. This last point was one of the unexpected positive results of our experiments. This new principle is therefore useful and comes along to reinforce principle 2 of DBR. In THEDRE, research organization depends mainly on Guide 1 to describe tasks inherent to the job of researcher in keeping with an iterative principle grounded in a continuous improvement approach. It gives an overall vision of what thesis work entails (another guide, not presented in this article, combining Ishikawa diagrams and a Kanban). The use of Guide 1 was very positive. It was perceived as useable and encouraging collaboration between supervisors and doctoral students. This first THEDRE method guide therefore provides guidance in reflection and the different steps of research construction. The other guides proposed to facilitate doctoral work were sometimes difficult to use at first sight. Effectively, the questions posed in these guides to encourage reflection are not familiar to doctoral students. They belong to the domain of researcher activities. Nonetheless, after using them for a time, doctoral students found them useful, useable and structuring. They can therefore facilitate the work of a doctoral student and, more largely, incite them to interact with the principles of DBR. Regarding the principles of DBR, two of them seem hard to apply when doing thesis work. Namely principle 5: “Field actors are included as collaborators in the research”. Indeed, mobilizing field actors is always a delicate task when conducting experiments in a real situation (*e.g.* the participants don’t necessarily have time to participate; having an observer in a classroom can be intrusive, etc.). In the case of principle 5, the contribution required of collaborators is still more important because they are asked to participate in the elaboration of the research question, platforms and evaluation tools. The profile of collaborators can be very different within the

same project. In addition, these people are not always experienced in research work. They have to be initiated into it. In a thesis situation this principle cannot be implemented by a doctoral student. On the other hand, it should be made visible at the level of a project or a wider research context and not in a doctoral work restricted to a three-year period. Furthermore, at the level of a research project, this collaborative work should be empowered to monitor the evolution of the research question. In these conditions, should a guide be created that accompanies this principle or involve a mediator to conduct this research in the field? The ninth principle "Researchers should optimize local design without losing sight of generalization" seems more difficult to implement and empower. Nonetheless, Wang and Hannafin (2005), prior to the nine principles, used a set of properties to qualify the domains of research. The property "Contextual" refers to the ninth principle. We feel it is more explicit. The property "Contextual" concerns the necessity to clarify the relationship between results and the context in which data was produced. Several contexts could be studied; this multiplicity of contexts allows a certain genericity of results to be guaranteed and to increase their level of validity according to the measurement points studied. We feel that a thesis should be evaluated in a minimum of two contexts and repeated over time to study the situations comparatively. To do so, the doctoral student must be informed, right from the beginning of his or her thesis, of the fields to be explored. This phase of the work can turn out to be difficult and time-consuming but is an integral part of work using DBR. This search for a validation field appears, therefore, to be a competence worth acquiring or to be mobilized by doctoral students.

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Conflict of interest

The authors declare that they have no conflict of interest.

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