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Design-Based Research in Science Education: One Step Towards Methodology

Abstract
Recently, there has been critiques towards science education research, as the potential of this research has not been actualised in science teaching and learning praxis. The paper describes an analysis of a design-based research approach (DBR) that has been suggested as a solution for the discontinuation between science education research and praxis. We propose that a pragmatic frame helps to clarify well the design-based research endeavour. We abstracted three aspects from the analysis that constitute design-based research: (a) a design process is essentially iterative starting from the recognition of the change of the environment of praxis, (b) it generates a widely usable artefact, (c) and it provides educational knowledge for more intelligible praxis. In the knowledge acquisition process, the pragmatic viewpoint emphasises the role of a teacher's reflected actions as well as the researches' involvement in the authentic teaching and learning settings.

Introduction

It is possible to place educational research into two categories: research *about education* and research *for education*. The former has an intellectual objective to better understand teaching and learning. The latter has a pragmatic (not just practical) objective to improve teaching and learning praxis. Especially in the UK, there has been a critique towards educational research, because the believed potential of the science educational research has not been actualised (Bennett, 2003; Leach, 2005; Ratcliffe et al., 2005). Based on our experiences on combining designing and research, this paper clarifies *design-based research* that has recently emerged aiming to bridge the gap between educational research and praxis. It combines the designing of an educational artefact and research concerning the learning in the designed settings. Recently, several groups have been active in endeavour combining the design of an artefact (at least a teacher guide or a synopsis of a teaching sequence) and educational research using several names: *Design experiment* emphasises the comparison of several versions of designed artefact (Brown, 1992), *developmental research* emphasises the analysis an artefact or a successful design process (Richey & Nelson, 1996), *user-design research* emphasises the role of user and focus on information system (software) design (Carr-Chellman & Savoy, 2004), *design research* emphasises the process, the features of an artefact and educational knowledge (theory) development (Edelson, 2002), and *design-based research* (Design-based Research Collective, 2003; Bell, 2004) that, in addition to design research, emphasises the long time projects in single settings and compelling comparisons of innovations and collaboration between teachers and researches.

There are several problems of bridging the gap between educational research and praxis. Teachers tend to express opposition to the innovations suggested by researchers. (cf. Fullan, 1991). Teachers appreciate research results obtained from quasi-experimental design because they think that it proves whether a new learning environment or a new pedagogical approach is better in some way than previous ones (Ratcliffe et al., 2005). The appreciation of quasi-experimental research design is natural: science teachers and science education researchers tend to begin their studies in physics, chemistry, or biology, where an (quasi-)experimental setting is conventional. Thus, science teachers may perceive results gained from research using methods other than quasi-experimentation – e.g. interviews – as being nothing more than personal opinion. However, science teaching and learning phenomena is very difficult to treat as an independent or dependent variable. For example, classroom settings, social and psychological atmosphere, pupils' motivation, affection and conceptions toward a topic to be learned or toward schooling as such, and moreover, students' experiences outside the school such as discussions with their parents and media, are hard-operationalised factors that have an influence on science teaching and learning.

Although a few experts have been active in both designing national curriculum and writing text books based on curriculum as well as performing research on science teaching and learning, traditionally, the design and research processes have been seen to be separate. A designed artefact has been seen as an implementation of an educational theory and a quasi-experiment an instrument to test this theory. However, for example, in the field of educational technology there is much design not based on research (Randolph, et al., 2005). To state provocatively, a designer might have an idea of how to solve problems in science teaching and learning through his or her innovation. In this kind of situation, design perhaps, is based on a designer's own experiences and beliefs of effective learning or design is purely technology driven. Even if the design is based on theory, (i.e. research-based practice), teachers' may think that the introduced artefact may work well in the designers' context, but not at all in an authentic real-life setting i.e. their school context (c.f. Linn, 1996). Further, the designed artefact could be simply 'too' innovative or revolutionary. We claim that in the field of science education research, the research based knowledge about diffusion and adoption of innovation (e.g. Rogers, 1995) have seldom been taken into consideration. We agree with Fullan (1991) with regards to his general model of the factors having an impact on the acceptance or adoption of educational innovations or design solutions. These factors are: (a) The properties and usability of an artefact. (b) Local characteristics. These are the teacher's pedagogical knowledge, skills, and beliefs, and the administrative leadership and support available to teachers. (c) External factors influencing the adoption of the innovation such as educational policies, national strategies, curriculum, and different kinds of national networking as well as public hype of certain innovation. In countries where teachers are allowed to choose learning materials (e.g. textbooks), publishers conduct marketing research to publish the best-selling books. We suppose that one could consider how innovative and *for learning* market-driven learning material really is. We propose that one approach to answer critiques aimed at science education is to focus on, not only, the process of pupils' learning and the properties of the artefact to be designed, but also on teachers' knowledge and on authentic teaching and learning settings.

Research approaches engaging design consist of three parties: (a) a designer (e.g. researcher), (b) a practitioner (e.g. teacher), and (c) an artefact (e.g. web-based learning environment for science education). The role of the parties varies depending on the endeavour. The following describes the example of endeavours that are close to design-based research, but which emphasise the different roles of a designer, an artefact, and a teacher and, moreover, their interaction. In *emancipatory action research*, introduced by Carr and Kemmis (1986), teachers are responsible for developing, understanding and evaluating actions. Anyone in the group of teachers could take the role of researcher, or the researcher could also be an outsider. The researcher's role could be just as a producer of the artefact to be designed. An outsider could facilitate the process of reflection to help the teachers think critically about their goals, actions on a classroom, evaluation, and moreover, reflect on the present teaching and attempt to improve the nature of their approach to teaching.

The user-design research (Carr-Chellman & Savoy, 2004) adopted ideas to engage practitioners to be more or less responsible for designing. Thus, it is, perhaps, more a type of action research than design-based research. Typically, the aim of action research is to improve the praxis of the correspondence group. Even action research produces an artefact, it is designed for insiders and others have difficulty in finding any benefit in it.

Compared with the above-mentioned approaches, *user-centred design* emphasises the different roles of teachers: even when they are taken into consideration, teachers are not empowered. According to the standard of human-centred design processes for interactive systems (ISO 13407:1999), a design process is characterised by: (a) the active involvement of users and a clear understanding about user and task requirements, (b) an appropriate allocation of functions between users and technology, (c) the iteration of a design solution, and (d) multi-disciplinary design. Rationales for user-centred design are essentially economic: users' needs are easier to understand; therefore it reduces training and support costs, improves user satisfaction, productivity and efficiency of the user, and quality of the products. A practitioner's role is to be a usability tester and adopt a designed artefact.

Further, there are articles, especially, in the field of *educational technology* that describe a designed artefact showing very little research based evidence (Randolph, et al., 2005; Driscoll & Dick, 1999). These articles describe the technical properties of the designed educational innovation and, perhaps, discuss the potential of it in learning.

Construction of research based teaching sequences through *Developmental research* (Linsje, 1995), *Educational reconstruction* (Duit, Komorek & Wilbers, 1997), or *Ingenierie Didactique* (Artigue, 1994), can be considered very similar with design-based research. On the one hand, these approaches take into careful consideration students' previous knowledge and emphasise basic scientific concepts and how they are related to the teaching sequence (Méhuet, 2004) and on another hand they aim to design the artefacts. For example, Andersson and Bach (2005) produced a teacher guide as an artefact describing the research-based sequence for teaching geometrical optics. However, these approaches focus on research-based design and the adoption of the innovations needs, for example, teachers' in-service training.

In *Design[-based] research*, Edelson (2002) suggests the combination of theory development, the prescriptions of successful design processes, and the prescriptions of successful design solutions. This is practical, as the design process includes all these aspects. Even some problems of trustworthiness have been introduced; design-based research scholars have shown little emphasis to explicate the methodological or philosophical background.

This paper analyses design-based research as an approach to answer to the critiques towards science education research such as the exiguous diffusion of research results for teaching praxis and lack of adoption of educational innovations. The ambitious objective is to take one step toward the methodology of design-based research.

Our group has been active in research having objectives to improve science teaching praxis. The projects have focused on (a) educational software and hardware design emphasising the analysis of the designed artefact (microcomputer-based laboratory system) (Lavonen, Aksela, Juuti, & Meisalo, 2003), (b) analysis of the designing process (Lavonen & Meisalo, 2002) (c) learning environment designing from upper secondary school electronics (Lavonen, Meisalo, & Autio, 1998; Lavonen & Meisalo, 2000) to primary school mechanics (Juuti, Lavonen, & Meisalo, 2004: Juuti, 2005) as well as analysis of environments (Meisalo & Lavonen, 2000), and (d) professional development projects stressing the collaboration with practising teachers while developing the pedagogical use of information and communication technology (Lavonen, Juuti, Aksela, & Meisalo, 2006).

The analysis of design-based research described in this article is based on our own encounters in research concerning design and evaluation of learning environments for science education, the body of the related literature and implications of a proposal for grounding design-based research on pragmatism. We propose pragmatism as a framework for design-based research because they both take seriously the objective to improve praxis, especially actions as a means to acquire new knowledge to reach that objective.

We use our own design-based research project "Arithmetic, Science and Tehcnology E-Learning" *ASTEL* as an example (see Design narrative). During the project, we designed a web-based learning environment that is available in internet both in Finnish and Swedish (http://www.nextpoint.fi/astel/ruotsi/).

In what follows, we describe the pragmatism as a framework for the design-based research and abstraction of the features of the design-based research, and we present the suggestions of trustworthiness criteria for design-based research.

Pragmatism as a proposed framework for design-based research in science education

Pragmatism is a philosophical tradition which was founded in-order to provide an answer to the mind-body –problem: how our immaterial mind can acquire knowledge of a material world. Classical pragmatists, Peirce, James, and Dewey opposed the correspondence theory of truth and the view of knowledge as representation; they, especially Dewey, focused on knowledge and the acquisition of knowledge within the concept of action. (Rorty, 2004; Biesta & Burbules, 2003).

Biesta and Burbules (2003) argue based on analysis of Dewey's pragmatism from the educational research point of view that pragmatism offers a theoretical background for educational research because as well as pragmatism, educational research is highly practical in orientation. However, we emphasise the difference between practical and pragmatic. In the previous, the knowledge and action have been separated; actions are guided by habits (cf. Rescher, 2001). This is the situation for which science teaching and science education research have been blamed: science teachers and researchers do not communicate. In the latter (pragmatic), knowledge and action are intimately connected. In this situation, knowledge about science teaching and learning and teachers' actions in the classroom are not separate. Teaching is reflected and knowledge about science teaching and learning emerges from teaching and feeds back into teaching.

Based on detailed analysis of Dewey's work, Rodgers (2002) emphasises "that the process of reflection is rigorous and systematic and distinct from other, less structured kinds of thinking. It has its origins in the scientific method and, as such, includes precise steps: observation and detailed description of an experience, an analysis of the experience that includes the generation of explanations and development of theories, and experimentation – a test of theory" (Rodgers, 2002, p. 863). In order to broaden ones understanding of an experience, reflection needs to happen in interaction with others. Further, she underlines the importance of the attitude that values personal growth.

When Dewey's view of knowledge as an organism-environment interaction is applied to research-based design in science education, knowledge is a construction that is located in the teacher – the learning environment interaction itself (c.f. Biesta and Burbules, 2003). In this interaction, over and over again the dynamic balance between teachers and learning environment is construed. Environment includes not only classroom settings, but social and psychological atmosphere, pupils' motivation, affection and conceptions toward a topic to be learned as well as their intentions. Knowledge of science teaching and learning manifests itself firstly in the way by which science teachers interact with and respond to changes in the learning environment. In the context of design-based research researchers suggest changes for the learning environment in order to obtain new knowledge about science teaching and learning. The interaction is an active, adaptive, and adjustive process in which the teachers seek to maintain a dynamic balance with the learning environment. (cf. Biesta & Burbules, 2003).

It is emphasised that teaching experience as such is not knowledge. In order to obtain knowledge, teaching actions need to be reflected. By means of reflected action, an experience becomes knowledge. Dewey emphasised that experience covers the whole range of human possibilities and the world as we experience it is the real world. For example, 'a self-educated' unqualified teacher and science education researcher in all likelihood would describe and rationale their teaching rather differently. However, their experiences about teaching and learning are equally real. Differences in their background, viewpoint or intention explain different rationales. Dewey separated several modes of experience that restore reality to all dimensions of the way in which human beings are in the world (Biesta & Burbules, 2003). These modes of experience can be, for example: cognitive (knowing), practical, ethical, aesthetic and religious. Cognitive mode of experience supports actions and knowledge helps a teacher to better control his or her actions: i.e. to teach more intelligible. Consequently, the objective of the science education research is to help teachers to act more intelligible in the science learning environment.

However, the pragmatic view does not assume that there is one real world that will be uncovered through scientific inquiry. Pragmatists criticise the correspondence theory of truth. Any correspondence of a belief to reality can only be the reality under a particular description, and that any such description is not ontologically or epistemologically privileged. This means that the truth of researchers' utterance is highly dependent on context (cf. Pragmatics as a linguistics approach of semiotics). Pragmatism avoids falling into the solipsism, subjectivity and relativistic concept of truth by the notion of intersubjectivity. Humans have similar experiences in the shared world. A science teacher constructs individually knowledge about science education and then co-reconstructs it in social practices through communication with other teachers and researchers.

Communication is a process of the mutual coordination of action, and therefore, it is *not* a process in which a teacher simply reacts to a researcher's movements, after which the researcher reacts to the teacher's reactions, and so on. Dewey's point here means that successful coordination requires that the teacher reacts to what the researcher *intends* to achieve with his activities, just as the researcher reacts to what the teacher intends to achieve with his activities. Successful coordination requires that the partners in interaction try to *anticipate* the other's actions" (Biesta & Burbules, 2003, p. 41).

Davidson (1990) describes, from the pragmatic point of view, a triangle that relates speaker (here researcher), interpreter (here teacher) and the world (here designed learning environment as an expedient of more intelligible teaching). The problem is: If the researcher engages in the correspondence theory of truth and scientific realism, it cuts out the interpreter and teacher's side of the triangle. This leads, perhaps, to the teaching experiments led by a researcher and focus being placed on the relation between the researcher and design solution. Thus, it is clear that a teacher does not "live in the same world" as the researcher, and therefore, it is likely that a teacher does not adopt the design solution (cf. Rorty, 2004). Further, we claim that if a researcher (as a designer) engages in social constructivist view of science, it cuts out the world and researcher side of the triangle. Following this view, the research may conduct interviews focusing how teachers and pupils experience teaching and learning. Consequently, the researcher may ignore an artefact and observations in authentic classroom settings. Traditional critiques towards social constructivism are the risk of relativism and the idea that scientists literally 'make the world' (Downes, 1998). Our interpretation is that researcher engaging in social constructivist view of science, again teacher and researcher live in the different worlds.

In addition, we argue that if a researcher engages in social constructivist view of science, it cuts out the world and researcher side of the triangle. Following this view, the research may conduct interviews focusing how teachers and pupils experience teaching and learning. Consequently, the researcher may ignore an artefact and observations in authentic classroom settings. Traditional critiques towards social constructivism are the risk of relativism and the idea that scientists literally 'make the world' (Downes, 1998). Our interpretation is that when researcher engages in social constructivist view of science, again teacher and researcher live in the different worlds.

Through reflective discussion, obtaining similar experiences in the classroom and anticipating each others' intentions, the researcher and the teacher could share the same world. Then a teacher could act more intelligibly using a novel design solution. However, in the situation, when a researcher or a teacher does not know how to act, the staring point is to uncover the problem: What is the required change, what is the actual change in the teaching and learning environment, what are the opportunities and constraints. Answering the questions, researchers explicate the problem that needs to be overcome with the artefact to be designed.

After the problem explication, researchers and teachers interact with each other and decide the main objectives pursued by the artefact and create a strategy for achieving objectives and they test the strategy. In the case of success, the point is not just that the researcher and teacher managed, but their understanding about the problem was sufficient. Still, description to manage the problem is not the description of the "world out there", but a description of a relationship between actions and their consequences. (Biesta & Burbules, 2003).

Features of the design-based research

This chapter aims to describe features that determine design-based research in the context of one of our own design-based research projects called *ASTEL* (see Design narrative (2006) describing the designed learning environment, designing process and learning outcomes in address www.edu.helsinki.fi/astel-ope/narrative.pdf). We argue that the following three features determine the design-based research: (a) A design process is essentially iterative; (b) objective of the design-based research is to develop an artefact to help teachers and pupils to act (teach and study) more intelligible (in a way that leads to learning); (c) design-based research renders novel knowledge about science teaching and learning. All three features together constitute endeavour that is called design-based research.

Design-based research is essentially an iterative process

Implicating the ideas of pragmatism, a design-based research project in the field of science education starts in the situation, when one recognises that there is something problematic (e.g., educational policy decisions should be implemented or research findings suggest change in science teaching and learning): neither researchers nor teachers know how to act in certain circumstances (cf. Design narrative chapter 'the new national core curriculum'). Especially, micro-computers and the Internet raise the question, with regards to all their possible applications, of: how all these ICTs are to be used in science education. The starting point is to use the best research literature available and then to try to figure out the way to approach the problem (Design narrative, chapter 'Setting goals through theoretical problem analysis'). The first task is to conduct a literature review and find answers to questions such as the following suggested by Psillos (2005):

- What are the basic science models in the area?
- What are students' conceptions or mental models in that area?
- How are students' conceptions employed in the designed learning environment; or in the designed teaching learning sequences?

Similarly, in the field of educational technology Clements and Battista (2000) emphasise that designers should, before designing, explicate models of pupils' conceptions, attitudes, beliefs etc., and learning. These are questions of the evidence-based practice as well as the designing of teaching-learning sequences approaches (see Méheut & Psillos, 2004).

In addition to the previous questions, we claim that the following are also important to ask in order to share the world of science teaching and learning.

- What are practising teachers' experiences, ideas, and needs concerning the topic of design?
- How practising teachers' perceive the current temporal (e.g. feeling of hurry), spatial, (e.g. available equipments), and social (e.g. available support or culture of co-operation) teaching and learning settings? (cf. Mandl & Reinmann-Rothmeier, 2001)

The first task is to find answers from the available literature. This phase of the design-based research could be called *theoretical problem analysis*. Still, in many situations, it is not possible to explicate the models of pupils' conceptions and learning or share teachers' world of teaching and learning without novel research. In the beginning, designers only have a tentative strategy by which to manage the problem. One approach to generate these tentative strategies is to use creative problem solving methods: positive and non-judgemental feedback and acceptance of all ideas, possibilities to ask constructive questions about an idea, and combine and redefine ideas a way that tentative strategy is a combination of several ideas. (cf. Design narrative chapter 'The process and resources of the designing')

Design-based research scholars typically report prescriptive models of the successful design process. Clements and Battista (2000) proposed the following phases of design: (a) Draft the initial goals; (b) build an explicit model of students' knowledge and learning in the goal domain; (c) create an initial design for software and activities; (d) investigate the components; (e) assess prototypes and curriculum; (f) conduct pilot tests in a classroom; (g) conduct field tests in multiple classrooms; (h) recurse; (i) publish. Another example of a model is Lavonen and Meisalo's (2002) seven stage research-based process for designing sponsored learning materials. The phases are: (a) Determination of the general aims in co-operation with experts (sponsors, members of teachers' pedagogical associations) considering teachers' needs for a learning environment and financial limitations; (b) the detailed design of objectives, contents, strategies and tasks following the principles of creative processes; (c) the preparation of a preliminary manuscript; (d) in-service training to test the manuscript; (e) collecting feedback about the manuscript from teachers in in-service training; (f) planning the use of the material designed; (g) user evaluation to improve the material over the years.

These kinds of process prescriptions should be understood as examples, not as standards. Namely, European committee for standardization has published a standard for human-centred design processes for interactive systems (ISO 13407:1999, 17). The standard provides the detailed prescriptions of design activities. In general, the standard emphasises four phases: (a) To understand and specify the contexts of use; (b) to specify the user and organizational requirements; (c) to produce design solutions; (d) to evaluate design against requirements.

The key issue here is that before designing, designers should accept the situation of uncertainty of the strategy and they should be ready to change totally tentative strategy. This emphasises the seeking of the dynamic balance through iterative design and testing -phases. The prescriptions of the design processes help a designer to plan their own unique design process. Figure 1 describes a design process of the *ASTEL*-project as a design-based research result (Juuti, 2005, see also Design narrative). Although, the figure overlooks the change in the learning environment requiring a teacher to respond, it emphasises three essential aspects of the design-based research: (1) the importance of clarification of intended users' needs (understand teachers' world) and objectives for an artefact to be designed i.e. *theoretical problem analysis*; (2) iterative designing of the artefact. (3) mixed-methods approach to acquire knowledge of teaching – learning context and knowledge to explicate models of pupils' learning, conceptions, attitudes etc in order to teach more intelligently.

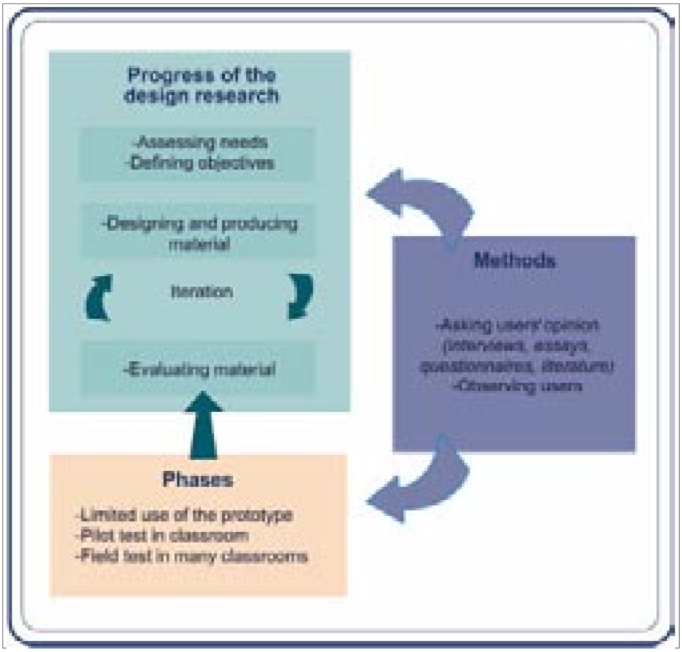

Figure 1. Example of successful design process as research result of design-based research (Juuti, 2005, p. 102).

One important aspect of the design-based research in the context of science education is that not just researchers or designers, but also ordinary teachers in the field with insignificant knowledge about the designed artefact and its educational theory background are able to use it successfully. Therefore it is important to understand intended user teachers' competence, beliefs, intentions, and attitudes toward the topic that designing concerns: or in other words, share teachers' worlds.

In order to help teachers to teach more intelligently, and not to only adopt, the artefact should be (metaphorically) in the zone of the proximal development of teachers' pedagogical knowledge. Designing is based on designers' tentative understanding about the context and findings of evaluations. Through these testing phases, designers attempt to manage uncovered needs and decide on objectives to refine the artefact after testing. The crucial viewpoint here is: how the evaluation is arranged. If designers engage in pragmatism, the main viewpoints are teachers' reflections on actions in natural settings (cf. Design narrative chapter 'Properties of the designed primary physics learning environment'). Thus, it is not a researcher who tests a design solution, but a teacher with his or her own pupils in their own classroom. Researchers' role is to observe classroom activities and help teachers to reflect on their actions on the classroom asking questions and telling how researchers experience testing. A teacher and a researcher compare and share their experiences. At the beginning of our *ASTEL*-project, we used a case study approach to collect data. During the project, we realised that discussion with a teacher, who taught a testing, uncovered the essential aspects of the testing. Formal data analysis seemed to be mainly a legitimization and specification of the discussions. Further, researchers could assess learning outcomes or arrange quasi-experimentations etc. (cf. Design narrative chapter 'Empirical problem analyses dealing with the designing of the learning environment'). Therefore, evaluation may employ multiple methods as Bell (2004) proposed. The main goal is the coordinated communication between a teacher and a researcher. Throughout the communication, a researcher helps teachers to verbalise (articulate) their experiences gained whilst teaching. Thus, it is not just an individual experience any more, but knowledge about teaching and learning has been constructed.

The design-based research process is consequently abductive employing practical reasoning. A researcher and a teacher recognise the situation P. The reflection focuses on "guessing" what action Q in the environment E caused the situation P. If teachers' (and researchers') intention was a situation P' and after reflection (and after data analysis and literature reviewing) they believe that action Q' would cause the situation P', then the design group will realize changes E' to the artefact that are believed to help to obtain an action Q'. According to Peirce, people have a "natural instinct for the truth: the human mind is akin to the truth in the sense that in a finite number of guesses it will light upon the correct hypothesis" (Peirce, 1931–58: 7, 139).

Bell, Hoadley and Linn (2004) introduced *compelling comparisons* as an approach to evaluate different versions of design solutions. According to them, compelling comparisons test hypotheses (Q') about learning embedded in the design solutions.

Based on our experiences it is not appropriate to attempt to achieve the detailed criteria of data collection or data analysis methods for design-based research (cf. Design narrative chapter 'Empirical problem analyses dealing with the designing of the learning environment'). We argue that in design-based research the specific design task or specific reflected problem in action determines the data collection and analysis.

Designing generates an artefact

From the pragmatic point of view, the role of the designed artefact is to help a teacher to act more intelligently. This requires the cognitively active role of the teacher. The teacher, ultimately, creates the learning environment by her or his actions in the classroom. Thus, every designed artefact has intrinsic immaterial and undetermined aspects that constitute on a classroom action and are possible to treat only with the teacher's thinking. The teacher 'personalizes' every artefact applied in teaching. In order to use it successfully, at some level, a teacher should understand and agree with the artefact. Based on our experience on the designing and teacher adoption process (Lavonen, Juuti, Aksela & Meisalo, 2006), it seems quite clear that it would be fruitless to design a brilliant or futuristic artefact, if teachers will not understand what the artefact is aiming to achieve; teachers would simply not adopt the artefact.

The existence and nature of an artefact distinguish design-based research from other endeavours, such as action research. In the action research, practitioners are developing their own actions and outcome of the research is a new way of action. The objective is not that artefact, but a new way of acting, would be employed by others. In design-based research, the objective of a widely usable artefact is one of the fundamental requirements (cf. diSessa & Cobb, 2004; Kelly, 2004). Further, it is not possible to design a "perfect" or "absolutely correct artefact because the intended users do not have the same competence, intention etc. in a topic as designers. The point in the designing is not that teachers should learn plenty of new things to enable them to use the artefact. The point is that the artefact should be suitable for teachers' current competence, beliefs, intentions, and attitudes towards the topic that artefact concerns. However, at the same time an artefact should help teachers to teach more intelligently. To design an artefact to be in the zone of the proximal development of teachers' pedagogical knowledge is a huge challenge for researchers.

The *ASTEL*- project (Design narrative chapter 'The context of Finnish primary physics teaching and learning'), as an example, shows that design solutions are typically designed for a specific national educational context and perhaps, they are difficult to use in other contexts not only due to language, but due to cultural traditions as well. The objective from the research point of view is not just to produce an artefact, but construct knowledge of science teaching and learning through designing actions.

Designing render novel educational knowledge

This chapter focuses on knowledge that emerged through design-based research. The point of educational research is to acquire new knowledge so that practitioners are able to act more intelligently. Designing, producing and testing processes offer various kinds of experience. According to Edelson (2002), acquired knowledge is either prescriptive or descriptive. Knowledge about the designing process and properties of a design solution is prescriptive. These prescriptions show an example of the successful process and product. Design-based research offers possibilities to acquire knowledge about learning. This topic knowledge is descriptive. Edelson (2002) calls knowledge acquired during the designing process as theories: design methodologies, design frameworks and domain theories. He distinguishes between two types of domain theories: context theories and outcome theories. Context theories are context-specific and outcomes are aimed to be more general. Bell, Hoadley, and Linn (2004) do not emphasise an important distinction between prescriptive and descriptive principles. Instead, they propose four levels of topic knowledge, naming these as principles: general cognitive principles, metaprinciples, pragmatic pedagogical principles [however, they seem to mean practical], and specific principles. Similarly, diSessa and Cobb (2004) introduce four types of "theories" that design-based research produces. We claim that the point is not how many vertical categories of topic knowledge are presented. The point is the explicated proposals for achieved inter-subjective knowledge. However, such categorisations might help DBR scholars to emphasise not only an artefact to be designed, but new knowledge as well.

From the pragmatist point of view, through action, it is possible to achieve knowledge and without knowledge, actions are guided by habits. Context makes actions understandable. The challenge is to abstract teachers' experiences obtained from actions to be inter-subjective i.e. fellow DBR scholars, as well as teachers outside of the project, are able to understand it and share the designed world.

As the pragmatic view implies, during the design-based research, research literature offers possibilities to act (i.e. design and use a learning environment) more intelligently as well as actions (designing and testing of the learning environment) offering possibilities to revise or at least refine "grand theories" or "orienting frameworks" (cf. diSessa & Cobb, 2004).

Trustworthiness

In her introducing article of the endeavour, Brown (1992) analyses methodology. She concentrates on data gathering and analysis. In design-based research, there is a similar problem of collecting, selecting and analysing data as in case study research: How does a researcher ensure that the data collection method thoroughly covers the phenomenon researched and how do they decide which particular set of data should be selected for detailed analysis. Especially, Yin (1994) emphasises three critiques towards case study research that are critical, as well, for design-based research.

Firstly, there is lack of rigor of research. Too often, as Brown (1992) remarked with the Bartlett effect, designers are careless with their data gathering, data analysis and they draw biased conclusions. Hoadley (2004) refers to the *measurement validity* to the robustness of specific evaluations. Dede (2004) warns design-based researchers about the situation of unfalsifiability: "Without standards for determining when to abandon a design approach as unpromising, the DBR field risks being seen as a venue for suboptimal educational strategies endlessly tweaked by their proponents in hopes of an unlikely breakthrough" (Dede, 2004, p. 108). Bell, Hoadley, and Linn (2004) answer the problem of falsifiability from the point of view of knowledge acquired during the design process. According to them, the design process offers design principles that are inductively generated from previous successful designs. These principles are falsifiable if they don't yield success in future designs. "[T]hey will be debated, altered, and eventually dropped" (Bell, Hoadley, & Linn, 2004, p. 83). Still, there is a problem of determination of successful design.

Also Kelly (2004, p. 126) asks evaluation criteria for designed artefacts. We propose that design-based research scholars need to state explicit goals that should be reached in the testing of the prototype. If goals are not reached, something should be changed. Yin (1994) suggests, that for example data, method, theory and investigator triangulation are techniques to ensure the quality of case study research. These are employable in design-based research as well.

The second critique emphasised by Yin (1994) is that case study research provides only a little basis for scientific generalization. He answers the critique that "case studies, experiments [and design-based research], are generalizable to theoretical propositions and not to populations or universes" (Yin, 1994). Edelson (2002) stresses that design research should be evaluated from the point of view of how productively knowledge, gained through design-based research, helps to explain educational phenomena. From the pragmatic viewpoint it could be formulated that how fruitfully knowledge, gained through design-based research, helps to act more intelligible in educational settings: launch novel design processes, design a novel artefact, and improve teaching and learning.

The third critiques DBR scholars should take into consideration, highlighted by Yin (1994) as well as Richey and Nelson (1996), are the long period of time and massive unreadable reports. The time period should not be long on purpose, but it is clear that an ambitious design process may take time.

Our approach is to divide the whole design project in several phases and to report these in separate papers. The phases of the project described in Juuti (2005) were introduced in four conferences before the final reporting. Teachers' needs were clarified in the Nordic science education research symposium (Juuti, Lavonen, Kallunki, & Meisalo 2004), the usability test of the prototype was described and discussed in the Girep conference (Juuti, Lavonen, Kallunki, & Meisalo, 2002), the evaluation of the pupils' views on designed learning environment was reported in the ESERA conference (Juuti, Lavonen, Kallunki, and Meisalo, 2003), and evaluation of pupils learning achievement were presented in the IASTED conference (Juuti, Lavonen, & Meisalo, 2004) The main benefit of the reporting in phases is the possibility of communication between DBR scholars during the process. This communication helps designers to report the project in a way that others could better understand the world where designing exists. Further, the final report could be published as journal articles as Linn's outstanding project in the special issue of the International Journal of Science education (Gilbert, 2000) or, more typically, in monographs (i.e. Lavonen, Meisalo, & Autio, 1998; Jorde, Strømme, Sorborg, Erlien, & Mork, 2003).

Bell, Hoadley, and Linn (2004) introduce *design narratives* as technique to communicate with other scholars in the field. Design narrative describes the features of the design-based research: the process (who to whom, context, resources, how) (Design narrative chapter 'Primary school teacher education in Finland') artefact (goals, properties and changes during the process) (Design narrative chapter 'Goals for and properties of the designed web-based learning environment for primary school physics'), and rendered knowledge that may consists of learning outcomes and other aspect of learning in designed settings which helped practitioners act more intelligently, i.e. improve teaching (Design narrative chapter 'New knowledge acquired during the project'). The point of the design narrative is to show that design-based research is cogent.

Edelson (2002) emphasises two aspects of certainty in design-based research: novelty and usefulness. "A design[-based] research program should yield new theories that have utility for resolving important problems" (p. 118).

Design-based research provides a novel artefact and novel knowledge highly interconnected with each other. Thus they help researchers to improve teaching and, perhaps, teachers to teach more intelligently.

As a summary, we propose two levels for trustworthiness. The first level considers, in accordance with Hoadley's (2004) *systemic validity*, the whole design-based research. *Unity trustworthiness* has the aspects of novelty, usefulness, cogency. A researcher shows that through the process something new (artefact and knowledge) (see Design narrative) has been produced and based on testing and revising it improved teaching in certain contexts. Another level considers one phase of the project. *Partial trustworthiness* is the case when a researcher decides, how he or she will try to understand teachers' worlds, how to collect data during the testing, how to analyse the data etc, how to help teachers to reflect on their experiences. Here specific criteria of different research methods (interviews, observations, etc.) are employed.

Conclusions

Design-based research as an emerging research approach needs clarification. When the novel approach is adopted, it is very important to take into consideration the problem of demarcation. It is crucial to be able to distinguish design-based research as scientific endeavour from pseudo science that is in the worst case, sloppy in design as pseudo-testing trials could be. In this paper, we have proposed principles to ensure design-based research as a scientific approach. Firstly, we clarified our view of the essential features of design-based research based on existing literature and our own experiences on designing in science education research. Secondly, we reflected design-based research reflecting with basic ideas of the pragmatic philosophy.

We propose that there are three aspects that constitute the design-based research. Firstly, design-based research projects produce an *artefact* that is applicable to a wider audience than just the correspondence group. Secondly, the process of design-based research is essentially *iterative*: parties' mutual coordination of action seeking a dynamic balance. Thus, the first prototype is hardly appropriate. In one sense, the documentation of revisions increases trustworthiness; during the project, designers have learned something new. Thirdly, the design-based research offers *new educational knowledge* to act (teach, learn, and design educational innovations) more intelligently. Typically, at the beginning of the project, we have investigated the teachers' expectations from the point of view of the artefact. This kind of research contributes to the design project, but also to the research concerning teachers' believes and school improvement (e.g. Lavonen, Juuti, Aksela, & Meisalo, 2006). Further, for example through quasi-experimental prototype testing, the research contributes to the research on students learning of scientific concepts (e.g. Juuti, Lavonen, & Meisalo, 2004.)

It appears that design-based research manifested in existing literature is easy to interpret within the pragmatic framework. Further, the pragmatic framework helps design-based research scholars to direct their actions. Especially, the pragmatic view of truth emphasises the relationship between a teacher and a designed artefact. These three aspects are emphasises others as well (e.g. Edelson, 2002). Our contribution is the pragmatist interpretation of these aspects and emphasis of the importance that researchers and teachers have similar experiences while testing the prototype of a designed artefact.

There are still plenty of aspects to clarify. For example, how should researchers convince themselves that the intended user, a teacher, lives in the same world, e.g. understands and shares the same goals for learning with researchers?

The design-based research approach offers a possibility to research novel phenomena. Designers construe the phenomenon with a designed artefact, not in a laboratory, but in authentic classroom environments with ordinary teachers and pupils. Thereby, researchers engage in the *for education* approach to improve teaching and learning.

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