Research Report 256

Kalle Juuti

Towards Primary School Physics Teaching and Learning

Design Research Approach

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RESEARCH REPORT 256
KALLE JUUTI: Towards Primary School Physics Teaching and Learning: Design Research Approach

ABSTRACT

This thesis describes a project to design a primary school physics learning environment which takes into account teachers' needs, design procedures, properties of the learnig environment, and pupil learning outcomes. The project's design team has wide experience in research and development work in relation to science education, the use of ICT in education, the way students think about physics, curriculum and teaching method development, and the design of instructional materials. This knowledge base was the starting point for design. The project engaged in design research. Design research is here considered to be a form of educational research, and offers opportunities to study unique educational phenomena. It produces artefacts to be applied directly in an educational setting, and thereby engages the researcher in the direct improvement of educational practice. Design research can even offer a strategy for the development and refinement of educational theory. The first main research result was a design procedure. The procedure contained four phases: 1) needs assessment; 2) definition of the objectives for a design solution; 3) design and production of the material; and 4) evaluation of the material. The phases apply research literature and empirical research. Phases three and four are iterative and include three stages: limited use of the prototype, a pilot test and a field test. The second main result was a designed learning environment as an example of a learning environment. The research showed that an environment should be: 1) concrete and illustrative, offering examples for the classroom; 2) mentally stimulating, for both study and practical work; 3) physically and pedagogically meaningful 4) usable; 5) offer peer and expert support for teachers. In addition, the research uncovered many contextual features that are important concerning the usability of the learning environment. The third main result was that qualitative level models delivered by way of stories offer much potential for learning primary school physics. From the Finnish perspective, the designed learning environment offers a novel phenomenon to investigate primary physics teaching and learning in a new situation where, from the point of view of this research, rather ambitious new National Framework Curriculum for physics education has been introduced.

Keywords:
Physics education, primary school, design research, Stories, Newtonian mechanics, learning environment

HELSINGIN YLIOPISTO, KÄYTTÄYTYMISTIETEELLINEN TIEDEKUNTA
SOVELTAVAN KASVATUSTIETEEN LAITOS

TUTKIMUKSIA 256
KALLE JUUTI: KEHITTÄMISTUTKIMUKSELLA KOHTI PERUSKOULUN ALALUOKKIEN FYSIIKAN OPETUSTA JA OPISKELUA

TIIVISTELMÄ

Tutkimus kuvailee peruskoulun alaluokkien fysiikan oppimisympäristön kehittämisprojektin tarpeiden analysoinnista kehittämisproceduurin ja oppimisympäristön ominaisuuksien kautta oppimistuloksiin. Kehittämisryhmällä on laaja osaaminen tutkimus ja kehitystyöstä luonnontieteiden opetukssa, tieto- ja viestintätekniikan opetuskäytöstä, oppilaiden käsityksistä luonnontieteellisistä käsitteistä, opetussuunnitelman kehittämisestä, opetusmenetelmien kehittämisestä sekä oppimateriaalien kehittämisestä. Projekti sitoutui kehittämistutkimukseen. Kehittämistutkimus nähdään kasvatustieteellisenä tutkimuksena, joka tarjoaa mahdollisuuden tutkia ainutlaatuisia kasvatuksen ilmiöitä, tuottaa artefakteja suoraan hyödynnettäväksi ja siten kehittämistutkimus sitouttaa tutkijat kasvatuspraktiikan kehittämiseen. Kehittämistutkimus myös tarjoaa mahdollisuuden kehittää ja tarkentaa kasvatustieteellisiä teorioita. Ensimmäinnen tutkimuksen päätulos on kehittämisproseduuri, jossa on neljä vaihetta: 1 tarpeiden analysointi 2) tavoitteiden määrittely 3) materiaalin tuottaminen ja 4) materiaalin arviointi. Vaiheet nojaavat tutkimuskirjallisuuteen ja empiiriseen tutkimukseen. Vaiheet kolme ja neljä ovat iteratiivisia sisältäen kolme tasoa: rajoitettu testaus prototyypin osalla, pilottitestaus prototyypin ensimmäisellä versiolla, kenttätestaus prototyypin toisella versiolla Toinen päätulos on kehitetty oppimisympäristö. Tutkimusprojektin aikana selvisi viisi tärkeää ominaisuutta alaluokkien fysiikan oppimisympäristölle: 1) oppimisympäristön tulee olla konkreettinen ja havainollistava, sisältää luokkaa vietäviä esimerkkejä 2) sen tulee aktivoida oppilaita kognitiivisesti, aktivoida työskentelmään ja ohjata kokeelliseen työskentelyyn 3) sen tulee olla fysikaalisesti ja pedagogisesti mielekäs 4) sillä tulee olla selkeä rakenne ja helppo käyttöliittymä 5) sen tulee tarjota mahdollisuus vertas- ja asiantuntijatukeen. Lisäksi tutkimus paljasti joukon kontekstiin liittyviä oppimisympäristön käytettävyyden kannalta tärkeitä piirtetä. Kolmantena päätuloksena tutkimus näytti, että kertomuksissa esitellyillä laadullisen tason selitysmalleilla on potentiaalia oppilaiden fysiikan oppimiseen. Suomalaisesta näkökulmasta kehitetty oppimisympäristö tarjoaa mahdollisuuden tutkia uutta ilmiötä: alaluokkien fysiikan opetusta ja opiskelua tilanteessa, missä uudet, tämän tutkimuksen näkökulmasta melko kunnianhimoiset, kansalliset perusopetuksen opetussuunnitelman perusteet on julkaistu.

Avainsanat:
Fysiikka — opetus, perusopetus — alaluokat, kehittäminen — kehittämistutkimus, oppimisympäristö, kerronta, mekaniikka

PREFACE

My first position as a postgraduate student was research assistant in the *Department of Applied Sciences of Education* in the Nordic co-operative project *NORDLAB,* from 1999 to 2001. Following that, I was an assistant in mathematics and science education for one academic year. From autumn 2002 to autumn 2004, I have been a full-time researcher in the *GISEL* project (Gender Issues, Science Education and Learning) which is a sub-project of the ESF-funded *EQUAL* programme. Since autumn 2004, my position has been lecturer in physics and chemistry education at the University of Helsinki. These positions have given me an opportunity to become familiar with research and development work in the field of science education. In particular, I got to know the design research methodology (Juuti, Lavonen, & Meisalo, 2003) which I have used in this thesis.

This doctoral thesis is based on my licentiate thesis in education (Juuti, 2003). Working as part of a research team, my responsibility was to plan the research design and conduct data gathering and analysis. My fellow researchers lent their expertise to this work.

My roles in the design research project have been designer and evaluator. I have participated in almost every design meeting from the beginning of the project in autumn 2001. In my role, I solicited and followed up the user point of view, and reflected on how the prototypes were based on the problem analysis of teachers' needs and tests, in particular, and the research literature, in general. It is difficult to point out what each designer contributed during the design meetings. The process followed a creative process: one made a comment and another built on that initial idea. Like every member of a design team, I was required to comment on manuscript drafts and graphics.

I was not responsible for writing articles on the learning environment. Design and comment together were crucial. For example, the graphic designer worked with me for some time, so it was easy to comment on her drafts. My comments on the manuscripts or drafts were mainly related to problems in physics: correction of errors and suggestions to help avoid reinforcing compromise models. However, sometimes gender stereotypes or the user interface needed to be revised in the drafts.

The designed learning environment is available online: www.openet.fi/astel/.

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I would like to thank my supervisors Professor Jari Lavonen and Professor emeritus Veijo Meisalo, who, from the very beginning, have shared their enthusiasm and professional knowledge on research on science education to the benefit of my research. They have encouraged and helped me to focus on essentials in this thesis.

My gratitude also goes to the rest of the design team, to my colleagues in the research centre for mathematics and science education, assessors Professor emerita Maija Ahtee and Professor Jouni Viiri, and to all those who have listened to, read and commented on my reflections in this thesis.

I would like to thank all the teachers and pupils who have participated in the needs assessment and evaluation of learning environment.

And finally, my warmest thanks to Hanna.

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CONTENT

1 INTRODUCTION

This doctoral dissertation analyses a design research project aimed at developing a learning environment for the teaching and learning of Newtonian mechanics in primary schools. In this research, *primary* means grades 1 to 6 in comprehensive school. At this level in the Finnish school system, each teacher usually teaches almost every subject. The research focus is grades 5 to 6. At grade five, according to the new Finnish National Framework Curriculum (FRAME, 2004), pupils start to learn a subject called *Physics and Chemistry*. There were four main objectives for this design research project. It was meant to produce a learning environment that helps pupils to (1) learn the concepts of physics, (2) acquire practical working skills, (3) learn about the nature of physics as an empirical science, and (4) increase interest in and positive attitude towards physics.

In brief, physics is a natural science that explains observable phenomena with models. These models were originally based on human experience, rational thinking, and detailed experiments. Justification for the models (concepts, laws, theories) is based on evidence from experiments and consensus in the research community (Niiniluoto, 1980; Popper, 1959). The view of physics as a discipline has traditionally affected how physics has been taught. For instance, according to Kuhn (1970), when a physics student solves exercises and carrying out laboratory tasks, he or she learns the conventions and traditions normally used. He or she learns how to use natural laws and theories to explain a certain phenomenon. The student learns when it is appropriate to use a particular law, model, or theory. Furthermore, he or she learns the types of problems that can be solved as a physical research question. During this learning process, the student makes theoretical, conceptual, instrumental, and methodological commitments that he or she cannot impugn. After this process, a student is able to be a normal science scientist: to study specific problems that are appropriately related to the body of physical knowledge.

In science education, there is a large body of research literature on the way students understand physical concepts and how these ideas change over time (Andersson & Renström, 1979; Driver, Guensne, & Tiberghien, 1985; Halloun and Hestenes, 1985; Schnotz, Vosniadou, Carretero, 1999; Ahtee 1994; Juuti, 2000) and on students' views about physics and their concept of themselves as physics learners (Simpson, Koballa, Oliver, & Crawley, 1994; Hoffmann, 2002). These are crucial aspects of learning from the point of view of constructivist learning theory. There is also plenty of research on practical work and the use of information and communication technologies (ICT) in education (Millar, 2004; McFarlane & Sakellariou, 2002; Lazarowitz & Tamir, 1994, Tinker, 1996).

In addition to research on education in physics, there are also a wide variety of suggested teaching approaches (Arons, 1997; Gilbert & Boulter, 2000; Kurki-Suonio & Kurki-Suonio, 1994; Wells, Hestenes & Swackhamer, 1995; White, 1998) based mainly on different views of physics as a science.

Although current textbooks have been well-evaluated (Mikk, 2000), there is a distinct lack of research on the design and development of instructional materials or learning environments for science education (Driscoll and Dick, 1999). Recently, the results of some new research into design have been published (Jorde, Strømme, Sorborg, Erlien, Mork, 2003; Linn, 2000; Gilbert, 2000; Jorde, 2000; Vosniadou, Ioannides, Dimitrakopuolou, Papademetriou, 2001; Lavonen, Meisalo & Lattu, 2002; Lavonen, Aksela, Juuti, & Meisalo, 2003; Juuti, Lavonen, & Meisalo, 2003). However, the processes which help teachers to easily adopt innovations in their teaching are still poorly understood. Linn (1996) argued that when designers test innovations in educational technology, researchers achieve promising results, but end users – typically teachers – fail to use the innovation. To address this problem, Linn, Davis, and Bell (2004) suggested a partnership between teachers, researchers, and technologists. Engaging in design research offers an opportunity for teachers to participate in design work, as Crosier, Cobb, and Wilson (2002) suggested.

In addition, design research offers an opportunity to test educational theories and refine them. Design work provides a productive channel for theory development. It helps designers avoid big mistakes when producing material, and it provides highly contextual research results. Furthermore, it directly improves teaching, because the design solution – a learning environment – is the direct result of the design research and the design process (Edelson, 2002). This methodology is similar to what happens in technology design and usability testing, where the focus is on users' opinions and behaviour. Recently, this connection to technology design has been noted in the literature on educational technology design (Opperman, 2002). Fullan (1991) emphasised three factors that are crucial when implementing an educational innovation. These are 1) *characteristics of innovation* (e.g. need for innovation or clarity of an innovation), 2) *local characteristics* (e.g. teacher's ideas, school context), and 3) *external factors* (e. g a national framework curriculum). The theoretical and empirical problem analysis of this thesis describes how these factors have been taken into consideration to ensure that learning environments are easy to integrate into school practice. After the learning environment prototype has been adjusted, it is possible to evaluate the extent that pupils have learned (for example) Newtonian mechanics.

Concentration on the intended users' opinions and experiences in the actual user context during the design of teaching materials leads to the research questions of this thesis.

Research questions

Design research offers three kinds of knowledge: *domain* knowledge about teaching and learning, *methodological* knowledge about the process of design, and *framework* knowledge about the properties of the design solution (Edelson, 2002). The present design research focuses, during the research process, on a number of detailed problems described in the problem analysis (see chapters 3 and 4). Overall, this research attempts to answer the following questions:

1. What kind of design procedure leads to a primary school physics learning environment?
2. What properties does a primary school physics learning environment have?
3. How do primary school pupils learn Newtonian mechanics in the learning environment designed in the project?

Chapter 2 describes the design research methodology. Chapters 3 and 4 provide a literature review, an empirical needs assessment, and testing, offering answers to Questions 2 and 3. Each phase of the empirical problem analysis has its own special method, result, and discussion, providing specific design objectives for the learning environment. Chapter 5 describes the design process, which addresses Question 1. Chapter 6 describes design innovations, answering Question 2 in the form of a conclusion. Finally, Chapter 7 summarises the present research.

2 DESIGN RESEARCH METHODOLOGY

This chapter describes the methodological approach of the research. Educational research can be divided into two main categories. The first category is research that describes reality. This can be called basic research. The second is research that aims to change reality. In this case, the goal is to change teaching by re-design of the learning environment.

This section contains the principles, methodology, and reliability of the entire design research project. Special approaches will be described in the problem analysis (Chapter 4).

Design research can be explained through an advanced organiser that I call as design triangle (Figure 2.1). The objective here is to show the relationship between design research and its sister endeavours such as action research (e.g. Carr & Kemmis, 1986), user-centred design (e.g. ISO 13407:1999), and research about diffusion of innovation (Rogers, 1995).

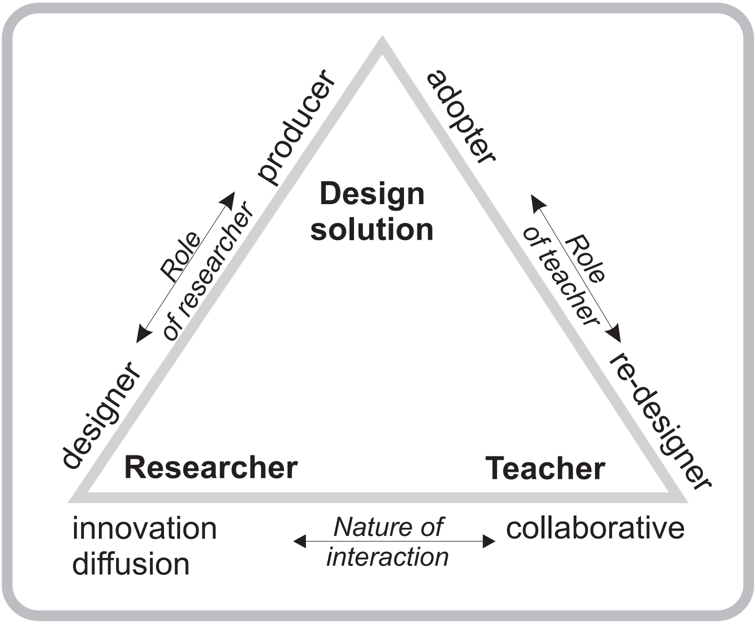


Figure 2.1 The design triangle shows the involved parties and their roles in the design process.

Design research and its related endeavours share the same involved parties. It is possible, at least at the conceptual level, to distinguish artefact as a design solution, correspondence actor as a researcher, and practitioner, which in the school context is a teacher. The design solution could be a novel idea, way of working, product, or way to use the product. The researcher is in charge of the design and development process, which in practice could be a professional researcher or other person outside of the practicing context, such as an administrator, or even a teacher. The teacher in the school context is meant to use the novel solution in her or his praxis. The design triangle describes the parties' *roles* in the design. These roles show the emphasis of each research tradition. Power makes the difference between these traditions: who has the power to decide, what kind of solution is needed, what kind of solution there should be, and how the solution should be applied. In short, the *nature of the interaction* between the parties.

The following section describes *action research*, *user-centred design*, and research about *diffusion of innovation*. These endeavours will be reflected back to the design triangle in order to emphasise particular elements of this research project.

2.1 Sister endeavours for design research

2.1.1 Action research

The goal of action research is to understand and improve practice. Practitioners find a situation unsatisfactory, establish goals, and – maybe – invite an outside facilitator to co-ordinate and assist in their actions.

According to Carr and Kemmis (1986) there are three kinds of action research: technical, practical, and emancipatory. A traditional example of technical action research is a project to improve agriculture in a native Americans reservation. Administrators (outsiders) noticed problems with nutrition on a native Americansn reservation. The administrators launched a project to facilitate the improvement of local farming. The goal in technical action research is to be more effective in practice. Although the goal is to improve conditions and praxis, outsiders lead design and operations.

In practical action research, (for example in educational context) teachers and researchers work together. Researchers help teachers to recognise their interests. Outsiders design actions, analyse problems and the efficiency of change, and evaluate the change process (Carr & Kemmis, 1986). As in technical action research, practical action research is led by outsiders. However, the outsider's role is more as a facilitator than an enforcer of discipline (cf. Messner & Rauch, 1995). The researcher's role is Socratic in helping teachers in self-reflection (Carr & Kemmis, 1986).

Carr and Kemmis (1986) claim that only actual action research can be emancipatory. In emancipatory action research, teachers are responsible for developing, understanding and evaluating actions. Anyone in the group 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 design solution. An outsider could facilitate the process of reflection to help the teachers think critically about their goals, actions, and evaluation.

In the action research context, a design solution is the novel practice or working model that remains after the project. In technical action research, the teacher's role is as adopter, trying to cope with changing practice and making it fit to the requirements of the design solution. In practical action research, the teacher's role is re-designer. He or she modifies facilitated working models – solutions – to fit her or his praxis. In emancipatory action research, the teacher is a designer, who truly is in charge of change and its resulting design solution.

In action research, there is a strong emphasis on the empowered participation of teachers. There is no clear distinction between researchers and teachers. The interaction between researcher and teacher is collaborative, and the teacher's role is to be a redesigner, or even a designer of the solution. The researcher's role is to be a producer of the solution (cf. Figure 2.1).

2.1.2 User-centred design

The origin of user-centred design is in engineering product design, where designers are experts. The design process starts with brainstorming and benchmarking and continues rapidly throughout the design and production process. Novice designers think wishfully that a design solution or design project will be hard to abandon by intended users or administrators if it turns out to be unsatisfactory (Zaritsky, Kelly, Flowers, Rogers, O'Neill, 2003). According to Carr-Chellman and Savoy (2004), user-centred design takes into consideration the users but they are not empowered. User-centred design research has focused on understanding users' needs, desires, and contexts. They argue that designers have the power to decide design actions and the intended user's (practitioner's) role is to be a usability tester or final evaluator.

On the other hand, the standard for human-centred design for interactive systems (ISO 13407:1999) describes in great detail how practitioners should be integrated within the design process from the very beginning of the project. 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. According to the standard, a user-centred design process is characterised by 1) the active involvement of users and a clear understanding of user and task requirements; 2) an appropriate allocation of functions between users and technology; 3) the iteration of a design solution; 4) multi-disciplinary design.

Multi-disciplinary design means that user-centred design needs a variety of skills. Researchers form a design team that should reflect the relationship between the organisation responsible for design and the user. According to the standard (ISO 13407:1999), a design team can include the following roles: 1) user; 2) manager of user; 3) application domain specialist; 4) programmer; 5) marketer; 6) visual designer; 7) human factors expert; 8) technical author and support personnel. This multidisciplinary team could conduct a user-centred design project.

The project proceeds through four stages: from 1) understanding the context through 2) user requirement specifications and 3) the production of design solutions to 4) the evaluation of the design against the requirements. The standard emphasises the iterative process of prototyping, testing, and designing until the design solution (artefact) meets the requirements.

User-centred design focuses on the researcher's role as designer. Interaction between teacher and researcher is collaborative to ensure an easy adoption of the artefact. Thus, the teacher's role is to adopt the design solution (cf. Figure 2.1).

2.1.3 Diffusion of Innovation

The third sister endeavour for design research, reflected within the design triangle (Figure 2.1), is the theory of diffusion of innovation established by Everett Rogers. He defined diffusion as follows:

> "*Diffusion* is the process by which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas. *Communication* is a process in which participants create and share information with in order to reach a mutual understanding" (Rogers, 1995, pp. 5 – 6).

The design triangle illustrates the relationship between a design solution, a researcher, and a teacher. Rogers' (1995) model of diffusion of innovation emphasises the characteristics of a design solution. *Relative advantage*, *compatibility*, *complexity*, *trialability*, and *observability* are all characteristics that determine an innovation's rate of adoption (Rogers, 1995). The degree of relative advantage implicates economic measuring; in addition to that, social prestige, convenience, and satisfaction are also important aspects. Rogers (2001) emphasises that objective advantages are not significant for adoption. When an innovation is appropriate to the existing values, practises, and needs of users, the innovation is compatible. It is quite clear that new ideas that are simple to understand will be more rapidly adopted than complex ideas requiring training and new skills. Trialability means that an innovation is easy to try. A triable innovation causes less uncertainty for the user; he or she could learn while testing the solution in the actual context. Thus, it is more likely to be adopted. According to Rogers, an important characteristic of an innovation is its observability. The easier the innovation is visible to others, the more likely users are to adopt it. Visibility stimulates peer discussion and other kinds of communication.

Another feature of Rogers' (1995) theory of diffusion of innovation is that there are communication channels. Rogers (2001) claims that mass media channels are most effective in creating knowledge about an innovation, and inter-personal channels are most effective in forming and changing attitudes towards a new idea.

The third feature of the theory of diffusion of innovations is time. Time is considered in three ways: 1) the innovation-decision process takes time; 2) the innovation is adopted in different times in the five adopter categories; 3) the rate of adoption is the relative speed of adoption of the innovation. Rogers (2001) breaks adopters into five categories. The first 2.5% of individuals are *innovators*; they must be able to cope with a high degree of uncertainty about an innovation. Their point of view is more cosmopolitan and their skills must be more advanced than typical members of the social system. Their peers may well not understand them. The second 13.5% of individuals are called *early adopters*; they are local opinion leaders and change agents. Peers acquire information about the innovation from them. The third 34% of individuals are the *early majority*; these people adopt the innovation just before an average practitioner does. The next 34% of individuals are the *late majority*; their adoption may be the result of peer pressure. They do not adopt the innovation until the most of their peers have done so. The last 16% of individuals are *laggards*; they tend to be suspicious of innovations and change agents. They must be very certain that new idea will not fail before they will adopt it. Typically, laggards are quite isolated socially.

Roger (1995, 174) defines re-design (*re-invention* in Rogers' terminology) as a measure of how much users have modified the innovation. Thus, there seem to be more choices than just adopt or reject the whole solution. A user could adopt a limited version or modify the innovation to better suit the local context. Rogers (1995) particularly emphasises the possibility of re-design in educational innovation.

The theory of diffusion of innovation describes in detail the characteristics of a practitioner as adopter of the innovation. Researchers should produce design solutions ensuring advantage, compatibility, and so on, and the practitioner's role is more or less to adopt or reject an artefact. Further, the nature of interaction between researcher and teacher is diffusion of innovation. Carr-Chellman and Savoy (2004) call Rogers' theory a *colonial* approach to design and diffusion because of the disempowerment of users.

2.2 Design research

Design research is an endeavour that subordinates the process of design to refine and develop educational theory. The goal is to better understand teaching and learning. Thus, a design solution and a design research process (e.g. the design of a novel learning environment) provides unique educational phenomena for study. This design research approach is rather new as educational research (O'Donnell, 2004), and has been called variously *design experiments* (Brown, 1992), *design-based research and design studies* (Kelly, 2003), *developmental research* (Richey & Nelson, 1996), *user design research* (Carr-Chellman & Savoy, 2004), *didactic engineering* (Artigue, 2002), and *design research* (Edelson, 2002). For the purposes of this thesis, these are all synonymous, but only the term *design research* is used, because Edelson (2002) is the main model here.

It seems that some design researchers emphasise an understanding of the designing process. Richey and Nelson (1996) define design research as a combination of actual design where research is related to product evaluation, process evaluation, or someone else's design efforts. New knowledge about the domain plays only a minor role. They argue: "research can also result in context-specific knowledge and can serve a problem-solving function" (Richey & Nelson, 1996, p. 1216).

There has been lack of research-based design. In their literature summary, Driscoll and Dick (1999) claim that most published articles on design were typically not research articles. They suggest that researchers in educational technology should collaborate with teachers in the field and focus on questions related to instructional design procedures. Carr-Chellman and Savoy (2004) claim that there is almost no design research focusing on instructional systems that emphasise the participatory role of practitioners.

Considering this in the context of the design triangle (Figure 2.1), it seems that Driscoll and Dick (1999) and Carr-Chellman and Savoy (2004) emphasise a more active role for teachers than Richey and Nelson (1996). However, Richey and Nelson (1996) argue that researchers could be outsiders from the designing team and the research focus is then on others' design efforts. Then the situation is similar to emancipatory action research, but the focus is to research another group that is responsible for design, not necessarily practitioners in the field.

In action research, the goal is to change the actions of participants. In design research, the goal is to design a solution that meets the needs of the wider group. The teacher's role is re-designer. Every interaction is collaborative: the role of researchers is to be designers, and researchers are in charge of the design research process.

In the following, I will describe in more detail the design research approach for educational research. There are five characteristics that describe design research: 1) the purpose is to develop educational theories; 2) it uses a wide variety of methods; 3) it creates conditions to inquire about unique educational phenomena; 4) the process of design is essentially iterative; and 5) it produces solutions directly applicable in practice (Edelson, 2002; Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003; Design-Based research Collective, 2003; Collins, Joseph, & Bielaczyc, 2004).

Theory development through design research

According to Edelson (2002), three types of theories can be developed through design research. These theories are in close relation with the educational problem which creates the motivation to conduct design efforts, and develop design solutions and procedures. Categorisation of these theories is: *domain theories* (descriptive knowledge about the problem to be solved through design), *design frameworks* (prescriptive knowledge about the properties of a successful design solution), and *design methodologies* (prescriptive guidelines for a successful design procedure).

There are two types of domain theories: *context theory* and *outcomes theory*. The context theory characterises the challenges and opportunities in a specific teaching and learning context. Edelson (2002) and Cobb et al. (2003) emphasise that design research provides contextual knowledge. They criticise major theories, such as constructivism, as lacking detailed guidance for teachers to organise teaching. Clements and Battista (2000) emphasise that in the beginning of a design process, designers must construct a model of how pupils learn a topic. If no explicit model is available, designers must construct it through research.

Outcome theory describes answers to the desired outcomes of the successful testing of the design solution. On the other hand, unsuccessful testing demonstrates outcome theory about undesired outcomes (Edelson, 2002).

Throughout the design research process, the designers' knowledge about the requirements for a successful design solution increases. Thus, the design framework is a generalised, prescriptive description of the design solution. Design research provides information for other educational designers coping with the similar problems to design similar solutions for their own contexts (Edelson, 2002).

Design methodology is the third theory type described by Edelson (2002). Design methodology provides guidelines for the procedure to find a successful design solution. Developing the design models are common for many design fields (e.g. the user-centred design described earlier).

As an example of the design model, Clements' and Battista's (2000) nine-phase design model for instructional computer programs focuses on a combination of design and evaluation. The first three phases focus on the initial stages of design (initial objectives, explicit model of how pupils learn the topic, initial draft). The next four phases focus on evaluation (testing of the components, confirmation of the prototype and curriculum, pilot testing, extended testing). The eighth phase focuses on combining design and evaluation, and the final phase is publishing.

Another model is Lavonen and Meisalo's (2002) seven-stage research-based process for designing sponsored learning materials. The phases were: 1) 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; 2) detailed design of objectives, contents, strategies and tasks following the principles of creative processes; 3) preparation of a preliminary manuscript; 4) in-service training to test the manuscript; 5) collecting feedback about the manuscript from teachers in in-service training; 6) planning the use of the material designed; and 7) user evaluation to improve the material over the years.

The last example to be presented here is Moonen's (2002) three-space design strategy. There are three spaces, where the output of a previous space is the input for the next. The spaces are: consensus space (input is a design problem, the goal is agreement, the output is the functional specifications of the product), task space (the goal is designing, the output is a prototype of the partial product), and the implementation space (the goal is user-adaptability; the output is a final partial product). The significant aspect of Moonen's (2002) design strategy is that it emphasises the practitioner as a designer: the practitioner defines the final product. He uses Microsoft software as an example of how a user can re-design the final product. One can change colours, change tools in the toolbar, and so on.

Common to all is that the prescriptive design models are ensure that researchers assemble the necessary expertise and conduct appropriate procedures to achieve successful design solutions. The clearest distinction between user-centred design and design research is the meaning of research. Design research is research-driven, aimed at better understanding teaching and learning, while user-centred design rationales for inquiry are economic (cf. ISO 13407:1999). The main difference between action research and design research is the role of power and the nature of goals. In design research, the design solution is meant to be applicable not just to participants, but a larger group. In design research, participants are the representatives of intended users.

Wide variety of methods

Design research processes are complex and continue in stages (as described above). In each stage, the emphasis is on different research objectives. Thus, it is clear that multiple sources of data and mixed methods are needed. Cobb et al. (2003) state that the nature of design research is interventionist. It enables the creation of new forms of teaching and learning in order to study them. Cobb et al. (2003) list examples of sources of information. Their list can be organised with case study research principles that Yin (1994) suggests for a case study data collection: multiple sources of evidence should be used. This strategy is also called data triangulation. Yin (1994, p. 79) categorises six sources of evidence: documentation, archival records, interviews, direct observations, participant observations, and physical artefacts. In addition to that, quasi-experimental research design may be needed to convince audiences and policy makers (Edelson, 2002).

Conditions to inquire unique educational phenomena

According to Cobb et al (2003) as well as Collins et al. (2004), design research has two aspects: *prospective* and *retrospective*. The prospective aspect is hypothetical and intentional. Designers implement a hypothetical learning process. During the designing process, designers obtain information about teaching and learning in the novel environment. A retrospective or summative aspect is comparable with theory testing. This kind of approach has been used in education to inspect or analyse ready-learning materials rather than do research before and while designing.

Procedure of design is essentially iterative

As descriptions of design methodologies and close relations with user-centred design imply, design research is essentially iterative. When a first version of the design solution has been designed and – maybe – refused, a new version will be developed and tested. The result is an iterative design procedure including cycles of innovation and revision (Cobb et al., 2003).

Solutions directly applicable in the practice

Edelson (2002) emphasises that education has a nature of design. Teachers design activities for students and administrators design school systems. Therefore, research results that directly help design activities, learning materials, and educational systems are most useful. Design frameworks and design methodologies provide for practitioners in directly applicable results.

Further, Richey and Nelson (1996) as well as Kelly (2004) emphasise that the existence of a design solution is essential for design research. Design research should produce a design solution that outlasts the design research project and can be used by others. Thus, research-driven design ensures useable solutions for the praxis. Edelson (2002) argues that designers conduct the design process in a real educational context. Thus, they engage in the improvement of education. Typically, design research projects are free from the market considerations that drive traditional educational design; designers have the opportunity to create truly innovative designs.

2.3 Reliability criteria of a design research

Research can be considered *trustworthy* if it achieves *credibility, transferability, dependability and confirmability* criteria. (Lincoln & Guba, 1985; Eisenhart & Howe, 1992)

The goal of design research is to develop new, useful theories of teaching and learning. Thus, the *novelty* and *usefulness* of design research should be evaluated (Edelson, 2002). In addition, *improvement* of teaching and learning is suggested as a value criterion for design research (Design-Based Research Collective, 2003).

Design research is very similar to engineering (e.g. user-centred design). There are different parties to *convince* during and after a design research project. There are groups of designers, administrators, managers, education researchers, and most essentially, teachers. Design research is a theory-driven endeavour; therefore, researchers should follow general educational research criteria to convince other researchers. Qualitative research methods such as interviews and video analysis are very time-consuming. Therefore, the members of the design team responsible for research should be flexible while using research methods. It is unlikely that manuscript authors, graphic designers, or coders would wait for a long period while a researcher is transcribing a video. During the design process, it is important to be able to convince designers to revise, perhaps totally, their products.

Cobb et al. (2003) argue that it is important to distinguish *analysis during* and *after the process*. The purpose of the *during-process analysis* is to help produce a new cycle in the iterative process. The aim of *after-process analysis* is to place design research in the broader theoretical context. If the design research process is to be published as a case study, then a detailed retrospective analysis could be appropriate.

Retrospective analysis can be seen as closely related to traditional textbook or learning material research where certain aspects of ready-made learning material are analysed (i.e. Leite, 1999). The results of that kind of research might be a collection of suggestions for textbook authors, but not any concrete improvement efforts. Thus, it may be more or less against the principles of design research. When a design solution is produced and practitioners use it, then it is more interesting to launch a new project to improve the use of the designed artefact.

3 THEORETICAL PROBLEM ANALYSIS

Design research requires three types of decisions to make. These are *design procedure*, *problem analysis*, and *design solution*. This theoretical problem analysis and the next chapter, empirical problem analysis, describe the goals, needs, opportunities, and constrains for design (cf. Edelson, 2002). Problem analysis raises problems to solve with design solution. Theoretical problem analysis introduces research literature that is relevant to the design of the learning environment. In the end of the every theoretical problem analysis sections, there is section explicating design objectives.

3.1 Conceptual change in physics

Clements and Battista (2000) emphasise that designers in the design research project, should produce an explicit model for learning the topic that the design concerns. This section describes the model of learning motion that was advanced during the design process.

The focus of this research was to design a learning environment for physics, especially Newtonian mechanics. Jonassen & Land (2000) emphasised intention, activity, consciousness, and reflection as aspects of learning. Learning is seen as a process of making meanings. Knowledge of a specific domain cannot be separated from interaction with its context. People interact with nature, other people, and physical objects. Making meaning is the process of making sense of these interactions. To understand the relationship between action and reaction, learners build (mental) models. Furthermore, the process of making meaning is highly social. Humans rely on feedback from peers to determine their own existence as humans and to verify their personal beliefs. Furthermore, the individuals in the community in which one lives and their beliefs and values influence one's own knowledge and beliefs of the world. Thus, "knowledge also exists in the discourse among individuals, the social relationship that binds them, the physical artefacts that they use and produce, and the theories, models, and methods they use to produce them" (Jonassen & Land, 2000, p. vi). Knowledge is seen as a relationship between the world and people (cf. Marton, 1981). Marton calls this internal relationship *non-dualistic ontology*, and is illustrated by the following example: "Considering person and world to be internally related. An internal relation between A and B implies that neither A nor B would be identifically the same without the relation between them" (Marton, 1996, p. 175). Furthermore, there is nothing in the world that is not experienced. Each person describes the world as he or she experiences it, and it is impossible to imagine any world that is independent of our description (Marton, 1996).

The aim of the learning environment was that pupils learn to use Newtonian mechanics to understand and explain motion phenomena. Pupils' conceptions about movement and force has been well-researched (Viennot, 2001; Halloun & Hestenes, 1985). Student thoughts on these topics can be divided into two categories: *initial schemas* and *compromise models*. The basic idea is that a pupil's conceptual grasp of physical phenomena is formed by teaching, cultural context, and bodily experience (cf. Duit, 1999). The initial schema forms in connection with the appearance of a single phenomenon. The schema produces expectations on how things are organised (Rowlands, Graham, & Berry, 1999). When pupils explain or represent a phenomenon, they form a model that explains it. This compromise model is influenced by models and terminology originating from teaching, cultural context, and initial schemas. I shall call the models and terminology from teaching and culture *a theory model*.

Posner, Strike, Hewson and Gertzog (1982) introduced a model about conceptual change based on cognitive conflict, or anomalies. According to their model, when pupils face an anomaly, they become dissatisfied with their concept, and thus acquire a new, better formulated concept through teaching. Teaching strategy consists of five aspects: 1) lectures, demonstrations and lab work should create cognitive conflict in students; 2) teachers should concentrate on diagnosing errors in pupils' thinking; 3) teaching should focus on creating strategies to deal with student errors; 4) teaching should help pupils to make sense of science content using verbal, mathematical, concrete-practical, and other representations; 5) evaluation methods should help trace the process of conceptual change. According to Posner et al. (1982) "the content of science courses should be such that it renders scientific theory *intelligible, plausible, and fruitful*" [italics added] (Posner, et al. 1982, p. 225).

However, research has shown that cognitive conflict does not necessarily cause conceptual change (Sinatra & Pintrich, 2003, p. 2). From a pupil's point of view, the cognitive conflict may appear to be too big, causing the two-perspective outcome that Gilbert, Osborne, and Fensham (1982) have described. It seems that Posner's et al. model for cognitive conflict is too straightforward, assuming that change is more rational than the latest research implies. Student motivation, affect, beliefs, and attitudes seem to influence conceptual change (Sinatra & Pintrich, 2003).

One possible constraint on conceptual change is that pupils themselves are not aware of their own conceptual understanding (Vosniadou, 1999). Lack of metacognitive awareness of one's own beliefs and preconceptions complicate conceptual change. Chi, Slotta and de Leeuw (1994) explained why one concept changes more easily than another using ontological categories. Entities belong to mental states, processes, and matter. Typically, pupils place entities to the matter category, but from the physics point of view, they belong to the category of processes. When an entity is placed in the wrong category, conceptual change is difficult. If an entity is placed in the correct category, learning no longer requires conceptual change, but becomes essentially knowledge enrichment.

Southerland and Sinatra (2003) distinguished between acceptance and understanding in order to explain how a student can understand a concept without accepting it. If the issue is not controversial, there is a strong relationship between acceptance and understanding, but no relationship between acceptance and the belief system or understanding and the belief system. If issue is controversial (such as human evolution or quantum mechanics), there is strong interaction between acceptance and the belief system but a weak relationship between understanding and the belief system. If the issue is complex and controversial, and thus cannot be resolved by simple basic knowledge, intentional constructs may be evoked to aid problem solving and learning.

The distinction between acceptance and understanding may help to explain why students learn how to solve mechanics problems at the quantitative level (calculation), but do not learn how to explain movement with force at the qualitative level. One interpretation could be that at the qualitative level, pupils do not accept Newtonian mechanics. For example, the idea that the forces exerted by a wall and a human are equal could be seen as nonsense. In this case, force is conceptually connected to a source that can create movement. At the quantitative level, an acceptance of the background assumptions of Newtonian mechanics is not needed. It may be enough to mechanically apply rules.

From the cognitive science perspective, the goal of learning can be seen to develop mental models. It is only possible to find out about others' mental models indirectly, through communication. Students are asked to write, tell, or draw their views about the issues they study. Thus, pupils produce representations of their mental models. By analysing these representations, a researcher can construct and interpret the models (Justi & Gilbert, 2000). Vosniadou (1994, p. 53) defined an *initial model* of Earth as a model that is "based on everyday experience and does not show any influence from the culturally-accepted, scientific model of the spherical Earth". Initial models of Earth are often the rectangular Earth and the disc Earth. Thus, an initial model does not demonstrate any clear scientific basis.

3.3.1 Initial schemas

According to the phenomenological interpretation, there are three entities concerning movement: the Earth, physical bodies (objects), and living body. Earth is the main reference point for movement, since it does not move (Himanka, 2000; 2002). In addition, it can be argued that Earth is a closed surface and asking its shape is senseless. This is a problem of the questions of Vosniadou's (1994) research. Asking "What is the shape of the Earth?", the researcher forces the child to consider the Earth as a physical body, or thing (cf. Ivarsson, Schoultz & Säljö, 2002) However, analysing the pupils' representations of their mental models, it is possible to understand why the learning of some issues is so difficult, and how they should be taught. For example, Vosniadou (2003) argued that it is important to teach the principles of gravity before teaching the shape of Earth, so that pupils are able to understand why people do not fall off the other side of the Earth.

Spelke, Breinlinger, Macamber and Jacobson (1992) proposed that a young child organises the movement of (physical) bodies with four factors: 1) *continuity*, objects move only on connected paths; 2) *solidity*, two distinct objects do not coincide in space and time; 3) *gravity*, objects move downward in the absence of support; 4) *inertia*, objects do not change their motion abruptly and spontaneously. I interpret Spelke's *et al* (1992) four factors, phenomenological entities concerning motion, and phenomenological interpretation of an unmoving Earth as initial schemas concerning motion. There are also some parts of the schemas that contradict Newtonian mechanics. Newtonian mechanics includes plenty of assumptions that are not mentioned in a typical science textbook. Newton's zeroth law concerns these assumptions (cf. Hestenes, 1992). These disconnect Newtonian mechanics from everyday bodily experience. The living body and Earth are replaced by inanimate physical bodies. Zeroth law defines Newtonian space and time. Table 3.1.1 describes and compares *initial schemas* and Newtonian background assumptions.

3.1.2 Compromise model

Vosniadou (1994) described conceptual change as a process from *initial models* through *synthetic models* to *scientifically correct models*. Her synthetic model is a combination of specific facts (or belief), ontological presuppositions and epistemological presuppositions. Gilbert, Osborne and Fensham (1982) coined the term *hybrid model*, to which there are three levels: 1) *the two perspectives outcome,* where a pupil uses learned terminology and concepts only in studying context; 2) in *the reinforced outcome,* where a pupil uses learned scientific terminology to describe common sense conceptions; and 3) *the mixed outcome*, where a pupil has learned scientific principles and concepts, but they are not interrelated and may be self-contradictory, or common sense and scientific ideas coexist.

Table 3.1.1 Comparison of initial schemas and Newtonian background assumptions

Initial schema	*Theory model (Newtonian mechanics)*
There are physical bodies to moveThe living body is able to create motionEarth does not move	Every object can be idealised as a rigid body
Vertical motion is primary and time is defined by the experiences of an experiencer.	Time and space is the same for every observer. There is no primary direction or place.
Foundation for perception is a living body on Earth that does not move	Foundation for perception (reference frame) can be chosen arbitrarily.

Both Vosniadou (1994) and Gilbert et al. (1982) assume that it is possible to interpret the initial and synthetic model (hybrid model in Gilbert's et al terminology) from pupil representations. I believe that interpreting the initial model from these representations is problematic. When children learn to move, they learn to manage with moving objects by knowing how these move. Further, when children learn to speak and their vocabulary increases, they learn scientific terminology (cf. Spelke & al, 1992). I claim that it is very difficult to differentiate the initial model and the synthetic model from representations. Therefore, I call the representations *compromise models.* In a compromise model, the pupil integrates new knowledge with earlier compromise models, and initial schemas constitute this integration. I agree with Vosniadou (2003, p. 386) that *compromise models* arise when "students attempt to reconcile incompatible pieces of information, some of them stemming from everyday experience and some coming from surrounding culture, often in the form of science instruction in the schools" (Vosniadou, 2003, p. 386). Rowlands et al. (1999) explain why pupils' misconceptions remain and are difficult to overcome. When a child is asked to represent or explain movement, the first time this is done requires a cognitive effort. They suggest "the intuitive concept [compromise model] of force is not formed until the subject is asked to describe a particular motion in terms of force" (Rowlands et al., 1999, p. 258). Following this line, I argue that a compromise model forms when an individual is required to represent or explain phenomena. A compromise model does not need to be in connection with bodily action; it could just as well appear only in discourse.

Hestenes, Wells, and Swakhamer (1992) emphasised that in teaching, it is not necessary to be worried about every students' compromise model. They argued that if the conceptualisations students have most difficulty changing – impetus and dominance – alter, then minor misconceptions will change spontaneously. Table 3.1.2 compares the most common compromise models to explain motion with the correspondent Newtonian qualitative explanation model (Halloun & Hestenes, 1985; Hestenes et al., 1992).

3.1.3 Theory model

Hestenes (1992) suggested an approach to overcome misconceptions in Newtonian mechanics. Qualitative models are given to pupils as tools to represent and explain movement phenomena. Hestenes claimed that in textbooks, background assumptions are described only indirectly, as they are considered obvious. In addition, qualitative level descriptions are typically omitted from textbooks. The books very rapidly represent and explain movement at the quantitative level (calculation exercises). Hestenes (1992) recommended that physics teaching utilise qualitative models.

Pupils are usually required to learn Newtonian description and explanation – a theory model – about motion. Justi and Gilbert (2000) distinguish four models from the teaching point of view: 1) the *consensus model*, which is the model that, over time, is considered to be the best way of explaining things; 2) the *scientific model*, which has gained social acceptance after testing by the scientific community; 3) the *historical model*, which has been a previous scientific model; 4) the *curricular model*, which is a simplified version of any consensus or historical model. In certain topic areas such as chemistry, these distinctions may be appropriate (for example, in models of atomic structure). From a student point of view, these all appear as theory (often considered as "truth") to be learned. They are all meant to represent and explain some phenomenon. Therefore, I call them all *theory models*. The essential difference between a compromise model and a theory model is that a theory model has (or at least should have) a strict qualification area. At primary school level, Newtonian laws in qualitative form are the most representative and explanatory models for theories of movement. It covers movement phenomena, when the moving object is idealised as a rigid body appearing in everyday life.

According to Gilbert, Boulter and Rutherford, (2000) in the educational context, an explanation is an answer provided in response to a specific question. Therefore, there are two crucial parties: one who asks a question, and one who answers it. They emphasised the appropriateness of the explanation from both the respondent's and questioner's point of view. Futher, they introduced three ways to evaluate an explanation:

1. *Suitability*: How questions and answers relate. Is the explanation intentional, descriptive, interpretative, causal, predictive, genetic, functional, and so on? …)?
2. *Relevance*: Does the explanation meet the needs of the questioner?
3. *Quality*: How scientific is the given explanation? Is the explanation historical, curricular, and so on?

Table 3.1.2 Comparison of compromise models and qualitative Newtonian models (theory model)

Compromise model	*Newtonian law (theory model)*
Impetus: a force, energy or power keeping a body moving. Impetus is stored in a physical body. While a body moves, impetus wears out and movement stops.	I: A body free from interaction does not change motion.
Active force: Active party (living body, motor, or other mover) is able to create motion.	II: To change motion, (net)force is needed. Change of motion (acceleration) depends on quantity of interaction (force), and inertia (mass) of bodies.
Dominance: In interaction, a bigger, more massive, or more active party exerts larger force.	III: Interacting parties experience equal, but oppositely directed forces.

The quality of the explanation is crucial when a schoolteacher starts to teach Newtonian mechanics. The teacher may share essentially the same compromise models as the pupils have. However, I consider relevance to be the most important issue. On the one hand, there is a risk of overloading the answer. The questioner may not need, or might not understand, such a detailed or abstract explanation (such as micro-level explanations for phase transformations or temperature). An explanation is not relevant if, as an answer, it is too far from the question. A qualitative or macro-level question does not need a quantitative or micro level explanation. For example, while in primary school, if a pupil asks for a reason for motion (when it means change of motion), the quantitative formula $\sum \overline{F} = m\overline{a}$ may not explain anything. Maybe the qualitative model *force is needed to change motion* is relevant enough. On the other hand, the teacher may not know the relevant explanation. A physics teacher may not know enough about human evolution (at least not in pedagogically meaningful level to take into consideration pupils' initial schemas, beliefs, and background assumptions). Then, in both situations, the given explanation does not meet the questioner's needs. This problem of explanation relevance is crucial for schoolteachers and their pupils.

At the qualitative level, the meaning of the concept relates to sensory experience. First of all, the object (or phenomenon) needs to be recognised. This recognition is based on the relationship between the invariance of the object and the conceptual structure of the recogniser. (cf. Koffka, 1935; Eysenck, 1998). For example, the meaning of weight is heaviness or lightness. At the level of perception, one recognises the variance of degrees of heaviness. It is possible to compare objects by a comparative concept (cf. Niiniluoto, 1980), so one could arrange objects in order from heavy to light. Qualitative models of cause and effect can then be formulated.

The transition from qualitative level to quantitative level requires an operation called quantification (Kurki-Suonio & Kurki-Suonio, 1994; Koponen, Mäntylä, & Lavonen 2004). With the process of quantification, the meaning of a concept is expanded. One is able to measure how much heavier one object is than another. At the quantitative level, the meaning of the concept is based on the operational definition (experimental laws). To exaggerate, if one measures the weight in another way, one measures a different weight (different concept). One operationalisation in the classroom could be the following: hang objects on a string, and the measurement of the length of the stretch is a measurement of weight. The measurer needs a standard string and standard objects.

The transition from object-dependent operationalisations to abstract and general definitions requires a structured theory. Newtonian mechanics is structured theory that creates object-independent meaning for motion. The operational and perceptual meanings of concepts remain in structured theories.

3.1.4 Design objectives for learning environments aimed at conceptual change in mechanics

Conceptual change requires more than the consideration of initial schemas, compromise models, and qualitative level theory models. Mildenhall and Williams (2001) emphasised the role of conversation in the process of conceptual change. The aim is not to replace, exchange, or overcome pupils' conceptualisations, but to critically evaluate these. Sinatra and Pintrich (2003) stress the importance of intention. If pupils set their own learning goals, to be able to more coherently represent and explain movement phenomena, their understanding may change more permanently.

Perhaps, practical work fosters conceptual change. During practical work activities, pupils undergo novel experiences, and it could motivate pupils to study physics and further increase their interest (Bennett and Kennedy, 2001, p. 98). To sample novel experiences through practical work is especially important for girls who, collectively, have less out-of-school science and technology experiences than boys (Sjøberg, 2002).

Considering initial schemas, compromise models, theory models, and principles to promote conceptual change, it is possible to set design objectives for learning environments for the teaching of mechanics at primary school level.

- A learning environment should offer qualitative models to represent and explain the movement phenomena met during classroom practical work and everyday life. Pupils then learn to use qualitative models.
- Pupils should become aware of their previous ideas about movement. Pupils should understand why they have problems learning Newtonian models.
- The learning environment should assist pupils in their intention for a conceptual change in mechanics. Pupils intend to learn the (Newtonian) model of movement – a model more coherent than their own schemas and compromise models.

In the Design solution (Chapter 6), I describe how these objectives were realised in the designed learning environment.

3.2 Finnish ational framework curriculum for chemistry and physics

The Finnish National Framework Curriculum (FRAME, 2004) is the norm that the curricula of all Finnish schools must follow. In addition, the curriculum of a school district is the norm for teachers to follow. Therefore, it sets constraints on design. The Framework Curriculum (FRAME, 2004) defines, for the first time, precise goals and content for chemistry and physics in primary school Grades 1 – 6 (pupils aged 7 to 12). However, it is still quite flexible in that municipalities design their own curriculum, in which they describe their objectives, contents, teaching methods, and evaluation in more detail. A novel aspect in the Finnish school system was the time allocated to chemistry and physics (on average) one lesson (45 minutes) per week for Grades 5 – 6.

The Framework Curriculum emphasises awareness of the student's previous knowledge and an experimental approach as a starting point for teaching and learning. In objectives, there is a strong recommendation that physics and chemistry in Grades

1 – 6 should be taught in a practical manner and pupils should practise the experimental method by studying suitable natural phenomena. There are also requirements in the curriculum that pupils should learn to understand how knowledge about natural phenomena is obtained through observation and measurement. Students should also be able to plan and carry out simple experiments on or investigations into natural phenomena. The Framework Curriculum (FRAME, 2004) describes three content areas: 1) energy and electricity, 2) scales, and 3) substances around us. There are two topics in the content descriptions that belong to Newtonian mechanics:

- gravity and friction, movement, and balance phenomena due to forces;
- moving about safely and preventing accidents.

Thus, the total time allocation for Newtonian mechanics in Grades 5 – 6 can't be more than about ten to fifteen lessons.

3.2.1 Objective for designing

In actual fact, chemistry and physics were included in the earlier Finnish Framework Curriculum in a subject called *environmental and natural studies*. In practice, teachers usually presented topics such as biology and geography and avoided chemistry and physics. The National Framework Curriculum allowed a lot of free choice in topic and teaching models were applied as the teachers saw fit. But the time allocation in the new Framework Curriculum has made teachers reassesses the situation: now they must face the fact that teaching chemistry and physics starts in primary school. Many teachers are anxious about the situation. They have very limited experience in physics, especially in the teaching of physics. Currently, in educational programmes for Finnish primary school teachers, there is only a very short period (about 20 hours) of studies in physics education.

Thus, a clear objective of design is to ensure that the learning environment should support teachers and help them to plan and conduct their teaching in accordance with the Finnish Framework Curriculum.

3.3 Learning environment

In the editor's introduction of the first issue of the journal *Learning Environments Research,* Fraser (1998) defined the scope of the journal from the American perspective

> "'Learning environment' refers to the *social*, *psychological* and *pedagogical* contexts in which learning occurs and which affect students *achievement* and *attitudes* [italics added]. Classroom-level and school level environments are included, as are out-of-school learning environments such as home, science centres, museums, fieldtrips, television, etc IT (information technology) learning environments, including multimedia, internet and World Wide Web instructional settings, also included explicitly. Pre-primary, primary, high school, college and university, and lifelong learning environments all are included, as are all subject areas (science, humanities, etc.). The psychosocial significance of the physical environment (e.g. school architecture, classroom design is relevant to journal" (Fraser, 1998, p. 3).

As a definition of learning environment, the scope of the journal is rather broad, but it refers to the atmosphere of learning. In Mandl and Reinmann-Rothmeier (2001) described that learning environments "represent the current temporal, spatial, and social learning situation and also includes the relevant cultural context" (p. 4679). According to the Finnish National Framework Curriculum, "The learning environment must support the pupil's growth and learning. It must be physically, psychologically, and socially safe, and must support the pupil's health." (FRAME, 2004). The framework curriculum emphasises: 1) versatile teaching methods; 2) the use of information and communication technology; 3) an active and self-determinative role for pupils in planning and evaluating learning; 4) aesthetic aspects in design; and 5) versatile pupil–teacher and pupil–pupil co-operation and study in small groups.

Lorsbach and Basolo (1998) claimed that research has concentrated on how the perceived environment meets the requirements of each teacher's and pupil's own personal preferred learning environment. They argue that research should focus more on developing learning environments. I see this as a strong request for design research, but not just educational technology design without formative testing, as Clements and Battista (2000) suggest (cf. Chapter 2).

Approaching school from a teacher's perspective, Lattu (2003) introduced the concept *teaching space* as one analogy for a learning environment. He argued that the key factor in the teacher profession is time (as both resource and structure). The new Finnish national framework curriculum allocates time for physics, so time in school should be used for the teaching of physics. However, it seems that in school, there is permanent lack of time. Lorsbach and Basolo (1998, p. 116) emphasised that "nature of learning environment depends on what happens in given period of time, who is present, when it happens, and the physical setting in which it occurs". They suggested that the expectations of teachers and pupils, history, and invisible cultural conventions all influence the learning environment.

Another important finding, defining teaching space, is the *teacher's uncertainty* (Lattu, 2003). Uncertainty can grow from doubt about learning outcomes and the teacher's own professional skill. If a teacher is uncertain about student learning, or about her or his own competence, it clearly influences the atmosphere in the teaching space and learning environment.

However, it appears that during the last few years, research on *learning environments* seems to have developed a bias towards teaching, and learning *with* computers, and is connected to designing and evaluating learning modules (e.g. Kolokotronis & Solomonidou, 2003; Linn, 2000). This is understandable, because computers and – especially the Web – offer great potential for teaching, studying, and learning.

3.3.1 Virtual and real learning environment

The term *virtual* is often used to denote the computer-based learning environment (e.g. Bopry & Eteläpelto, 2003). In any learning environment, it is possible to distinguish both the virtual and real components. A learning environment with only material resources can be called a real learning environment. Lavonen, Meisalo, Lattu, Leinonen, and Wilusz (2001) labelled classroom equipped with computers and information and communication technology (ICT) a *rich learning environment*. They used an *open market* metaphor for the design principle to ensure that the learning environment is not just restricted to the classroom. The library, outdoors (e.g. a forest near the school), and museums can also be part of a learning environment (Meisalo & Lavonen, 2000). A computer may offer access to the virtual environment. Virtual components include resources that may be difficult to arrange in the pure, real environment.

Development of the WWW has greatly expanded the resources available in schools. Meisalo, Lavonen, Juuti, and Aksela (2001) described examples of Internet use in lower secondary schools: using course management systems for pupil–pupil interaction between schools, and using databases of regional newspaper articles in the process of writing projects. In between-school studying, the use of the computer is well established: it is the principal medium of communication. However, there is research evidence which suggests that pupils find it difficulty to establish fruitful collaboration without the active support of their teachers (Rasku-Puttonen, Eteläpelto, Arvaja, & Häkkinen, 2003).

In their summary, Voogt and van den Akker (2002) saw the role of teachers as central when implementing ICT in the classroom. They found several problems to overcome: educational programs are isolated, teachers are not competent to integrate computers into the curriculum, ICT in school does not fit into the existing instructional culture, and the teacher feels that ICT is ineffective. In order to use ICT, teachers are forced to change their pedagogical approach, classroom management strategies, and routines. These problems are similar to those that Fullan (1991) placed under the local characteristics of the implementation of an innovation. One possible way to overcome these challenges is to provide carefully designed and validated curriculum material that "contains procedural specifications in order to guide teachers concerning the essential, but vulnerable, aspects of ICT integration" (Voogt & van den Akker, 2002, pp. 2475 - 2476). Although there are computers in schools, the use of them is quite limited: in year 2001 there were on average one computer for five students in Finnish secondary schools. According Hakkarainen et al. (2000), only one-fifth of Finnish teachers used ICT in teaching in a significant degree, and two-thirds considered their pedagogical and technical competence inadequate for using computers in the classroom.

3.3.2 Choreographies of teaching

The teacher's intended action to facilitate study in the learning environment can be called teaching method, instructional behaviour, models of teaching, choreography of teaching, and so on. Joyce (1980) categorised teaching methods into four families, where each family shares the common goals of teaching and learning. These families are: 1) *social interaction models*, such as co-operative learning; 2) *information-processing models*, such as the advanced organiser; 3) *personal models*, such as awareness training aiming to increase one's capacity for self-exploration and self-awareness; 4) *behaviour modification/cybernetic models*, such as programmed instruction or direct training to learn skills. Oser and Baeriswyl (2001) introduced 12 basic models of teaching as *choreographies of the teaching–learning process* to emphasise the close connection between teaching and learning: they claim that typically, teaching is seen to be transmission, and learning as repetition. Oser's and Baeriswyl's (2001) categorisation is based on learning goals. A teacher chooses the appropriate method to facilitate pupils to engage in learning. Through proper learning methods, a pupil may reach the intended (teacher's and/or pupil's) learning goals.

Practical work

According to Millar (2004), practical work is one way of communicating scientific knowledge. He defines practical work in science education in the following way: "Practical work means any teaching and learning activity which involves at some point the students in observing or manipulating real objects and materials" (Millar, 2004, p.2). It is also a way to acquire new knowledge, and it plays a crucial role in justifying acquired knowledge. Hodson (1996) mentioned three traditional goals for science education: 1) acquire and develop scientific concepts; 2) develop an understanding of nature of science and the scientific method; 3) develop expertise in scientific inquiry. Practical work is a way to reach all three goals. Hirvonen and Viiri (2002) suggested that the nature of science and scientific knowledge requires a different approach to learning. Although offering a biased view of the nature of science, practical exercises give the impression that research is the core domain of science. In addition to the three goals mentioned above, Bennett and Kennedy (2001) emphasise that practical work increases pupil motivation, interest, and enjoyment. Moreover, pupils experiences physical phenomena first-hand. Table 3.3.1 integrates Hodson's (1996) descriptions of *mimic, process approach,* and *constructivist approach* to practical work.

The practical work described in Table 3.3.1 may help pupils learn physical concepts or practical working skills. In order to learn the nature of science Hodson (1996) suggests that four principles be taken into consideration. "…focus on the particular characteristics and distinctive features of each phase.

- "A design and planning phase, during which questions are asked, hypotheses formulated, experimental procedures devised and techniques selected.
- "A performance phase, during which the various operations are carried out and data are collected.
- "A reflection phase, during which the experimental findings are considered and interpreted, in relation to various theoretical perspectives.
- "A recording and reporting phase, during which the procedure and its rationale, and the various findings, interpretations and conclusions are recorded for personal use and/or communication to others"

Hodson (1996, p. 129).

Table 3.3.1 Bizarre views on the nature of practical work

Mimic scientific inquiry	Process approach	Constructivist approach
Science *starts* from observation.	Scientific inquiry can be described in terms of a series of discrete processes.	Identify students' ideas and views.
Science observations are reliable and unprejudiced.	The processes are generic. That is, they are context-independent and, therefore, transferable	Create opportunities for students to explore their ideas and test their robustness in explaining phenomena, accounting for events and making predictions.
Observation produces objective, value-free data.	Scientific knowledge results from engagement in these processes.	Provide stimuli for students to develop, modify and, where necessary, change their ideas and views.
Generalizations, facts and laws will emerge from these data.	Performance of these skills can be readily observed and accurately and reliably measured	Support their attempts to re-think and reconstruct their ideas and views.
Explanations, in the form of principles and theories, can be induced from these data		
These theories can be confirmed in a straight-forward and unambiguous way by further observations and experiment		

Note: from Hodson (1996, pp. 117, 122, and 127); three bullet lists have been integrated into one table.

At the Finnish primary school level, the Finnish National Framework Curriculum (FRAME, 2004) emphasises motivation, conceptual understanding, enquiry skills, and the overall nature of science. Hirvonen and Viiri (2002) describe qualitative level practical work (they refer to Kurki-Suonio & Kurki-Suonio, 1994). Pupils make observations and describe phenomena in their own words. At the qualitative level, the goal is to recognise what changes are produced by the phenomena under study. The changes could be growing, warming, speeding up, changing direction, etc. To take into consideration Hodson's (1996) bullet list (quoted above) designing qualitative level practical work, pre-inquiry activities should be emphasised (cf. Section 3.1).

Co-operative learning

In Section 3.1, *Conceptual change*, it was suggested that communication between students is an important factor to aid in conceptual change (Mildenhall and Williams, 2001). Co-operative learning is one approach to encourage communication between pupils and help pupils to learn better communication skills.

In their systematic review of small-group discussions in science education, Bennet, Lubben, Hogarth, and Campbell (2004) suggested that successful communication within a group is based on intragroup conflict (diversity of views) and external conflict that a teacher could facilitate.

Johnson and Johnson (1994) defined five essential elements which characterise co-operative learning methods: 1) *positive interdependence,* when an individual is not able to succeed in a task without working with others; 2) *face-to-face promotive interaction,* where students assist in each other's learning and participate equally; 3) *individual accountability,* where every group member has their own responsibility for assessment*;* 4) *social skills,* where pupils should be trained to work together effectively; and 5) *group processing*, where group members evaluate their own work. Perhaps one of the simplest co-operative learning methods is *think-pair-share*: Students individually think about a topic provided by the teacher; then pair up with another student to discuss it. They then share their thoughts with the class (Kagan & Kagan, 1994). It is important to consider pairing. Howe, Tolmie, Anderson and Mackenzie (1992) suggested that pupils in a group with diverse views learn more than pupils who share the same views on a topic. They recommended that random grouping is good enough to ensure diversity in ability. In addition, they stress ensuring a critical mass of girls in mixed-sex groups. Hoffman (2002) showed the importance of single-sex groups: boys and girls, taught part-time in single-sex groups, did not lose their general interest in physics during an academic year.

Storytelling

Storytelling is a traditional teaching method at primary level. Bruner has offered help in the interpretation of the role of narratives for learning. He argued that with stories, growing children create meaning from school experiences that they can relate to their lives. Two modes of thought can be distinguished: *paradigmatic* (or *logical-scientific*) and *narrative*. Both modes organise and give meaning to experience (Bruner, 1996). Tolska (2002) analysed Bruner's conception of narrative. According to his analysis, Bruner means that with the paradigmatic mode of thought, people explain physical reality and build theories to explain physical phenomena with context-free laws. With the narrative mode of thought, people explain psychic reality and human actions. With the paradigmatic mode of thought, people discover universals and with the narrative mode of thought, people make singular, lifelike connections between events. Narrative mode explains intention and the paradigmatic mode explains cause. Bruner (1996) also claimed that cultural origins and beliefs are in story form, only the content is not the grasping aspect, but the narrative structure.

Tolska (2002) described two of the main confusions between the narrative and paradigmatic modes of thought: animisms and radical behaviourism. In animism, physical phenomena are explained by the intentions of inanimate objects. In contrast, radical behaviourism interprets human actions with natural laws.

The narrative and paradigmatic modes of thought occur differently in different cultures. Narratives and stories are particularly culturally dependent. Bruner (1996) claimed that there is no culture where only one of either the narrative or paradigmatic modes of thought exists; in every culture there are both modes of thought, but they are differently emphasised. One may organise experiences with time in the story form. With the narrative mode of thought, one may form the individual identity.

This different emphases help to understand different traditions of physics education and (for example) religious education. In physics, the emphasis is on the paradigmatic mode of thought (the objective being to explain natural phenomena with one fundamental theory) and in religions, the emphasis is on the narrative mode of thought (stories about Zeus, Moses, Jesus, Buddha, Mohammed, etc. or personal stories about one's own enlightened awakening). This provides one reason why stories are often used in religious education, but very seldom in physics education. At least, the small amount of research literature concerning stories in science education implies that the potential of story in this context has not been fully clarified.

Luumi (2002) described the role of fairy tales and Bible stories in primary-level education. He emphasised that stories are a highly child-centred teaching method. While listening, a child "sees" story events in the mind. A listener is not a passive receiver, but an active world-builder, using feelings, imagination, and intelligence. An important aspect of stories is that they describe experiences reachable for the child. The storyteller invites listeners to ascertain the realism or significance of the related experience.

Streib (1998) discussed Lyotard's meta-stories in the religious education context. Meta-stories eliminate all particularities and names. They are myths explaining that "it-could-not-be-otherwise". Meta-stories lead to fundamentalism; a fundamentalist does not tell a personal story, but refers instead to a meta-story in which personal fate has been integrated.

One could claim that science education offers pupils meta-stories, or universal truths. The learners do not have any possibility to personally evaluate these truths. In addition, the pupils do not have any personal connection with them: the teacher is a medium between student and science. Mitchell (1991) distinguished two facets of the teacher's role as medium: the teacher communicates science, or the teacher communicates *about* science. Communication about science can be seen as paradigmatic mode of thought. The teacher offers one kind of textbook reconstruction about science, an idealised version of scientific knowledge and process (cf. Kuhn, 1970). Bruner (1996) argued that science as process creates a narrative: playing with ideas, creating anomalies, and finding solutions for anomalies. Thus, science education should facilitate not only the paradigmatic mode of though, but narrative aspects as well.

It has been claimed that when conducting scientific investigation, pupils learn scientific knowledge, research skills, and the nature of science. However, school-based research may show the nature of science in quite an odd way (cf. Hodson, 1996). To better communicate the nature of science, Tao (2003) designed stories based on the history of science to help pupils understand the nature of science (see also Solomon, 1999).

Knox and Croft (1997) designed a storytelling course for university-level meteorological studies. During the course, students heard many kinds of stories. The roles of the stories in their teaching experiment varied. They used historical stories to introduce the discipline and to create connections between concepts, myths to help students to orientate and decrease fears towards the course, acculturation stories (e.g., why computer models are used), and detective stories or mysteries to engage students in the application of models of climate. They added personal experience for more abstract topics, such as atmospheric dynamics.

Bloom (1992) stressed that research on science teaching and learning has mostly focused on constructing paradigmatic knowledge (Bloom used the term *semantic knowledge*) and has ignored narrative (*episodic*) knowledge. He claimed that individuals are not aware of all of their cognitive processing. He cites categorisation as example: an individual may automatically categorise entities without recognising that it is happening. He interviewed primary school pupils in order to ascertain their understanding of earthworms, and found that they used narrative, providing a context for meaning. He emphasised that in teaching the meaning of context, student narratives should be taken into consideration. According to Tolska (2002), Bruner also emphasised each pupil's own narrative and its role in their learning.

3.3.3 Promoting interest

According to the Finnish National Framework Curriculum (FRAME, 2004), teaching should arouse in students the interest to study chemistry and physics. Students can acquire two different kinds of interest: *individual interest* and *situational interest* (Krapp, 2002). Individual interest is connected to the relative permanent reference for a particular topic or learning task. Situational interest refers to the context of learning. Interest is the immediate outcome of a situation. As Krapp (2002) stated: "interest is conceptualised as a *relational concept*: An interest represents a specific relationship between a person and an object in his of her 'life-space'" (p. 410). Krapp believes that when a person and an object are in close relation, in certain conditions, the relationship between them could become an individual interest.

A teacher can strongly influence the situational interest. Based on their literature review, Schraw, Flowerday, and Lehman (2001) made three suggestions to promote situational interest. Firstly, teachers should increase student autonomy. This is especially useful for pupils with very low motivation. Secondly, teachers need to provide better texts. Texts should be coherent and informationally complete as well as vivid and surprising to the reader. Students should be familiar with the texts: they should either be part of a familiar context, or the teacher should prescribe background reading to help students better comprehend the scientific principles they are studying in the classroom. Thirdly, teachers should help students to process information at a deeper level. Interest increases active learning and vice versa. Active learning leads to situational interest.

Häussler and Hoffman (2002) suggested seven principles for physics teaching to promote student interest: 1) opportunities to marvel, 2) content linked to prior experience, 3) first-hand experience, 4) discussion about the topic's relevance for society, 5) connection with applications, 6) connection with the human body, and 7) demonstration of the benefit of quantitative-level concepts. Juuti, Lavonen, Uitto, Byman, and Meisalo (2004) show that student interest in studying physics in Finnish lower-secondary school is highly dependent on the context in which phenomena are met. They evaluated ninth-grade student interest in physics in the following six contexts:

- *Ideal context.* In this context, physical concepts are presented in a universal way. For example, qualitative explanation models are used for movement phenomena.
- *Science and technology in society.* This context emphasises the physical principles playing a significant role in society, such as energy production.
- *Technical application (equipment).* Here, functional principles of technical applications are studied. For example, how the design of a car depends on air resistance.
- *Human being context.* Something happens inside a human being or a human being does or experiences something.
- *Investigations.* Pupils conduct practical work to learn physical concepts. They investigate phenomena (recreated in the school laboratory) and their properties.
- *Technology design and construction.* This context is in close connection with the investigations context, but emphasises design and production issues.

The researchers found a large difference between the interest of boys and girls in the applications context, and no interest difference in the human context. Further, they emphasise that the overlap between boys' and girls' scores in every context is substantial. The technical application context was most interesting to the boys and the human being context was most interesting to the girls.

Häussler and Hoffman (2002) use the term *first-hand experience* for the last two contexts. The Finnish National Framework Curriculum (FRAME, 2004) emphasises practical work investigations and technology education as a thematic entity. This means that every subject covers a part of the theme. In physics, the role of technology could be dealt with while studying technical applications (e.g. mechanical or thermal engines), science and technology in society (e.g. energy resources or manufacturing or construction of artefacts in industry), and the design and construction of technical devices for specific purposes. Technology education is not just knowledge about technical applications, but the skill to design and produce an object such as a mechanical toy, which uses the principles of physics in its operation.

3.3.4 Design objectives

As a summary of discussion in Section 3.3, designing objectives for learning environment are:

- The learning environment should help teachers integrate computers into their teaching.
- The teacher should be able to redesign the environment to be appropriate for teaching objectives. Thus, the learning environment should be easily changed into different kinds of physical learning environments. For example, classrooms should have different technical facilities (computers, laboratory equipment etc.).
- The learning environment should support teachers in the use of co-operative teaching methods to allow versatile communication between pupils and to promote conceptual change
- The learning environment should introduce physics in a practical manner
- The learning environment should ensure that pupils use both narrative and paradigmatic modes of thought.
- The learning environment should encourage pupils with different interests to study physics and develop a situational interest, as well as generate a positive atmosphere.

3.4 Gender issues in physics

During the last twenty years (at least), there have been a great number of *gender-and-physics* research and development projects. Worry about supplies of enough qualified personnel in the future has been one of the key reasons behind this research. The number of students choosing physics as a course of study has decreased in western countries. Girls in particular are seen as an unused resource. Thus, educators and industry have launched projects to increase the number of girls in physics-related fields of study and occupations. In addition, the less-segregated labour markets, such as equal number of girls in technology and boys in nurture, have been trying to improve the levels of equality in society (Osborne, 2003; Hoffman, 2002).

In principle, there are two possible approaches: intervention focus on girls or intervention focus on physics. In the former, the goal is to change girls' behaviour, attitudes, or interests. In the latter, the goal is to change teaching and learning, educational policies, and social structures on the basis of research or speculation on student interest in science (cf. Biklen & Pollard, 2001).

It can be argued that the major fault with gender-and-physics research and intervention is that researchers and developers have not properly analysed the concept of gender. In recent Anglo-American gender research, the *gender as social construct* viewpoint has been dominant. However, in mathematics and science education research and intervention projects, the implicit meaning of gender has been *gender as a sexual difference* (Biklen & Pollard, 2001; Gilbert, 2001; Gilbert & Calvert, 2003) According to Gilbert and Calvert (2003), the consequence of ignoring gender is that girls and boys are assumed to be homogeneous and independent groups. This assumption hides the within-group differences. Gilbert and Calvert (2003) emphasise that researchers and developers should take into consideration how the social environment defines boys and girls. The message here is that if researchers and developers do not take into consideration different meanings of gender, they might fail in their desegregation efforts, and even reinforce stereotypical gender roles.

3.4.1 Gender-bias

In this design research project, the design team intended to avoid gender-biased design solutions. It is possible to recognise several kinds of stereotypical beliefs, actions, and instructional materials. Typically, stereotyping occurs without conscious awareness of it. Thus, people do not recognise the beliefs, actions, or even textbooks that can produce stereotyping. A stereotype is a set of characteristics that every member of a group of people is believed to share. Stereotyping denies the existence of individual attributes and differences.

There are a number of apparent gender biases in the primary school classroom: girls get less attention that boys, who demand more, even negative, attention; teachers interact more with boys; boys tend to control the conversation in the classroom; girls are praised for appearance, co-operation, and obedience, while boys are praised for achievement (e.g. Evans, 1998). Girls tend to be inactive participants in most aspects of school life. In addition, the attention that boys get gives girls the impression that boys are more important. Stereotyping actions reinforce stereotypes. Thus, the self-esteem of boys develops more than that of girls (Evans, 1998). Boys are believed to be better in mathematics and science and girls are believed to be better in languages. In truth, girls tend to better boys in both areas (Guimond & Roussel, 2001). However, boys have more informal, out-of-school, science and technology experiences than girls (Sjøberg, 2002). This could influence the participation of girls in the practical work in a classroom.

In instructional materials, several types of gender bias can be found. 1) Females and minorities are *invisible*, in that they have almost no roles; 2) *stereotyping* shows males as active and powerful, and females as sweet, weak, frightened, and needy, and both genders are shown in traditional occupations; 3) *imbalance* and *selectivity* in instructional materials means that the interpretation of a group of people is presented only from one point of view; 4) textbooks often gloss over unpleasant facts and controversial events or another *curiosities*; 5) females are *isolated* from the main narrative, presented as fragments, and therefore as less important than males; 6) *lingual bias,* in words such as "mankind", denies the full participation and recognition of women and girls; 7) bias is *cosmetic* when women are seen in pictures, but are not often seen to participate in the action of a narrative (Zittleman & Sadker, 2002).

3.4.2 Design objectives for a gender-fair learning environment

Taking into consideration the above biases, it is possible to identify some design objectives:

- The learning environment should avoid lingual bias.
- Females and males have equal participation in narratives, figures, and other elements of the learning environment.
- Females and males are equally active in the classroom. The learning environment should ensure that boys and girls have equal opportunities to interact with other pupils and the teacher.
- The participation of girls in the study of physics is not an issue, but natural.
- The learning environment should avoid the stereotype that males have more ability in science and technology.
- The learning environment should ensure that both boys and (especially) girls have experiences with science and technology.

Girls may need special support. Evans' (1998) suggestion for the support of children entering non-traditional play could also be used in physics teaching. "Teachers may also need to play alongside females in such centers that have traditionally been more represented by male children. A teacher can also assist a female or male pupil into a particular play center by entering with him/her" (Evans, 1998, p. 85). It may be that because of lower self-esteem and fewer practical experiences, girls need more time than boys to answer question posed by the teacher.

3.5 Design principles for a usable web site

This chapter describes the major principles of designing web *usability*. Nielsen (1990, 143) argues that usability is traditionally associated with five usability parameters: *easy to learn, efficient to use, easy to remember, few errors, pleasant to use*. According to the ISO standard for guidance on usability (ISO 9241-11:1998), a usable product "can be used by specified *users* to achieve specified *goals* with *effectiveness, efficiency,* and *satisfaction* in a specific *context* of use [italics added]". These viewpoints may be difficult to relate to the educational context. For instance, the definition of effectiveness may be difficult. Thus, it may be better to define usability from an educational context. There are several concepts that relate to usability. According Nielsen (1993), an educational product has high *utility* if students learn from using it, and a product is u*seful* if the product can be used to achieve a desired goal. Usefulness is one factor in the *practical acceptability* of the product. Other main factors are: *cost*, *compatibility* (does it fit in the previous systems), and *reliability*. Practical acceptability is the second aspect of the *system acceptability*. The main factor for system acceptability is *social acceptability*. If an intended user finds the product socially unacceptable, the product is rejected, even if it was found to have a high utility or usability (Nielsen, 1993).

Bevan, Kirakowski and Maissel (1991) define usability as the *user's* views of product *quality*. When the product is usable, one can use it in the real sense of the word (Bevan, 1995). In an educational context, this real sense is represented by the school context. Previous definitions emphasise the following aspects: 1) users and their intentions, 2) properties of a product, and 3) context of use. In the thesis, usability was defined as follows: a learning environment is usable when pupils engage in learning in a way intended by a teacher (and researchers).

3.5.1 Conventions and principles in web design

Sinkkonen, Kuoppala, Parkkinen and Vastamäki, (2002) argue that there are design principles that are invariant throughout design projects. They are in relation to human perception, ergonomics, remaining (Western) culture and learned conventions (e.g. the hyperlink in a web page is blue and underlined). Still, there are plenty of attributes of design that need research to reach a high degree of usability: context, constraints, possibilities and tasks. This means that through a literature survey, designers could base their design on the findings of cognitive science, psychology, visual design, and, particularly in this research, science education. To reach usability, designers need to conduct research on user opinion and behaviour (cf. Chapter 2).

Oppermann (2002) claims that even though there is a huge amount of literature about user-interface design, there is only a little concerning learning environments. Thus, he emphasises two important aspects to consider while designing learning environments: the learner will never be a routine user of a specific solution, and the system is not under the control of the user (pupil) since he or she has to follow the curriculum. Thereby, the user interface of an educational product should not require any (or minimal) learning (Oppermann, 2002). A user interface should be intuitive (Nielsen, 2000). Although there is a huge body of literature about user interfaces, including standards and guidelines, designers are unable to properly use these (Thovtrup & Nielsen, 1991).

Oppermann (2002) suggests that a user interface should clearly distinguish three elements: *instruction*, *learning material,* and *feedback*. They can be coded by colour, place, frame, or wording. Figure 3.5.1 represents Oppermann's (2002) model for a user interface for a learning environment.

In his book summarising over ten years of usability research, Nielsen (2000) emphasises that the reason why users visit web sites is the content. Navigation is the means by which users find the pages. Thus, web pages should maximise the content on the page and minimise the navigation, advertisements, and other distractions. Currently, it seems that the page structure described in Figure 3.5.2 is conventional. By moving the instruction and feedback to newly opening windows, the content area could be maximised. However, new windows should not cover the previous page: the new pages should be smaller.

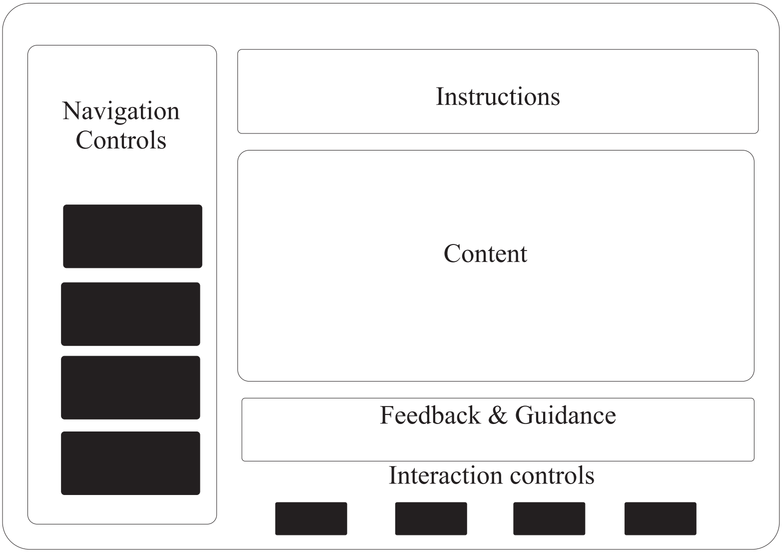


Figure 3.5.1. Place coded differentiation of display areas on the screen (Redrawn from Oppermann, 2002, p. 240)

The most important feature of a web page is the rapid loading time. Nielsen (2000) argues that the opening time of a page after a user clicks on a hyperlink should not take more than one second. Thereby, opening windows should not contain figures that are only decoration. Figures, photos, animations, and other plug-ins should only be parts of the content.

The HTML standard makes hyperlink texts blue and underlined. To turn off principles that standards describe, designers need well-justified reasons. Sinkkonen *et al.* (2002) point out that designers may consider a particular intended user, and that could be the reason for non-standard graphical design. It may be important that pages look suitable for the sub-culture of young people.

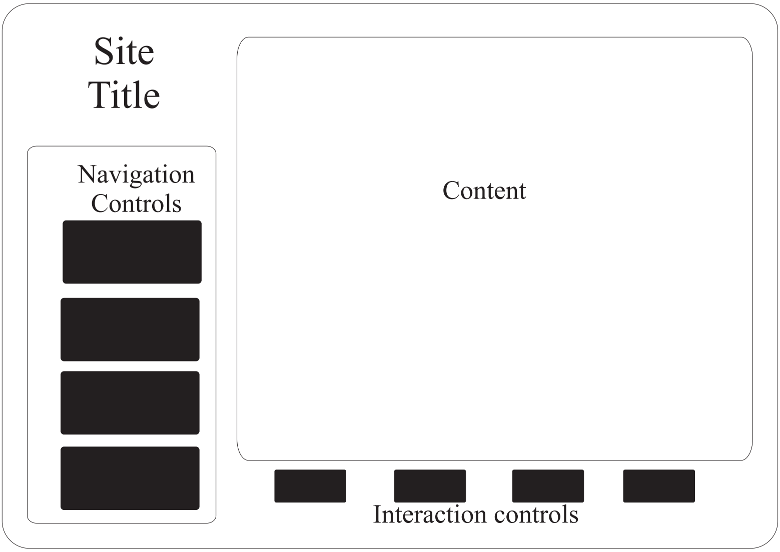


Figure 3.5.2 Conventional web page

3.5.2 Design objectives

Objectives for design, which have emerged in this chapter, are clear, but perhaps difficult to reach.

- From a pupil as well as a teacher point of view, the learning environment (both virtual and real) should be usable.
- Web pages delivering the learning environment should have a conventional structure taking into account the sub-culture of young people.

4 EMPIRICAL PROBLEM ANALYSIS

This chapter describes the empirical part of the design research project. The empirical problem analysis starts by assessing primary school teachers' needs for a primary physics learning environment (Section 4.1). It continues by describing limited (Section 4.2), pilot (Section 4.3) and field tests (Section 4.4) of the learning environment (Chapter 6 describes the designed learning environment). Every section starts with a specific research question and as in the theoretical problem analysis, each section in the empirical problem analysis ends with a discussion section which presents design and re-design objectives.

4.1 Teachers' needs assessment

Teachers' role is crucial in bringing to realisation improvement efforts. Engaging in design research implies that teachers should not only be listened to but that they should also participate in the design itself. Hence, before designs are implemented it is important to clarify primary school teachers' opinions and needs for science learning environments. Linn (1996) stressed the problems of the usability of computer-based innovative learning environments. Although well-designed teaching experiments indicate promising learning results, ordinary teachers still have difficulty in using them or organising learning activities around them. Therefore, it is extremely important to investigate the teachers' needs and expectations for science learning environments and to take note of their suggestions regarding science teaching.

The particular research question at the beginning of the design research process was: What are teachers' needs for primary physics learning environments?

4.1.1 Method

To clarify needs and requirements for the learning environment, teachers participating in in-service training were listened to. During autumn 2001, fourteen primary school teachers (12 women) participated in an in-service training course called *Environmental and natural studies* (25 ECTS credit points). This in-service course was held in the Department of Applied Sciences of Education. One member of the design team taught the course. Participating teachers were asked to write short essays about the following themes:

- *I as a physics teacher in primary school*
- *What is physics?*
- *How physics is taught / learnt in primary school?*

Teachers' essays were quite concise, altogether about 1500 words. Essays were used as a way of choosing different types of teachers to interview. Every teacher emphasised practical work. Further, they evaluated themselves to be quite incompetent in physics, but interested in being able to teach physics. This is only natural, because if they had felt themselves highly competent or uninterested in physics teaching they hardly would have participated in an in-service training course. After careful reading of the teacher's essays, three teachers were chosen to be interviewed.

The first chosen teacher had just graduated and she was teaching in a school for her first year. She had never taught physics or chemistry. She argued in her essay: "Physics is magic that should be understood, learning by heart is not enough". The second interviewed teacher was very experienced, she had taught physical topics, and it seemed that she had even reflected on her physics teaching. In 2001 a teacher who had taught physics at primary level, could be considered an exception. She considered that in physics invariance of the phenomenon is studied, and how a phenomenon can be influenced. "In physics the goal is to idealise and control the phenomenon, in order to observe while variables have influence on it". Her view about the teaching and learning of physics was based on pupils' conceptions, new experiences, and discussions: "Surprisingly often pupils' pre-conceptions lead their own observation. Therefore, it is important to offer entities to perceive with the variety of senses: hearing, smelling, feeling, tasting, and seeing. Versatile discussion about perceptions develops observation skills". Her essay was about four times longer than the others' were. Similarly, as the previous teacher, the third teacher had a long teaching experience and she had guided a science club in her school. Her view about physics was technological. "[Physics is] everyday phenomena –

principles and natural laws are valid in equipments and machines in everyday use (electricity, sound, magnetism, energy) etc. I hope that it is taught by constructing self, not by filling books". Further, the third teacher was the only one who talked about not only pupils, but also boys' and girls.

The interviews were designed in a way that the criteria for a *phenomenographical* approach had been taken into consideration. The objective of phenomenographical research is according to Marton:

> "…to find out the different ways in which people experience, interpret, understand, apprehend, perceive or conceptualize various aspects of reality…if we are interested in (to return to our example) how people think about school success, then we have to investigate this very problem because the answer cannot be derived from what we know …" (Marton, 1981, p. 178).

The phenomenographical approach is suitable for clarifying teachers' needs because the research question was to find out aspects that teachers *perceive* important for a learning environment. The background of phenomenography can be found in Gestalt psychology and phenomenography is closely related to phenomenological philosophy (Marton, 1981; Hasselgren & Beach, 1996; Uljens, 1996). This forms an interesting combination with the conceptual change chapter, especially with initial schemas. The non-dualistic ontology is a key to understanding why there are different conceptions of the physical phenomena (or concepts).

In the interviews, teachers describe their relationship to the world, particularly, their relationship to physics teaching and learning and computers in school etc. "'Ways of experiencing' or 'conceptions' are thus abstracted aspects of people's experience of something" (Marton, 1996, p. 180).

Asking first *what* questions and then *how* questions, the researcher could ensure that interviewees are able to tell their own experiences. First, the focus is on the ontological aspects of experience with *what* questions and then modes of experience of the experienced entity (Marton, 1996). Table 4.1.1 describes interview themes.

Table 4.1.1 Interview themes and their reasoning

Question	Reasoning
1Tell about your school, please?	Warm up question
2 Tell about one of the latest teaching periods about physics or chemistry?	Interviewee is asked to focus on physics and chemistry teaching, but interviewee chooses reference.
2.1 How did it go, please explicate this?	Interviewee is asked to describe structural aspects of teaching period.
3 What topics have been difficult to teach?	What-type question, reference
3.1 How have you have managed? Please give an example.	Structural aspects of a difficult topic to teach.
3.2 What kind of references have you used?	Opinions about useful references such as encyclopaedias, Web, colleagues, secondary school text-books, magazines, teachers' guides.
3.3 What kind of problems were faced?	Focus on referential aspects
3.4 What kind of references you need?	At the end of references, a straight question about needs.
4 What topics have been difficult for pupils?	Referential aspect
4.1 How have pupils learned?	Structural aspects
4.2 What kind of teaching and learning materials have you used? What role do computers have or could have in your teaching?	Referential aspect of real and virtual learning environment.
4.3 What kind of problems have you faced, while using these?	Structural aspect about real and virtual learning environment.
5 Describe your typical science lesson?	After difficult questions interviewee has time to breath.
6 What would you like to teach in primary physics and chemistry?	Interviewees views about important issues in physics and chemistry.
7 Is there anything you would like to tell more about?	Free speech.

One important aspect of phenonenography is the distinction between first and second order perspectives. Researchers are not interested, for example, in physics teaching as such, but in the teachers' experience of physics teaching. Marton (1996) argues that there is a limited number of different qualitative ways of experiencing something.

"Now we do not live in different worlds and we are able to communicate and we do experience the sameness of the world in spite of changes (in fact changes can only be experienced against the background of permanence). We have variation and resemblance in our way of viewing the world" (Marton 1996, p. 184).

Teachers participated in individual interviews (time consumed about 45 minutes) voluntarily and interviews were conducted during in-service training. After each interview, soft transliteration was made. This means that brakes, voice emphasises, and dialect expressions were ignored. Altogether, the transliterated interviews contained about 10 000 words.

Inductive content analysis characterises the analysis of the interviews. During content analysis, the researcher searched in the text for reoccurring words or themes with the object of reducing original expressions to find the core meaning in the text. The core meanings can be called *patterns* or *themes*. Patterns are descriptive findings that could be quite fuzzy. Themes are more categorical, even exclusive. Reducing the text, research forms *reduced expressions*, several hierarchical *sub-categories,* and *integrative expressions*. When interpreting the text, the researcher extracts reduced expression from one sequence or an idea. Categories and integrative expressions are answers to the research questions. (Patton 2002; Kyngäs & Vanhanen, 1999; Alasuutari, 1994). Table 4.1.2 shows an example of an analysis.

Table 4.1.2. One sequence from a teacher's interview.

Original expression	Reduced expression	Sub category	Interpreted need
K: Is anything that you mentioned very difficult to teach?M: Electricity is difficult as such, because I only read short courses in physics and mathematics in secondary school. In the process of the work, I started to think why phenomena take place the way they do. That is why I joined this course. I hope to get some basic information from this course. I hope that the practical work is not just tricks, but that there is a need to understand, too.	Electricity is difficult, lack of basics, need to understand	Knowledge of physics for teachers	Subject knowledge

(cf. Juuti, Lavonen, Kallunki & Meisalo, 2004)

4.1.2 Results

Altogether 244 sequences were extracted from the interviews. Two other researchers, members of the design team, familiarised themselves with reduced expressions and they participated in the classification of reduced expressions from the interviews. In the following categorization is presented the interpreted needs for the learning environment

Activate pupils: All interviewed teachers emphasised that a learning environment should activate pupils. According to analyses, there were three kinds of activation needs:

1. activating for practical work.
2. activating for thinking.
3. activating for work and study.

Subject knowledge: The teachers' subject knowledge of chemistry and physics, and their knowledge of chemistry and physics education was limited, thus, they need instructional material that is

1. Organised in a pedagogically meaningful way.
2. Is reliable.
3. Includes a detailed guide for practical work with solutions of the problems presented.
4. Teachers even need theoretical knowledge on the physics content they will teach to pupils.

Usability: Based on the teachers' descriptions, a learning environment should be usable. For teachers, usability is in close relation with classroom practice:

1. Flexible content. Teacher could easily divide the class; one half of group could use the environment by themselves in computer lab guided by the teacher, and the other half study in a classroom with the teacher.
2. Navigation should be easy. Teacher should be able to rely on pupils' being able to find content that teacher intended. On the other hand, many teachers have low ICT competence, thus, the environment should have clear structure.
3. In any event, the environment must support pupil-centred learning.
4. The environment has to be stable and instruction materials easy to print,
5. Teachers' should be able to use the learning environment as they use encyclopaedias, textbooks or other teacher guides.

Concreteness and illustration: The teachers emphasised the need for concrete and perspicuous approaches. The content should be contextual and from the children's world. Such approaches were in relation with activating pupils, with practical work using inexpensive equipment. Teachers even saw the theoretical content of chemistry and physics from a concreteness point of view. They argued that the most important thing is that pupils experience phenomena.

Support: Few primary school teachers are interested in chemistry and physics. They often feel abandoned and they do not know anyone who could help them. Teachers need

1. Support from peers
2. Support from experts.

4.1.3 Discussion

Design research is iterative and starts from asking intended users' opinions (compare chapter 2). Edelson (2002) uses the term *initial problem analysis* for a recognised problem to solve (including research literature) before the first prototype. Teacher interviews appeared to be very useful for deciding the design goals. Despite this there was one male primary school teacher in the design team; he really was not representative of Finnish primary school teachers. Therefore, by interviewing three female teachers, with different backgrounds, a wider view of the school context was obtained. One could argue that choosing interviewees from the special in-service course caused bias for needs. I claim that choosing teachers, who are interested in learning and in teaching chemistry and physics in primary school, offers a broader view of those teachers' needs, who will possibly use the design solution.

Interviews emphasised that pupils should have something to do, at least pseudo-activities. This avoids pupils disturbing others studying. Of course, teachers need subject knowledge, but it was quite surprising, how badly subject knowledge is needed. Therefore, a learning environment should, to some extent, co-teach with the teacher. Aggravating, teacher's role is to engage pupils in learning and materials' role in the learning environment is to introduce new concepts.

Usability, from teachers practice point of view, is not just *Easy to learn, efficient to use, easy to remember, few errors, pleasant to use* as Nielsen (1990) describes, it includes using context as well. Especially, analysis of the interviews raised the teachers' intentions, which is an important aspect. This is in accordance with teaching methods: teaching and learning in the learning environment can be considered as choreography of teaching to reach learning goals.

From teachers' point of view, concreteness does not mean only practical work, but it could be considered almost as the leading paradigm for planning and realising teaching in primary school. Primary school teachers seemed to take into consideration the cognitive development of children. Pupils in primary school, aged 7 to 12, are in the transition period from the level of concrete operations to the level of formal operations (using Piagetian terminology). Everything should be concrete and be able to be perceived.

Teachers emphasised the importance of support. The need for expert support is obvious. Even the comprehensive school in Finland last nine-years; the present situation is that class teachers (Masters in Education) teach classes one to six and subject teachers (Masters in Science) teach classes seven to nine. When class teachers start to teach physics and chemistry in classes five and six, they need support. One suggested option is collaboration between class and subject teachers. Furthermore, the learning environment should provide access to consult physics teaching and learning experts. A more crucial aspect was the need for peer support. The situation at primary level is that teachers are interested in music, arts, acting, craft, physical education etc., but more rarely interested in science. Therefore, if only one teacher is interested in science they may feel lonely. Perhaps, chemistry and physics in the new Finnish national framework curriculum will be seen as a "common enemy" and that facilitates teachers to collaborate and cope together with the chemistry and physics teaching. However, in-service training is needed, where teachers can reflect on their own teaching experiences. Further, the learning environment should provide teachers tools for peer support.

Based on theoretical problem analysis and needs assessment the design team has produced the first prototype. The next chapter describes the first, limited, classroom test of the prototype.

4.2 Limited test of the initial prototype

Based on the objectives explicated in the Problem analysis and results of the teachers' needs assessment, the design team designed and produced initial – the first – prototype of the learning environment (see Chapter 6, version used in the field test). According to design research methodology, a design procedure is essentially iterative. Thus, the design team arranged a limited test of the initial prototype. Attribute limited means that only one content module was tested to identify the major problems regarding usability.

According to Section 3.5, learning environment is usable when pupils engage learning in a way that teacher intended. To evaluate usability, it is important to test a design solution – the learning environment – as early as possible in its intended context, a real classroom.

One approach to achieve usability is to follow the guidelines of standards such as *User-centred design process for interactive systems* (ISO 13407: 1999). However, Thovtrup and Nielsen (1991) noticed that designers may not be able to properly apply the standards. Furthermore, usability guidelines are useful aids for planning, but the designer cannot assess usability by means of them. Moreover, it seems that these standards and tests are developed particularly for specific purpose software, such as customer transactions processing systems for banks, where satisfactory tasks are easy to define. Thus, they could be difficult to apply in educational design and development. Another approach to evaluate usability is to use tests such as SUMI (1993) or SUS (1986). Tront and Muramatsu (2004) introduced a questionnaire-based framework to evaluate, select, and use digital learning materials. Designers improve systems based on tests and questionnaires. A third approach to measure usability is to investigate user performance. Designers ask users to accomplish tasks. When users are performing these tasks, effectiveness and efficiency are measured (Bevan, 1995).

Especially in this project, where the focus is on science teaching and learning, usability means that pupils engage learning in the learning environment in a way intended by the teacher.

Nielsen (1990) argues that the most interesting findings on how to improve hypertext user interfaces have come from qualitative observational studies. Therefore, teachers' teaching and pupils' learning were observed in actual context while pupils learned mechanics using the initial prototype of the learning environment.

This leads to the particular research question of this phase of the research: What are the major problems of using the initial prototype of the learning environment?

4.2.1 Data gathering

To identify major problems of the initial prototype of the design solution, the design team organised two two-lesson testing sessions for 58 5th grade pupils (age 11–12 years). Both classes were divided into two groups. A teacher (Jyri Jokinen) taught one half (group 1) and the other half of the pupils familiarised themselves independently with the prototype (group 2).

Group 1 was studied in the following way: The teacher gave a short introduction to the theme, read the background story, and organised the students to work in small groups. The teacher was available all the time and pupils could ask questions when they wanted to clarify something. The teacher also read the summaries. A senior researcher (Jari Lavonen) observed the teaching and learning taking notes. The teacher had been away for a year writing the manuscript, but he was still familiar with the pupils.

Group 2 familiarised themselves independently with the prototype. A researcher (Kalle Juuti) gave the pupils brief instruction on the prototype: described the objective of the learning and structure of the learning environment. The pupils from the first class learning independently were videotaped. Videotaping focused on two pupils, but research assistants were instructed to video everyone once in a while. The purpose was to gain an overview of actions taking place in the classroom inorder to evaluate the atmosphere (cf. Section 3.3). The teacher and the researchers discussed about experiences and observations after the testing sessions, and wrote memoranda.

Pupils learning under the guidance of a teacher, and pupils who were learning independently were intended to first study the basic models of Newtonian mechanics via the space creatures Nano and Piko. Then pupils were meant to investigate appropriate phenomena in the school laboratory (next-door classroom) and use web-material as a reference. Pupils had a paper copy of the laboratory investigations worksheet. Pupils were asked to document their investigations. In the documentation, pupils had to answer the following questions: What did I investigate? How did I investigate? What results did I get and why?

To find the major problems regarding using the learning environment, the pupils' learning independently and under the guidance of a teacher needed to be observed. Teaching sessions lasted 90 minutes per class. One researcher wrote observation memoranda of both classes' teaching and learning and split the transcribed text into the sequences as described in Table 4.2.1. The codes are introduced in Table 4.2.2. The videotaped period of learning covered 80 sequences and took only 65 minutes. This was due to pupils having performed a few experiments in a corridor where there was no possibility to videotape.

Table 4.2.1: Example of two sequences of categorised observation data.

Observation notes	Codes
Time 10:18	
The teacher tells that force is required to start or stop movement.	T9
Teacher: How does force effect movement? Weight influences how a body starts moving.	T5
Now the pupils seem to have lost interest in listening to the teacher. When the teacher read the background story, the pupils listened. Now it seems that only a few are following the teaching. At least three pupils are whispering.	P9
Time 10:21.	
Pupils continue reading: forces appear in action, force and reaction are force pairs. Now it seems many pupils are listening. More listen now than earlier while teacher clarified content.	P2 P1
Teacher asks and pupils respond. Teacher: Is it possible to be a force without reaction force… etc Teacher: a force always requires reaction force. Now several pupils are whispering.	T4 P11

Note. Codes are described in Table 4.2.3.
(cf. Juuti, Lavonen, Kallunki, & Meisalo, 2002)

Table 4.2.2 Example of video-transcription

Time	Verbal	Interpretation of non verbal	Code
16:20		Pupil B moves infrequently in her chair. It seems that she does not know what to do next. Opens the background story.	P9
17:25	Pupil A: Hey, what is that, wait…let me see is that the same, oh yes, it is the same. B: Did you listen to this?		P5
	A: What?B: Did you listen to this?	A turns to see B's screen and nods as an answer. B continues reading the story. A turns back to her screen.	P4

Note. Codes are described in Table 4.2.3

I viewed the videotapes, read the transcribed protocols and observation memoranda several times and discussed the preliminary findings with other researchers. The senior researcher observed 31 sequences for the first class and 26 sequences for the second class. During one sequence, teaching and learning was in a sense similar. Through inductive classification, it transcribed that all the data could be classified into two main categories and several sub-categories as described in Table 4.2.3. Altogether, 11 categories described teaching and 11 categories described pupils' actions.

The research question in the limited test of the learning environment was to find major problems. Therefore, in Section 4.2.3 focus is on sequences where the intended teaching and learning process was disturbed and the process will be analysed in more detail.

4.2.2 Results

The limited test offered support to the basic structure of the learning environment. In independent learning and in the teacher-guided learning, while playing games and listening to the background story about the space creatures' experiences, pupils were eager. They seemed to perceive the function of the buttons easily and they quickly found the content they were searching for.

Table 4.2.3 Description of the categories that rose inductively from the data

Category code	Description Teacher	Category code	Description Pupils
T1	instructs, advises, or helps	P1	follow teaching
T2	asks to perform	P2	read
T3	asks about experiences	P3	do practical work
T4	asks identification question (what)	P4	think, reason, discuss
T5	asks description question (how)	P5	work
T6	asks explanation question (why)	P6	tell about experiences (previous, observations)
T7	asks 'what if' question	T7	tell about ideas of content
T8	reads aloud, or writes on blackboard	P8	ask for instruction or advice
T9	clarifies content	P9	whispering
T10	demonstrates	P10	doing their own things
T11	organises laboratory work	P11	being passive

(cf. Juuti, Lavonen, Kallunki, & Meisalo, 2002)

Still, analysing the observation memoranda and video transliteration, many problems appeared while using the learning environment. Table 4.2.4 and Table 4.2.5 show descriptions of actions during sequences when *whispering* (P9), *doing their own things* (P10), or *being passive* (P11) appeared.

Tables 4.2.4 and 4.2.5 describe teaching and learning while disturbing category codes appeared in observation notes or in the video transcription. Altogether, disturbing codes appeared 32 times in 19 sequences. Thus, major problems occurred when:

- Pupils, or teacher, read *models* articles
- Pupils had a possibility to play games independently
- Pupils started to conduct practical work in teams.
- Teacher asked direct questions
- Teachers clarified content

(cf. Juuti, Lavonen, Kallunki, & Meisalo, 2002)

The disturbing code appeared twice in relation to the background story. However, the observation notes like "*One or two pupils start looking around, now everyone is following again*" and "*one pupil draws but is listening*" imply that the pupils engaged in learning in a way that the teacher intended.

Furthermore, the limited test, observation notes and particularly the video transliteration, uncovered situations, when the students' problems seemed to be caused by the technical problems of the learning environment. There were four different problems: 1) voices did not work because the browser version used in the school was quite old; 2) it appeared that downloading times of some pages were quite long; 3) some pupils had difficulty in perceiving links, however, they learned them quite quickly; 4) pupils' actions gave the impression that the font size in the initial prototype was too small.

Table 4.2.4. Description of action during disturbed sequences in classroom learning.

Time	Description of action
	Class 1
10:08	Teacher reads the background story.
10:18	Teacher clarifies content and asks questions about content.
10:21	Pupils read aloud the theory. One sentence per pupil.
10:37	In a group, girls play with dolls and boys do their own things.
10:51	One pupil does nothing, teacher instructs him to write a report.
11:15	Just after summarising the discussion of practical work the teacher asks questions and clarifies content about science in society module.
	Class 2
12:27	Teachers read the background story.
13:07	Just after summarising the discussion of practical work the teacher asks questions and clarifies content about science in society module.
13:11	Teacher asks what if questions.

Table 4.2.5. Description of actions during disturbed sequences in independent learning.

Time	Description of action
	Computer class
7 min	Pupils make noise, compare their game scores.
16 min	A videotaped pupil A has obvious problems in deciding what to do. Researcher reminds that the goal is to conduct practical work. However, majority of pupils continue playing. A videotaped pupil starts a game.
23 min	The videotaped pupil (A) asks, "what time is it" while reading theory text. Another pupil (B) comments "this is a very long story, oh no!"
27 min	Pupil A clicks and clicks the yes-button to reach a game
36 min	In the gallows game pupils set characters and after a while, think about possible answers.
	Practical work in the classroom
42 min	One pupil follows while two are active
43 min	A boy walks through girls memos
45 min	One boy is active, others (in his group) just follow
49 min	Two boys are active, still quite many just follow
57 min	Girls giggle while constructing a balloon rocket

4.2.3 Discussion

During this limited testing evaluation, the objective was to uncover major problems in the use of the learning environment. The design research is essentially iterative (cf. Chapter 2). Thus, it is important to organise test sessions in a typical classroom of the learning environment. The testing session lasted two lessons; it obtained a great body of contextual information about the learning environment. The above bullet list described major problems in the usability of the learning environment. Therefore, it is possible here to state goals for further development of the learning environment.

Pupils had difficulties in concentrating on learning when the teacher or a pupil read aloud the *Model* articles. In independent study, pupils had difficulty forming practical work teams. Pupils organised three teams and only a few pupils were active.

This was not a problem in the teacher-guided learning. Still there was an unsatisfactory combination of theoretical content knowledge and investigations. Pupils had a printed version of the investigation worksheet. It appeared that connection between explanation models, described in the background story and model articles, was inexistent. However, the pupils were eager while investigating. On the other hand, the teacher taught the content knowledge occasionally in a quite teacher-directed manner: asking direct questions and clarifying the models in the article.

The design group discussed these aspects of the limited test and decided to combine the modules *Models* and *practical work in* to one, and shorten the texts. *The models* concentrate here on basic models of Newtonian mechanics at the qualitative level. The hypothesis for this was that there is not such a huge gap between the explication models and empirical evidence.

Pupils drew while they listened to the background story. It is possible that they need more visual representations. Thus, it was decided to add more illustrations with strip cartoons and animations to help pupils to focus on learning. It is important to avoid overloading pupils and to choose representations with care; they should not be just decorations (Nielsen, 2000).

The games were a problem. Pupils should not be able to play them by just clicking the mouse button. In addition to that, the learning environment needs a preface for teachers and pupils telling them how to apply it appropriately. However, one teacher's need was that the learning environment should activate pupils to work – to do anything, but disturb others. Hence, playing games could be one possible solution to this.

Anyway, it appeared that a specific topic would be difficult to find. The learning environment should have a glossary and an index.

Technical problems such as voices, font size, and links were easy to improve, but slow downloading depends on the users' connections. Voices require on-line access, because the technical solution is similar, with a streaming technique to save downloading time.

One goal was that a teacher could organise learning in such a way that they could split classes and every pupil would still have an opportunity to learn science with an appropriate combination of theoretical background and investigations. This limited test showed teachers' role in computer-supported learning to be very important. Pupils need more strict instructions and goals. Otherwise, pupils seem to run through pages searching games.

Based on the limited test, the design team re-designed the initial prototype of the learning environment. The next chapter describes the pilot test of the prototype, including all topics.

4.3 Pilot test to probe pupils' views of learning in the learning environment

Finnish National Framework Curriculum (FRAME, 2004) emphasises psychological aspects of a learning environment (Section 3.2). Thus, it is important to acquire information, on how fundamental end users – pupils – view learning in the learning environment. The goal, set in the theoretical problem analysis was: the learning environment should constitute a positive atmosphere. Thus, it is important to examine how pupils feel about and react to learning in the learning environment. Further, Stokking (2000) argue that pupils, especially girls, hesitate over their decisions – to choose or reject physics – as long as possible; they want to keep all their options open in the future. Despite this pupils in primary school are not able to reject physics, so a learning environment designed based on pupils' preferences could possibly increase interest, or at least, avoid decreasing it. Hence, the following characteristics are suggested to be in place in a learning environment in-order to improve students', especially girls', attitudes towards physics studies:

- Teaching based on pupils' experiences and pre-conceptions
- It is possible to experience physics
- The teacher listen to pupils
- The teacher gives pupils time for independent work
- The teacher praises quality of performance
- The teacher responds to questions posed by pupils
- The teacher is empathic
- The teacher supports intrinsic motivation

(Labudde, 2000; Reeve, 2002)

After the re-design of the learning environment the design team organised a teaching experiment to acquire pupils' opinions about studying in the learning environment.

The research question in the pilot test was: How do pupils engage in learning and experience pleasantness of learning in the designed learning environment?

4.3.1 Method

To clarify pupils' opinions about studying in the designed learning environment, the design team organised a teaching experiment. The primary school teacher who was the author of the manuscript of the learning environment taught his own class during the academic year 2002 – 2003. Pupils were in the 6th grade; this is typically the highest one taught by a class teacher. Pupils were 11 to 12 years old and there were 13 girls and 16 boys. The school is typical in the national capital region in middle and upper middle class areas. It could be said that the school is a quite typical Finnish comprehensive school. It was natural to organise the pilot test following the draft of the new national framework curriculum. The prototype of the learning environment was designed before the national framework curriculum was finished. In grades five and six, time allocation is about 10 to 12 lessons for Newtonian mechanics. This pilot test lasted for 16 hours. Researchers observed and videotaped two of the eight two-hour lessons. Four lessons were allocated for each topic (see Chapter 6). In the teaching experiment, four topics were studied. In the Finnish National Framework Curriculum, five topics are allocated for grades 5 to 6.

After the teaching experiment, pupils answered the questionnaire probing their interest to learn, attitude towards learning, and views concerning modules and topics of the learning environment (see Chapter 6). Figures 4.3.1 and 4.3.2 describe items concerning evaluation and topics of the modules of the learning environment (Original test is available on request).

THE BACKGROUD STORY WAS

Unimportant	☐ ☐ ☐ ☐ ☐	Important
Difficult	☐ ☐ ☐ ☐ ☐	Easy
Unpleasant	☐ ☐ ☐ ☐ ☐	Pleasant
Uninteresting	☐ ☐ ☐ ☐ ☐	Interesting
No help in learning	☐ ☐ ☐ ☐ ☐	Helped to learn

Figure 4.3.1. Example of the module evaluation item.

A FORCE CHANGES MOTION

Unimportant	☐ ☐ ☐ ☐ ☐	Important
Difficult	☐ ☐ ☐ ☐ ☐	Easy
Unpleasant	☐ ☐ ☐ ☐ ☐	Pleasant
Uninteresting	☐ ☐ ☐ ☐ ☐	Interesting
I did not learn	☐ ☐ ☐ ☐ ☐	I learned

Figure 4.3.2. Example of the topic evaluation item.

To acquire a deeper view of pupils' opinions, two interviews were conducted. In the first two girls and in the second two boys were interviewed. The teacher chose the pupils to be interviewed. He was asked to choose pupils, who are not especially high achievers or low achievers, but average pupils. In the interviews, pupils were asked to describe learning, to compare physics with other science lessons, and describe modules. The goal was to find out, how pleasant pupils find the learning in the learning environment. Further, pupils were asked to reflect on what they had learned (skills and topics) and usefulness of physics studies. Interviews were designed taking into consideration principles of phenomenography (cf. Section 4.1). During the interview, the researcher reflected on the situation. If the impression was that pupils were not able to describe learning, then more detailed questions on studying were asked.

4.3.2 Results:

After the teaching sequence, pupils answered the questionnaire described in Figures 4.3.1 and 4.3.2. The aim was to clarify pupils' views of pleasantness and usefulness of the learning environment. Tables 4.3.1 and 4.3.2 describe medians of girls' and boys' evaluation of modules and topics of the learning environment. Figures 4.3.1 and 4.3.2 show examples of the questions. In the Tables, scales are coded from minor = 1 to major = 5 (e.g. unimportant = 1 – important = 5).

In spite of differences between medians in Table 4.3.1, the only statistically significant difference between boys' and girls' distributions is marked with an asterisk. Statistical significance was analysed with Mann-Whitney's U test that is a non-parametric alternative to the classical Student's t test (Gibbons, 1993b). Girls seemed to evaluate the background story as being more important to learning (Mann-Whitney's test calculated using SPSS: $U = 42.00$, $p < 0.05$). In Table 4.3.2, gender differences are not statistically significant. The low number of respondents means that possible differences are not acceptable (not a basis to reject null hypothesis).

Table 4.3.1 Medians of the pupils' (N = 29) evaluation of the modules.

Evaluation perspective	Background story		Models and investigations		Phys. Around us		Additional information		Games		Exercises	
	Girl	Boy	Girl	Boy	Girl	Boy	Girl	Boy	Girl	Boy	Girl	Boy
Importance	4.5	4	5	5	4	4	3	4	4	4	4	4
Easiness	3.5	3	4	4	4	4	4	4	4	4	4	4
Pleasantness	4	4	4	3.5	4	4	3	4	4	5	4	4
Interestingness	4	4	4	3	4	3	3.5	3	4	3	4	4
Learning supportiveness	5	4*	4	4	4	4	4	4	4	4	4	4

Note. N_{boys} =16, N_{girls} =13

Table 4.3.2 Medians of the pupils' (N = 29) evaluation of the topics.

Evaluation perspective	Force changes movement		Movement at ideal conditions		Movement and friction		Mass and Inertia	
	Girl	Boy	Girl	Boy	Girl	Boy	Girl	Boy
Importance	4	5	4	4	4	4	4	4
Easiness	4	4	4	4	4	4	4	4
Pleasantness	4	4	4	3	4	4	4	4
Interestingness	4	4	4	4	4	3.5	4	3.5
Learning	4	4	4	4	4	4	4	4

Note. N_{boys} =16, N_{girls} =13

Overall, Tables 4.3.1 and 4.3.2 show that pupils' opinions towards the learning environment were very positive. It seemed to be pleasant and they believed that it helped them to learn.

To acquire more in-depth information about pupils' opinions with regards to learning environment, I interviewed four pupils. In the interview, pupils were asked to describe learning in the designed learning environment. In the following quotations, pupils describe learning. Expressions of pleasantness are in italics and expressions of usefulness are underlined. Below, the interviews are integrated.

> Researcher: Please, describe your studying? [in the learning environment]
>
> Ville: *Well, fun.*
>
> Hanna: *Well, fun.* It has been quite a good thing, or I don't really know.
>
> Researcher: Could you please specify?
>
> Sami: It was good that listening and you can play these games and then you learn quite well.
>
> Hanna: We have done *experiments, they are fun.*
>
> Mari: It has been quite versatile, *it was not monotonous, and it was not boring*. I feel that I am learning something.
>
> Ville: We have done experiments.
>
> Sami: *Amazing*… for example, if you don't use a seat belt, you'll fly out of a car and everything.
>
> Researcher: If you compare studying in the ASTEL environment and studying in the typical science lesson, is there any difference?
>
> Mari: Well, it is not just reading textbooks and writing reports. *In this ASTEL environment it is much more fun to study with computers*. Otherwise, you have to write everything by hand, *now we do not have too much to write by hand*, however, we have written by hand.
>
> Ville: Typically, we just read a textbook and do exercises. In the ASTEL environment, *we do experiments, and so on.*
>
> Sami: We got about fifty handouts to do.
>
> Researcher: If you had to describe the ASTEL learning environment to you cousin or to a friend of somebody who has not seen it, what would you say? [ASTEL is an acronym for the learning environment used by pupils as well as being an acronym for the project. See more in the Chapter 5]
>
> Sami: I would say that [the Web] *site is good*, because you don't have to read yourself, if you have reading difficulties or something like that, you could listen, then you can play games and you learn well. Then, there are curious experiments and so on.

> Hanna: Well, we look at a story on the net and then we do experiments and make notes.
> Mari: I would say that first our teacher shows us a story, it is a kind of teaching story. Then we do exercises according to the story.
> Researcher: Is this everything…
> Sami: I would add that we do a lot of experiments and exercises from handouts.
> Ville: And there is the story that we follow.
> Sami: There is Pico and…
> Ville: Pico and Nano, they explain physics for Sarah. She doesn't understand physics well, and Nano and Pico try to explain physics for her.

The interview continued with the evaluation of modules. In the interviews, pupils described eight aspects from the pleasantness point of view. Girls (Hanna and Mari) and boys (Sami and Ville) mentioned that the learning environment is fun in general. Both pointed out the background story. Sami emphasised the listening possibility. According to boys, games were very pleasant, but girls found that playing in a teacher-directed way caused viva voce voting.

> Researcher: There are several games, have you played?
> Mari and Hanna: Yes we are, a little.
> Researcher: Have they been in teaching?
> Mari: Yes, we tried the tic-tac-toe, but… If there were two answers, I think, but I don't know how Jyri [the teacher] picked that answer. It seemed that he picked the one yelled most loudly.

However, the girls saw as being positive the possibilities in using computers. In the boys' interview, there were two negative aspects mentioned: the first was the number of handouts and the other was the arrangement of roles during practical work. In one lesson, the teacher gave a role card to each pupil and they had to follow the rules of ones role (such as president, secretary, facilitator, and reporter).

> Ville: It was quite messy.
> Sami: Yes, one wanted to be a leader and one wanted to be a reporter, and then no one wanted to be anyone and the card flew away and we didn't find them any more...
> Ville: It was chaotic, and really, we didn't know, what we were supposed to do.

Further, girls described that practical work undertaken may have problems: there is a risk that one pupil in a group conducts practical work and the others just follow.

> Mari: First of all, everybody read the instructions, then we decided what material each of us would get. Then basically one person constructed it and everybody else thinks about what is going to happen.
> Researcher: Have you changed … has it been the same in your groups?
> Hanna: About!
> Researcher: Was it always the same person who constructed the equipment or…
> Mari: Not always, but quite often it was the same.
> Hanna: Yes, quite often, if we had pairs, then we both constructed.

To evaluate usefulness, pupils' expressions about learning were analysed. On the meta-conceptual level girls evaluated that learning environment helped to learn, and in particular that it is important that after an investigation that the teacher leads a discussion about the results groups got.

> Mari: Well, then we read our reports [to the pupils in another group] and then we came back to the classroom and we checked that the results were correct. I think that it helps me to prepare for exams.

Further, girls mentioned that the investigation report shows what one has learned. Even if, the goal for the learning environment was concreteness, girls said:

> Mari: It is always nice to know this and that. I am positive that there is some benefit in the future…
> Hanna: I have needed this knowledge only in school.

Boys evaluated on the meta-conceptual level said that the background story and games help learning. According to them, one can choose questions from an appropriate topic.

In the interview, I asked one question from each topic measuring conceptual understanding. The girls were much more unconfident than the boys.

> Researcher: Can you tell me, what does it mean when it is said that 'a force changes motion?
> Mari: Well, for example, I mean…
> Hanna: If I pull something…
> Researcher: Yes, you said when one pulls…
> Hanna: Yes…

> Researcher: And?
> Hanna: Eh, nothing.
> Researcher: Do you know what is measured by a Newton meter?
> Hanna and Mari: What we have done…
> Researcher: Can you tell me, what does it mean when it is said that ‘a force changes motion?
> Ville: Well, an object does not move, if a force does not effect it. And when an aeroplane arrives, the motor effect is turned back and it causes force…and a car stops because breaks make force and then it stops.
> Researcher: Do you have something to add?
> Sami: That is almost everything.
> Researcher: Do you know what is measured by a Newton meter?
> Ville: Well, one measures the force when Earth pulls the object or measures the needed force to get a car moving
> Sami: That’s all.

Boys argued that the most important thing about physics is the preparation it gives for secondary school. Further, the benefit could be the following:

> Sami: If you are a detective, and there is a car accident and the car has gone into the bushes, it is possible to calculate how long and far some missing object has been propelled through the air and from this one could find it, especially if it is dark and the forest is huge. Here you need the inertia, you consider the velocity and then you know where it has been thrown.

It seemed that pupils were familiar with the *background story*, *models and investigations* and *games*, but unfamiliar with the *physics around us* module. They did not know the “bird button” (see Chapter 6).

4.3.3 Discussion

The pilot test showed that pupils really enjoyed studying (cf. Juuti, Lavonen, Kallunki, & Meisalo, 2003). They evaluated the learning environment in general to be very positive. The median was four for almost every item in the questionnaire. This means that very many pupils evaluated modules or topics to be important, easy, pleasant, interesting and supportive for learning. In the interview, pupils’ evaluation was more detailed and the interviews didn’t show any contradiction between the results of the questionnaire and the interview.

Pupils noticed the role of the background story in helping them to learn physics. They could manage investigations, if they have listened to the story carefully. This offers support for using qualitative models in teaching as discussed in the problem analysis (Sections 3.1 and 3.3.2).

Girls said that they needed physics knowledge only in school. This is a problem that needs to be carefully considered. One solution could be to somehow develop the *physics around us* module and its integration to the learning environment. Pupils didn't recognise the button of the *physics around us* module in the interview. Science and technology in society should be integrated in a more personal way into the teaching and learning process.

Time allocation is a problem. The prototype was designed before the national curriculum was finalised. Therefore, it is important to somehow produce a more concise version of the materials to better help teachers to implement the framework curriculum. Further, the pilot test indicates that pupils (or even teachers) are not competent in choosing the most important features of the learning environment. It seems that while the learning environment is too open, pupils and even teachers have difficulties in choosing appropriate tasks and investigations. Therefore, a teacher may 'run through' the whole material and then there is not enough time for discussions before and after investigations. Similar problems were noticed during the limited test, the design solution had already then the preface, but it was not a proper solution.

To overcome the difficulties in concentrating on the essentials, learning paths were designed. These paths may help teachers (and consequently pupils) to focus on and discuss important phenomena in various contexts. This could help pupils to recognise the relevance of physical knowledge better. Chapter 6 describes learning paths.

4.4. Field test to evaluate pupils' learning

The tests of the learning environment showed that pupils could engage in learning in the learning environment in the way the teacher intended. Further, pupils obviously enjoyed learning in the designed learning environment. The third test focused on learning achievements. According to the Finnish National Framework Curriculum (FRAME, 2004) the goal is that pupils learn to work safely, learn to conduct practical work and consider their reliability, recognise the cause – effect relationships, and apply scientific concepts. This field test focuses on evaluating how pupils' learned Newtonian mechanics during the teaching sequence.

To answer the research questions, three teachers conducted a teaching sequence and pupils' conceptual understanding was measured with pre- and post-tests. The following describes the design of the conceptual understanding tests and the proceeding of the teaching sequence.

The needs assessment showed a crucial need in giving support to class teachers. Especially, teachers needed peer support. To answer the need for support, the design team organised an in-service training course for class teachers in co-operation with the city of Helsinki. The in-service course served two objectives. It offered information about optimal expert and peer support features that needed to be integrated into the learning environment, and it offered a group of teachers, unfamiliar with Newtonian physics and unfamiliar with the project, to engage in the testing.

According to design research methodology, it is important to ensure that the design solution is usable not only in designers' context but in other contexts as well. And by choosing a few teachers to implement the teaching in the designed learning environment, it is possible to evaluate the learning environment. One goal of design research is to avoid the situation where teaching and learning are successful only when designers use the learning environment (cf. Linn, 1996). Therefore, it is important to motivate teachers to participate in testing during the project.

The particular research questions for the field test were: 1) How do pupils' conceptually learn Newtonian mechanics? 2) How do boys' and girls' achievements differ?

4.4.1 Design of the conceptual understanding tests

To evaluate pupils' learning, a pre-test and a post-test were designed. The tests were based on the ideas of the Force Concept Inventory (FCI) test designed by Hestenes, Wells, & Swackhamer (1992). According to them, FCI requires forced choices between Newtonian concepts and compromise models (see Section 3.1). The FCI-test is designed in such a way that one individual item should not be given great weight. They argue that the FCI-test as a whole is a very good detector of Newtonian thinking. Items are qualitative multiple-choice questions. FCI-test items probe six aspects of Newtonian mechanics:

- Kinematics
- Firs law
- Second law
- Third law
- Superposition principle of forces
- Kinds of forces

Questions are designed in such a way that options tempt student to choose a compromise model in the questionnaire. However, the original FCI-test, designed for high school or university level, is too difficult for primary school pupils. In the pre-test it is not fair to ask questions that are not knowable. The FCI-test explicitly describes the idealisations: e.g. "Along the frictionless path you have chosen in question 8, the speed of the puck after receiving the kick" (Hestenes, Wells, & Swackhamer, 1992). Therefore, pre- and post-tests were developed in a way that the idealisation is obvious, but it is still needed to understand.

Design of the pre-test

In the problem analysis (Section 3.1), I concentrated on conceptual change in Newtonian mechanics. The main point was to consider compromise models. According to Hestenes, Wells and Swackhamer (1992) impetus and dominance conceptions are most difficult and usually the last to overcome. Therefore, the pre-test concentrated on these items. In the pre-test, there were nine multiple-choice questions based on the FCI test. Table 4.4.1 describes the pre-test questions. Fiqure 4.4.1 shows one question as a case (original questionnaire is available on request). The case question shows the similarity with FCI-test item seven. In the FCI-test, there is only one point to let go the hammer and five options of trajectories.

Table 4.4.1 Descriptions of the questions in the pre-test.

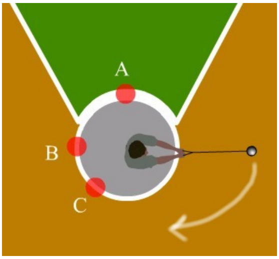
Question	Description	Law
1	A pupil pushes a teacher in the office chair†	NIII
2	A football player kicks the ball towards the goal	*
3	A space rocket moves engine off in the outer space†	NI
4	A girl pulls a pulkha on snow†	NI
5	A girl pulls a pulkha on the floor†	NII
6	Falling objects†	NII
7	Hammer†	NI
8	A space rocket turn off the engine in outer space†	NI
9	A space rocket starts the engine	NII
10	A truck collides head-on with a small car	NIII

Note. *Question 2 was a test question without choices and it was left out of analyses.
NI = Newton's first law, NII = Newton's second law, NIII = Newton's third law.
†Essentially the same question in the pre- and post-tests from physics point of view.

Questions one and ten are 'why questions' – explanations for forces; and the other questions ask 'how questions' – how object moves. Pupils were asked to write down the reasons for their choices. It is possible to use written information for more detailed analysis of the data.

Question 7

Hammer thrower swung in the direction showed by the arrow. At which point (A, B, C) does the thrower have to let go in order for the hammer to fly within the sector (in the middle)?



On what grounds did you chose the point you selected?

____

____

____

Figure 4.4.1. An example of the question in the pre-test.

Design of the post-test

As the pre-test, the post-test was designed based on the FCI-test. In the post-test, there was a question where a figure was drawn for every option of the question. Further, in the post-test, the space characters Nano and Pico are illustrated in the figures. Table 4.4.2 describes the post-test questions as a case.

In the post-test, questions 6, 7, 12, 14, and 15 ask about forces and others ask about motion. Figure 4.4.2 shows a case example of a question in the post-test.

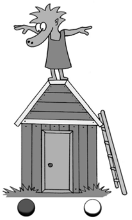
Table 4.4.2 Descriptions of post-test questions.

Question	Description	Law
1	Falling objects†	NII
2	A space rocket turns off the engine in outer space†	NI
3	A falling object	NII
4	Ice hockey player shot a puck†	NI
5	Street hockey player shot a puck†	NII
6	Two persons push each other (static situation)	NIII
7	Two person push each other, one of them uses all her forces (static situation)	NIII
8	Ball goes out from the half pipe	NI
9	Hammer†	NI
10	Human cannonball flies through the air	PM
11	One hits a bug from table to floor (which track)	PM
12	One pushes another on an office chair (dynamic) †	NIII
13	Ice hockey player changes the direction of the puck	PM
14	A pupil swinging	NII
15	A tennis player hit the ball	NII
16	A space rocket moves engine off in outer space†	NI

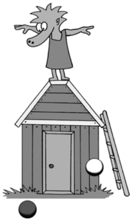
Note. NI = Newton's first law, NII = Newton's second law, NIII = Newton's third law, PM = projectile motion.
†Essentially the same question in the pre- and post-tests from a physics point of view.

1 Nano drops two same size balls on the roof of the shed. The mass of the dark ●. is twice as heavy as the white ○. Choose the correct alternative by circling a figure:

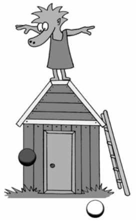
A



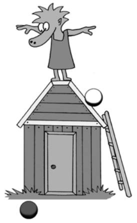
B



C



D



On what grounds did you chose the point you selected?

Figure 4.4.2. An example of the question in the post-test.

4.4.2 Participants and teaching sequence

Participating teachers for the field test were chosen from participants of the in-service training held in the city of Helsinki in spring 2003. About 25 teachers participated in the course. The course lasted for two days. The first day concentrated on the national framework curriculum renewal, pupils' conceptions in movement and force, and on the designed learning environment. The second day concentrated on sharing experiences of tests of the learning environment and topics in electronics and electricity. At the end of the first day, I asked a few teachers to conduct the pre-test and to participate in the field-test. The problem was that physics (and chemistry) was not an independent subject in spring 2003. There were only some teachers teaching classes five or six in pilot schools of the curriculum renewal in the city of Helsinki. Further, teachers felt that before teaching, they should participate in training, and perhaps, in the next semester they will teach physics and chemistry. Consequently, it appeared that only three teachers were willing to conduct the complete teaching sequence.

Two males and one female teacher participated in the pilot test. One of the male teachers and the female teacher had about five years experience and the other male teacher had about ten years experience as primary school teachers. The schools can be said to be typical Finnish urban schools (outside of the city centre).

Altogether there were 77 pupils in the three classes, but quite many pupils missed either the pre-test or post-test. Therefore, only 53 pupils participated both in, the pre-test and post-test. In order to evaluate pupils' learning, only pupils, who participated in both tests, were taken to the analysis.

Teaching sequences followed the teaching paths (Chapter 6). Pupils learned in the learning environment. Classrooms were normal, neither science laboratories nor exceptionally rich in modern educational technology.

Occasionally, teachers used computer classes for variation. The learning path suggested that teachers should start a lesson with a background story (audiofile). The pupils listened to the story. After this, it was recommended the teachers ask questions and in this way help pupils to recognize how Nano and Pico in the story and hints in the work sheets help them to explain various phenomena. In the female teacher's class pupils did not listen to the background story, she clarified models using transparencies emphasising a paradigmatic mode of thought (see Section 3.3). Then the pupils conducted practical work in small groups. The teachers supported pupils informally while they were investigating. After practical work, pupils wrote reports about their findings and sometimes got homework. Altogether, pupils studied about six lessons of Newtonian mechanics during (about) three weeks. I followed (non-participant observation) one lesson in school M and three lessons in school R. In addition to this, in the second meeting of the in-service training, a teacher of school K as well as others told how the teaching sequence proceeded. Pre and post-tests were conducted without unnecessary delay, just before and after the teaching sequence.

4.4.3 Results

Altogether, there were 53 (24 girls, 26 boys) pupils who answered the tests. Three pupils' names did not indicate the gender. Therefore, only 50 pupils' scores are included in the analyses comparing girls' and boys' achievements.

In this research, nonparametric tests are used, because they are distribution-free and therefore strict distribution assumptions are not needed. Girls' and boys' achievements were compared using crosstabs and Kendall's tau-b coefficient. Tau-b is a nonparametric alternative to the Pearson product-moment correlation coefficient. Tau-b is a nonparametric measure of correlation for ordinal or ranked variables that take ties into account. (SPSS, 2003; Gibbons, 1993a)

In the comparison of pupils' pre- and post-test results and in the comparison between schools the Wilcoxon Signed Ranks Test has been used. The Wilcoxon Signed Ranks test compares medians. Ranks are based on the absolute value of the difference between the two test variables. (SPSS, 2003; Gibbons, 1993b)

Table 4.4.3 shows the frequencies of correct choices in the pre-test and table 4.4.4 shows the frequencies of correct choices in the post-test.

Table 4.4.3 Frequencies of correct answers in the pre-test

Question	Frequency girls N = 24	Frequency boys N = 26	Kendall's tau-b
1	5	1	-0.261
3	4	13	0.352*
4	2	3	0.053
5	19	23	0.127
6	0	3	0,243
7	10	20	0.360*
8	5	14	0.340*
9	15	18	0.071
10	3	1	-0.159

* $p < 0.05$

In the pre-test boys out perform girls in questions concerning space rockets and hammer throwing that probe Newton's first law.

Table 4.4.4 Frequencies of correct answers in the post-test.

Question	Frequency girls N = 24	Frequency boys N = 26	Kendall's tau-b
1	11	15	0.119
2	20	21	-0.33
3	10	15	0.160
4	5	3	-0.127
5	19	20	-0.27
6	13	18	0.155
7	8	8	-0.027
8	8	8	-0.027
9	4	7	0.124
10	20	19	-0.124
11	14	16	0.033
12	10	11	0.006
13	9	10	0.010
14	1	2	0.074
15	1	2	0.074
16	17	22	0.166

On the item level, in the post-test there were no gender differences. Therefore, pupils' results can be analysed as a whole group. Table 4.4.5 compares items common in the pre-test and post-test. It shows how many pupils answer change or remain the same. A pupil could achieve one point per item.

According to the Tables 4.4.3, 4.4.4, and 4.4.5, pupils have learned how a space rocket moves in outer space, and that objects fall to the ground at the same time. Pupils did not learn how objects move on a surface with low-friction. The high-friction question seemed to be quite easy. It is obvious that in the situation with constrains – such as high friction – objects stop quickly. There was no difference between pre- and post test.

Table 4.4.5 Comparison between items in the pre-test and the post-test.

Pre-test question	Post-test question	Neg. ranks[a]	Pos ranks[b]	Ties[c]	Z[d]
1	12	4	22	27	-3.53*[e]
3	16	3	28	22	-4.49*[e]
4	4	5	8	40	-.83[e]
5	5	8	5	40	-.83[f]
6	1	1	26	26	-4.81*[e]
7	9	24	4	25	-3.78*[f]
8	2	5	30	18	-4.23*[e]

* $p < 0.05$.
[a] post-test < pre-test
[b] post-test > pre-test
[c] post-test = pre-test
[d] Wilcoxon Signed Ranks Test,
[e] based on negative ranks
[f] based on positive ranks

Further, pupils seemed to learn a compromise model of the trajectory of the flying hammer (question pair 7 – 9). This question needed analysis that is more detailed. Therefore, pupils' written explanations are analysed. Altogether, nine pupils choosing correctly for the hammer question in the pre-test did not write any explanation or they admitted guessing. In addition to that, five pupils' written explanations indicated the circular impetus compromise model. "[Hammer should be let go at point B] because the hammer does not fly straightforward" [pre-test, id 21]. Eight pupils, who answered correctly to the hammer question in the post-test, did not argue correctly. Only two pupils' answers contained implicit indication of the Newtonian model of motion (The first law). "Pico did not slice" [post-test, id 28].

Hestenes et al. (1992) argue that the whole FCI test measures the general understanding of Newtonian mechanics at the qualitative level. To evaluate learning in general, a sum variable was computed for pre-test and post-test questions. If a pupil chose correctly of every pre-test (post-test) question, the score was one. In the case of nine (16) wrong choices, the score of the pupil was zero.

The pre-test median was 0.33 and post-test median was 0.5. According to the non-parametric Wilcoxon Signed Ranks test for two related samples there was a statistically significant difference between pre- and post-test scores ($Z = -3.43$, $p < .01$). Expectation values in the same scale for pre-test (0.26) and post-test (0.25) shows that pupils unlikely guessed.

There were three similar urban schools participating in the field test. The difference between pupils' achievements in the pre- and post-test in the schools (Table 4.4.6) were analysed by the Wilcoxon test (Table 4.4.7). It appeared that there were no differences between schools in the pre-test, but there were statistically significant differences in the post-test.

Table 4.4.6 Medians of pupils' achievements per school and Wilcoxon Signed Ranks Test of difference between pre- and post-tests.

School	Pre-test median	Post-test median	Z^a	N
K	0.44	0.50	-2.19*	21
M	0.33	0.56	-3.01*	15
R	0.33	0.31	-0.45	17

* Asymp. Sig. (2-tailed) $p < 0.05$
[a] Based on negative ranks

Table 4.4.7 Comparison between schools

School pair	*Pre-test*		*Post-test*	
	Wilcoxon W	Z	Wilcoxon W	Z^a
K – M	244.5	-1.09	353	-1.16
K – R	310	-0.64	255*	-2.27*
M – R	246	-0.06	202*	-3.01*

*Exact Sig. (2-tailed) $p < 0.05$
[a] Based on negative ranks

Comparing schools using the Wilcoxon test, no differences between them were found in the pre-test. Between post-tests, there was statistically significant difference between schools M and R, as well as K and R.

4.4.4 Discussion

The results showed that during teaching sequences pupils' learned Newtonian mechanics (see also Juuti, Lavonen, & Meisalo, 2004). Further, during the teaching sequences, gender differences found in the pre-test vanished. However, in general pupils' achievement in the post-test was not very high; median score was only 0.5. Median 0.5 means that only half of the pupils gave correct answers for over half of the questions.

Test questions were designed according to the National Framework Curriculum and the conceptual understanding goal should be considered carefully. It seems that six hours is too short a time for conceptual change in mechanics.

A very interesting finding was the difference between schools. In school R, pupils' test score did not change. In fact, the median seemed to decrease, but the difference between distributions was not statistically significant. It could be said that pupils in school R did not learn Newtonian mechanics on the qualitative level. In contrast to this, in schools K and M, pupils' scores increased.

The teacher in school R was female. She was very insecure about physics teaching, but she was not the only one. The teacher in school M was insecure as well. The teacher in school K has taught technical craft and he was quite eager teaching physics. The main difference in teaching in school R was that the teacher did not use the background stories. Further, her pupils had no possibility to use computers themselves. Speculating even more based on teachers descriptions of the teaching sequences in the second meeting in the in-service training and observations, it seemed that in schools K and M pupils had more possibilities to feel autonomous (cf. Ryan & Deci, 2002).

In the future, the meaning of the background story should be emphasised in the in-service training and a summary of the pupils' achievements should be integrated into the teachers support materials. Further, in the learning paths, the importance of the background stories should be added. Questions, that needed force explanation, appeared to be very difficult. It could even be said that, pupils did not learn the force concept as an explanation for change of motion, but they learned how objects move.

5 DESIGN PROCEDURE

This chapter outlines the design research process, and describes the design team and its expertise. The final aim is to present a prescriptive model of the design procedure, providing an answer to the research question concerning design methodology. Section 5.1 describes the design procedure in detail, and Section 5.2 filters down the essential features of the procedure into a prescriptive model.

The description of the process is based on the project plan, e-mail discussions between designers (over 290 messages), and memoranda of the design team meetings (cf. Yin, 1994).

To acquire a deeper conception of their views on their roles in the design process, participants were asked the following question: how do the participating designers evaluate the design research process?

Section 5.1 describes the process of the project and answers this particular research question. To formulate an answer, every member of the design team was asked to write a self-reflective essay. In the essay, design team members considered the following theme:

How have you participated?

- Brain-storming (articles, figures, games, exercises, and user-interview)
- Producing the material
- Comments and re-design suggestions
- Other activities (management, preparation of grant applications)

Analysis of the essays (from half to three standard pages) painted a picture of how participants had experienced the common goals of the project and how these goals had been realised. The participants also described how they experienced their individual roles in the design research project.

5.1 Process of the design research project

The design process started with information about the Framework Curriculum reform (see Section 3.2) and the fact that primary school teachers in Finland have little experience with chemistry and physics. The need for appropriate teaching resources was crucial. In the autumn of 2001, the Deputy Director of the Association of Finnish Technology Industry decided to sponsor a teaching project in the Education Department of the City of Helsinki. At the same time, in the Department of Applied Sciences of Education at the University of Helsinki, lecturers in physics education were planning to develop materials for teacher education. These three parties knew each other from previous design and development projects. Therefore, it was relatively easy to integrate projects and co-operate. Based on the project plan, the objectives were *to design and produce web-based learning materials, organise in-service training, research the project, teaching material and its use*. During the year 2002, the National Board of Education and the GISEL project participated in the design research project. The GISEL (Gender Issues, Science Education and Learning) project is a sub-project of the EQUAL community initiative MIRROR project. The GISEL project was one project in the Department of Applied Sciences of Education, and therefore, it was easy to establish synergy.

The first official meeting was on October 11, 2001. During the meeting, the designers decided on the guiding principles of the project, based on the competence and intentions of team members (Table 5.1). Participants expressed a wide variety of ideas about learning environments. In the beginning of the project, team members found cultural differences between physics teachers and class teachers. "It was very confusing to read the first draft. It was quite long, including a number of difficult concepts to be learned. Also, the narrative form of the text was strange" [Jari Lavonen]. "In the beginning, I felt that these physicists did not understand the children's world, nor my world, and I did not understand physics. But we understood each other very quickly" [Jyri Jokinen].

The first point to be agreed was that members of the design team must subordinate their pre-conceptions about good learning environments for research-based knowledge. They then agreed on a design procedure: the participating teacher's role was to write manuscripts, while the other's role was to make comments based on previous experience, theoretical problem analysis, and empirical problem analysis. At least occasionally, everyone participated in the brainstorming process (Table 5.2). From the very beginning, the design team engaged in design research. The design team was divided into three main responsibility groups: 1) material production, 2) research, and 3) management. In addition, every member were expected to make comments on the drafts, except those who only participated in management. The researchers' responsibilities were to participate in designing, arranging needs assessments, planning prototype testing, and analysing the data from re-design suggestions (see Chapters 3 and 4).

Table 5.1 Responsibilities

Member	Responsibility	Competence
Jyri Jokinen	Pupils' material manuscript author*	Class teacher
Kalle Juuti	Re-design suggestion based on empirical and theoretical problem analysis* (see preface for more details)	Physics teacher, post graduate student in education, researcher
Veera Kallunki	Teachers' material manuscript author*, comments	Physics teacher, post graduate student in physics education, senior lecturer in teacher education
Jari Lavonen	Co-ordination*, management, re-design suggestions, teacher material manuscript author	Physics teacher, PhD in physics education, senior lecturer in teacher education, docent
Jukka Lepikkö	Coding*, user-interface design	Web coder
Anneli Manninen	Management* (sponsor)	Deputy Director of the association of the Finnish Technology Industry, Education division
Veijo Meisalo	Re-design suggestions*	Professor of physics education
Anniina Mikama	Graphics*, user-interface design	Graphic designer.
Marjatta Näätänen	Management*	Mathematics teacher, teaching consult in the City of Helsinki

* Member's main responsibility.

Table 5.2 Design team meetings for which memoranda were written

Meeting date	Main issue
11. 10. 2001	Launching the project, decisions on the participants‘ responsibilities.
22. 10. 2001	Ideation the basic structure of the learning environment: story characters, layout etc.
8. 11. 2001	Ideation of elements of the learning environment.
19. 12. 2001	Discussion on the first drafts of texts, figures, and further design suggestions.
29. 2. 2002	Discussion on the first drafts of games.
12. 6. 2002	Project update after the limited test, National Board of Education participates in sponsoring.
22. 8. 2002	Many detailed re-design suggestions.
7.11. 2002	Discussion on the final server for the web material.
28. 11. 2002	Memo concerning copyrights, discussion about re-design requirements after the pilot test.
10. 12. 2002	Project update
31. 1. 2003	Field test planning

Typically, meetings included the following features: 1) management, 2) research, 3) project update, 4) discussion on drafts and ideation, and 5) action plans.

The design project was a non-profit exercise funded by several parties. Therefore, it was crucial to ensure that parties agreed on common goals and procedures. It was important that parties saw the project benefit every participant. The main agreements were that the design solution had to be available for every teacher through the Internet without any fee or password. The Finnish National Board of Education sponsored the Swedish translation. In addition, management decisions during the meetings concerned balancing the resources of the project (sponsors or competence). The form of the project was novel for everybody. No-one really owned the project. All parties were co-operating towards shared goals. Consequently, the loose and novel structure caused bureaucratic problems. It was difficult when at the same time the class teacher was on leave, he had to work in the project as manuscript author.

There were several reasons why researchers (researcher, lecturers, and professor) from the Department of Applied Sciences of Education (former Department of Teacher Education) participated in the project. There was the possibility to participate in interesting design research and the possibility to obtain resources for a graphic designer to help produce teacher education learning materials. At the beginning of the project, parties agreed that design should be based on research in physics education (teaching and learning). During the meetings, researchers mentioned what is known about qualitative- and quantitative-level concepts, pupils' learning difficulties with these concepts, possible solutions to overcome these problems, and other research concerning physics education (Chapter 3). The planning of testing sessions began in meetings and the details were decided mainly via e-mail. After testing, researchers made re-design suggestions.

Because of the loose structure of the project, it was important to update participants on the changing design during the meetings. Members were told what the situation was in the field of their responsibilities. The co-ordinator facilitated the meetings. The update was a message for sponsors and other designers that the project was proceeding towards its goals. The team decided on design tasks in the project meetings and there was a high level of consensus in the design group that the project needed jointly-decided deadlines.

The co-ordinator took the main responsibility for planning the meetings and saw to it that they followed the principles of creative process. Before each meeting, authors sent manuscripts via e-mail to other participants. Researchers (mainly) read and became familiar with drafts and made comments. Comments were based on an analysis of the problem and members' own experiences of physics teaching and physics teacher education. Figure 5.1 describes the knowledge needed to comment on the drafts. Design meetings were planned following the principles of creative problem solving. There was positive non-judgemental feedback and acceptance of all ideas. During the design meetings, it was also possible to ask constructive questions about an idea, or combine and redefine ideas. Typically, the solution was a combination of several ideas. The designers felt that making comments formed the heart of the project: it offered a variety of views.

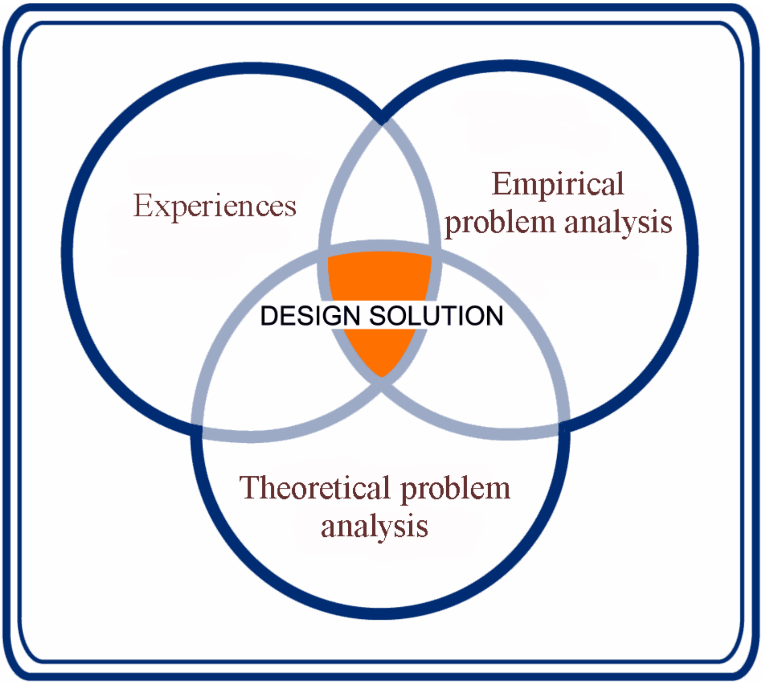


Figure 5.1 The integration of knowledge in design discussions.

Typically, researchers read manuscripts and carefully analysed figures before team discussions. After design team meetings, there were discussions between the manuscript author, graphic designer and researchers about details.

During the meetings, the co-ordinator wrote down three kinds of decisions: team members continued ideation as homework, further design approaches, and further design decisions.

Design was organised into responsibility areas, which were managing (three members), designing teachers' physics learning materials (three members), teachers' teaching model materials (two members) and pupils' study materials (four members), as well as the graphical user interface (two members). The research activities were designed and co-ordinated in parallel with more practical tasks (four members). Every participant had at least one specific area of responsibility (see Table 5.1).

The participants felt that their opinions were important. As shown in Figure 5.1, the design team was able to integrate their tacit knowledge (experience with physics teaching in primary and secondary level as well as in pre- and in-service teacher education) with theoretical and empirical problem analysis.

5.2 Design methodology

In this section, essential features of the design process are extracted in order to produce an ideal prescriptive model of design.

Figure 5.2 shows aspects of the design methodology: 1) progress of the design research project, 2) methods to gather data in empirical problem analysis, and 3) phases of testing the prototype. According to Edelson (2002), a design procedure is explicit and followed only in some design forms. The process of design is usually flexible and dynamic. The design procedure appeared to be flexible and loose. Therefore, there is no point in describing every aspect of the design process with the model, but instead provide a skeleton for designers to remind them to ask for user opinion, apply versatile methods in data gathering, and remember that the first prototype is hardly the final product. Iteration – design, evaluation and re-design – is essential.

Progress of design research includes a needs assessment, the articulation of explicit objectives for the product, decisions on the production of manuscripts, and a disciplined evaluation of the prototypes produced. The design process could consist of more than the suggested three evaluation phases. However, the point is that the prototype should be tested when something has already been produced. In this project, a limited test was conducted when one topic was available. The obvious benefit is that designers do not have to change all the material, but only the part which has been tested and shows a need for adjustment. After testing, designers could apply knowledge gleaned from testing and avoid major problems. The design research model suggests that designers should produce an initial prototype for classroom testing. After pilot testing, there should be enough time for finalising the product.

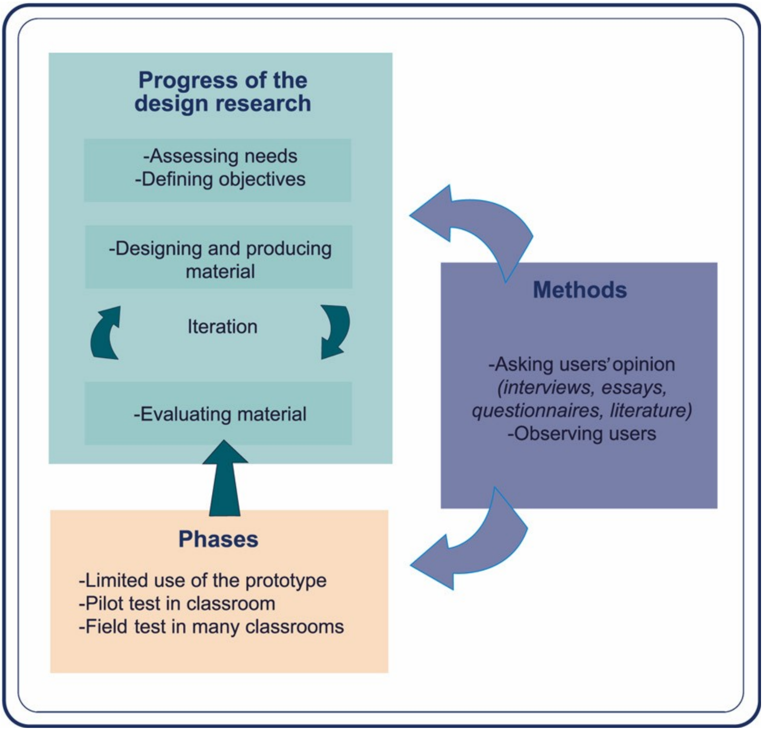


Figure 5.2 Prescriptive model of the design procedure

6 DESIGN SOLUTION

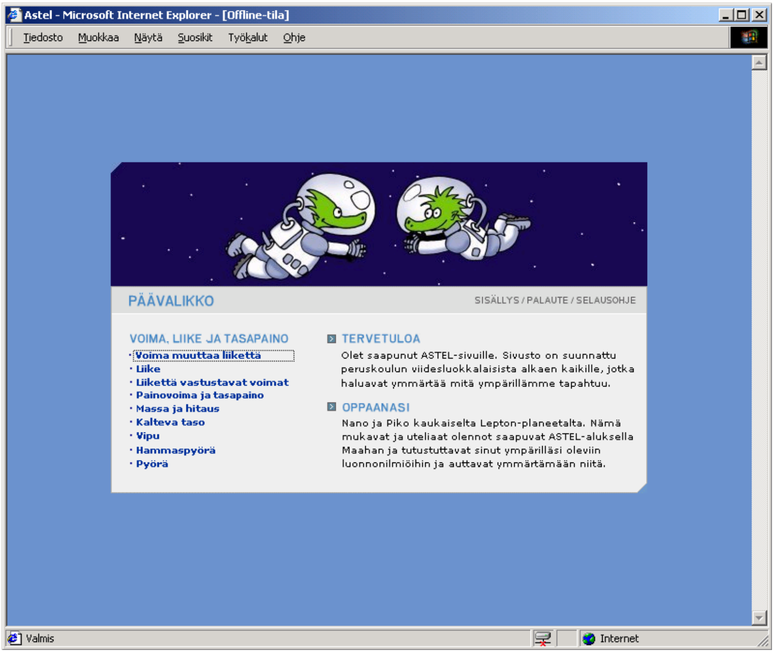
The aim of this chapter is to describe how the design solution meets the required properties of a learning environment for primary school physics. Furthermore, this chapter describes how theoretical and empirical problem analysis was taken into consideration. During the project, almost fifty design objectives were set. My role as a member of the design team was described in the Preface. Section 6.1 gives an overview of the structure and Section 6.2 presents an analysis reflecting the objectives set during the research project for the newly designed learning environment.

6.1 The structure of the designed learning environment

Figure 6.1 shows the home page of the on-line learning environment for primary school physics (available online: www.openet.fi/astel/). On the left is a topic navigation index. On the right, there is a short preface, and above these, there are hyperlinks for a content index (detail with hyperlinks), feedback, and a short guide for using the learning environment. On the top, there is a graphic of the two space characters that are the stars of this learning material. If a pupil or teacher clicks a navigation hyperlink, it opens a topic. The topics covering Grades 5 – 6 in the Finnish National Framework Curriculum are: 1) force changes motion, 2) motion, 3) forces constraining movement, 4) mass and inertia, and 5) gravity and balance. In addition, the web pages include topics for classes in lower grades that have not been not included in this analysis of the project. Additional topics are: 6) inclined plane, 7) lever, 8) gear wheel, and wheel. Figure 6.2 shows the topic view. On the left, there is the same navigation index. On the bottom left, there are also hyperlinks to the drill and practice test (the test will be changed to something more sophisticated after the test prototype has been modified based on the results of the field test), content index, glossary, and hyperlink to the front page. On the bottom right, there is a hyperlink to the copyright page. The material is free of charge for use in non-commercial educational settings. Module buttons are located on the bottom of the page.

The modules are:
1) Learning path, (Figure 6.9)
2) Background story (Figure 6.3),
3) Models and practical work (figure 6.4),
4) Physics around us (Figure 6.5),
5) Additional information, and
6) Games and exercises (Figure 6.6).

Table 6.1 presents the modules of the learning environment. The modules are discussed in more detail in Section 6.2.

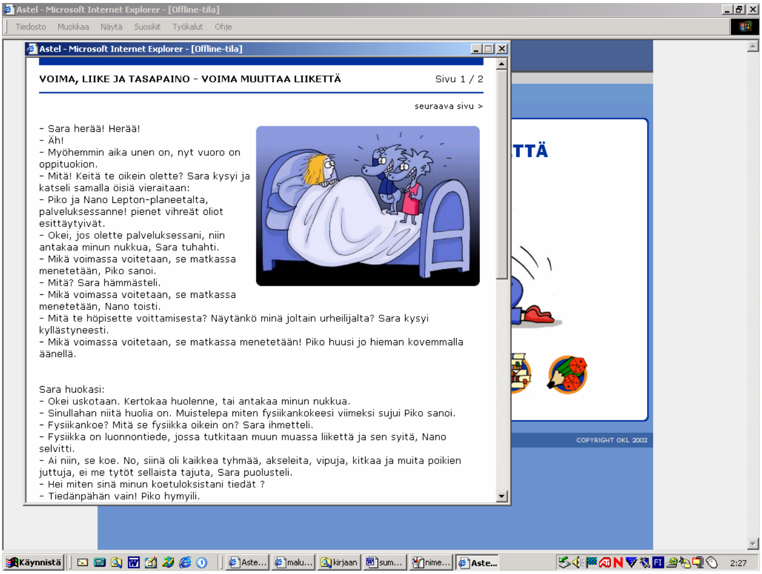


Olet saapunut ASTEL-sivuille. Sivusto on suunnattu peruskoulun viidesluokkalaisista alkaen kaikille, jotka haluavat ymmärtää mitä ympärillämme tapahtuu.

Nano ja Piko kaukaiselta Lepton-planeetalta. Nämä mukavat ja uteliaat olennot saapuvat ASTEL-aluksella Maahan ja tutustuttavat sinut ympärilläsi oleviin luonnonilmiöihin ja auttavat ymmärtämään niitä.

Figure 6.1 Home page of the learning environment.

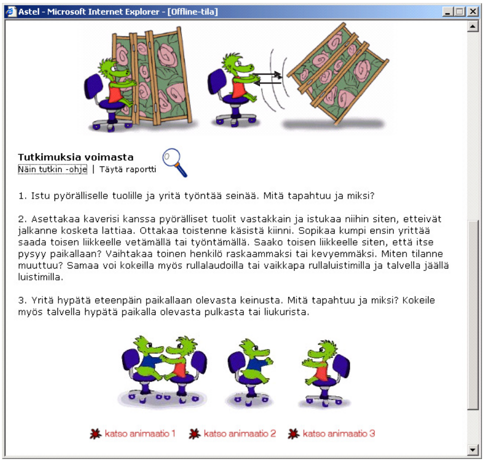
Figure 6.2 Topic view of the learning environment: Force changes motion.



- Sara herää! Herää!
- Äh!
- Myöhemmin aika unen on, nyt vuoro on oppituokion.
- Mitä! Keitä te oikein olette? Sara kysyi ja katseli samalla öisiä vieraitaan:
- Piko ja Nano Lepton-planeetalta, palveluksessanne! pienet vihreät oliot esittäytyivät.
- Okei, jos olette palveluksessani, niin antakaa minun nukkua, Sara tuhahti.
- Mikä voimassa voitetaan, se matkassa menetetään, Piko sanoi.
- Mitä? Sara hämmästeli.
- Mikä voimassa voitetaan, se matkassa menetetään, Nano toisti.
- Mitä te höpisette voittamisesta? Näytänkö minä joltain urheilijalta? Sara kysyi kyllästyneesti.
- Mikä voimassa voitetaan, se matkassa menetetään! Piko huusi jo hieman kovemmalla äänellä.

Sara huokasi:
- Okei uskotaan. Kertokaa huolenne, tai antakaa minun nukkua.
- Sinullahan niitä huolia on. Muistelepa miten fysiikankokeesi viimeksi sujui Piko sanoi.
- Fysiikankoe? Mitä se fysiikka oikein on? Sara ihmetteli.
- Fysiikka on luonnontiede, jossa tutkitaan muun muassa liikettä ja sen syitä, Nano selvitti.
- Ai niin, se koe. No, siinä oli kaikkea tyhmää, akseleita, vipuja, kitkaa ja muita poikien juttuja, ei me tytöt sellaista tajuta, Sara puolusteli.
- Hei miten sinä minun koetuloksistani tiedät ?
- Tiedänpähän vain! Piko hymyili.

Figure 6.3 The background story, as well as other modules, open in the front of the topic view.



Tutkimuksia voimasta

1. Istu pyörälliselle tuolille ja yritä työntää seinää. Mitä tapahtuu ja miksi?

2. Asettakaa kaverisi kanssa pyörälliset tuolit vastakkain ja istukaa niihin siten, etteivät jalkanne kosketa lattiaa. Ottakaa toistenne käsistä kiinni. Sopikaa kumpi ensin yrittää saada toisen liikkeelle vetämällä tai työntämällä. Saako toisen liikkeelle siten, että itse pysyy paikallaan? Vaihtakaa toinen henkilö raskaammaksi tai kevyemmäksi. Miten tilanne muuttuu? Samaa voi kokeilla myös rullalaudoilla tai vaikkapa rullaluistimilla ja talvella jäällä luistimilla.

3. Yritä hypätä eteenpäin paikallaan olevasta keinusta. Mitä tapahtuu ja miksi? Kokeile myös talvella hypätä paikalla olevasta pulkasta tai liukurista.

Figure 6.4 Part of the Models and practical work module.

newtonin voiman, sen sijaan hyppäävä hyönteinen kohdistaa lattiaan noin 0,001 newtonin voiman ja lattia siihen yhtäsuuren voiman.

Avaruusluotaimet

Aurinkokuntaamme tutkimaan lähetetyt avaruusluotaimet liikkuvat eteenpäin vakionopeudella ilman moottoria, koska avaruudessa ei ole liikettä hidastavia voimia.

Biljardi

Kun biljardinpelaaja lyö palloa kepillä, on oikea kosketus ratkaisevan tärkeä. Mitä enemmän käytetään voimaa pallon lyömiseen, sitä suuremman nopeuden pallo saa ja sitä pidemmälle se menee. Jos liikkuva pallo iskeytyy paikallaan olevaan palloon, törmäys saa toisen pallon liikkeelle. Usein on myös tärkeää saada pallojen törmäyksellä aikaan suunnan muutos.

Auto-onnettomuus

Törmäys maantiellä aiheuttaa aina tuhoa. Jos vastakkain ovat henkilöauto ja perävaunullinen rekka, kohdistuu molempiin yhtä suuri voima, mutta kevyempi henkilöauto rusentuu pahemmin.

Figure 6.5 An example of the physics around us items: space probe, billiards, and a car accident. Below, there is a print-the-page button.

Figure 6.6 Games and exercises.

Table 6.1 Descriptions of the module buttons.

Button	Description
	*Learning path*: Introduces goals, suggested practical work, and the main concepts of the topic. There are tips for discussion, and tips for scheduling.
	*Background story*: Space characters Nano (feminine) and Pico (masculine) appear in the dreams of a schoolchild. They compare their experiences in space with the schoolchild's experiences on Earth. The story can also be listened to on an audio file
	*Models and practical work*: First, there is a short theoretical summary of the situations and phenomena described in the background story. Below the summary, there are related practical work presented in the order suggested in the learning path. There are also animations from the situation under discussion to prompt discussion before or after practical work are completed.
	*Physics around us*: This item demonstrates phenomena that can be explained with concepts and principles learned from the topic
	*Additional information*: This is a hyperlink to *the network library for science education*. This contains subject knowledge and teaching methods material for teachers (this material is used in pre- and in-service teacher education) The support page is also in the network library.
	*Games and exercises*: Behind this hyperlink, the user can find models and practical work pages in printable PDF format.

The designed learning environment is not just web pages; it includes real life experiences as well. An important aspect of live experience is the classroom (as well as the corridor, the school library, the school yard, and so on). Typically, the room contains tables, chairs (office chairs are usually available in the computer lab), and office supplies. To reach concrete and illustrative properties of the learning environment (see Section 4.1), the learning environment includes a toolbox that contains simple and cheap research equipment for 16 pupils (half a class). During the design research process, the importance of easily-available investigation equipment became clear. A lack of equipment could be an excuse to neglect practical work. Figures 6.7 and 6.8 show the contents of the toolbox. It contains eight marbles, ten weights (100 g), elastic bands, clips (small and large), cocktail sticks, eight plywood boards for constructing Newton meter and inclined plane investigations, eight pieces of three sizes of wooden blocks, eight model cars, 16 skewers, two packets of plasticine, and eight corks. All other research equipment can be found in the typical classroom (e.g., many mobile phones feature a stopwatch), and no further special equipment is needed.

Figure 6.7 Overview of the equipment in the toolbox.

Figure 6.8 The toolbox has plenty of space to store more research materials when needed.

6.2 Analysis of the designed learning environment

The basic idea of design research is to recognise a problem (in teaching or learning), to set objectives to overcome the problem, and to design a solution to reach the objectives. The objectives were described at the end of the chapter on problem analysis. The main innovation to reach objectives was a background story module offering qualitative models to explain motion phenomena. The *Models and practical work*, *Physics around us*, and *Games and exercises* modules, despite some interactive features, are very similar to traditional textbooks. In the following sections, the modules of this learning environment are described in more detail, and related to the objectives.

6.2.1 Learning path

During the design, production, and evaluation of the learning environment, the need for guidance was seen as very important (Section 4.3). An overly open environment may mean that pupils or teachers have difficulty choosing the appropriate paper-and-pencil tasks and practical work. Therefore, learning paths were added to the learning environment. The learning paths integrate the learning environment and the Finnish National Framework Curriculum for Grades 5 – 6.

All six learning paths have a similar structure. Firstly, there is an overview of the topic: goals, practical work, equipment needed, content and core concepts. Secondly, there are detailed suggestions for the structure of the lesson. There are suggestions on how to use the background story, what would be some good examples of practical work and suggested articles . In addition, the learning path suggests relevant homework. The idea is to create versatility in learning.

A learning path is a solution with several purposes. In particular, learning paths offer expert support for teachers (Section 4.1). Primary school teachers have relatively little education in physics. Thus, a learning path offers one kind of lesson plan for teaching. Following a learning path, a teacher should be able to cope without a deep understanding of physics (Section 3.1). A teacher should use interactive teaching methods and ask about the personal experiences of their students, organise relevant practical work, focus on improving the knowledge of physics through the interpretation of physical phenomena in everyday life, and give relevant homework. Figure 6.9 shows an excerpt from the learning path of the topic *motion*. A learning path is one kind of template for teaching (a similar concept to templates in word processing software). Once competence grows, teachers can create their own templates.

6.2.2 Background story

The main innovation in the design research project is the background story. In the story, two space characters, Nano (feminine) and Pico (masculine), appear in the dreams of a school child (a girl called Sara). This ensures that females are in an active role in the educational narratives (cf. Evans, 1998). The space characters discuss physics with the girl, and they compare their pure Newtonian experiences in space with the experiences of the girl on Earth. During the discussion, the space characters introduce qualitative Newtonian models of force to describe and explain movement phenomena (Section 3.1). In the following excerpt from *Force changes motion*, Nano, Pico and Sara discuss a scooter:

> …
> "I have never used a scooter. How do I turn it on?" Pico asked.
> "You goof! You stand on it and one leg kicks the ground to build up speed," Sara answered, marvelling.
> "OK! When a foot touches the ground, a force appears, which causes the scooter to start moving." Pico cheered.
> "Yes, I think that one could say it that way," Sara said, and thought about Pico's words.
> Now it was Nano's turn to ask: "Sara, did you know that a moving object continues moving until a force stops it?"
> "That can't be true!" Sara said uncertainly. "My speed always slows down and I have to kick now and then."
> "It really is true," Pico replied.
> "When we were on our way here in our Astel spacecraft, we took a break and went out to see the Milky Way. I teased Nano and she pushed me and I fell out of the vehicle, because I had not put on my safety belt. I moved straight forward with a constant speed. I would probably still be moving

> like that if that meteoroid hadn't come along. The meteoroid moved in the opposite direction to me and we bumped into each other. The force of the thump changed the direction of my motion and again I moved straight forward with constant velocity. Fortunately, I moved towards Astel. I was in safe. …

As the excerpt shows, there is a positive atmosphere in the stories. These stories were planned to encourage pupils to engage in learning and to feel secure. Because the background story is available for listening through the Internet, it helps teachers integrate ICT into their teaching. There is a relevant reason to use ICT as required in the Section 3.3. In the story, a schoolgirl becomes aware of what she thinks about motion phenomena and space characters help her understand why she thinks that way (see Section 3.1).

Originally, the background story was intended to serve only student learning, but it also helps teachers' training. As stated earlier, Finnish primary school teachers have very limited knowledge of physics. The background story teaches the meaning of the basic models to both teachers and pupils at a qualitative level. The maturity of the teachers means that they understand the content much more easily. Thus, the teachers can then guide their pupils' learning processes.

Teachers tend to personalise the content they are teaching. They relate the topic to their own experiences and thereby create their own narratives. Because of the their lack of experience with physics, primary school teachers cannot add these personal narratives to their physics teaching. Therefore, the background story can substitute for the personal experiences and provide a narrative for physical phenomena.

TEACHING PATH – MOTION

Objectives

- To learn that there are two kinds of motion: constant and changing
- To be able to classify different kinds of motion
- To learn that velocity depends on displacement and time
- To be able to calculate average velocity

Practical work

- Different kinds of motion are studied
- Different kinds of motion are described and classified
- Time and displacement are measured and average velocity is calculated

Equipment

- Stop watch (e.g on a mobile phone)
- Measures

Content and main concepts

- In physics, motion can be classified as changing or constant. Changing motion could be accelerating or decelerating.
- Velocity depends on time and displacement. Units for velocity can be m/s as well as km/h.

Average velocity can be calculated as total displacement divided by time spent moving.

LEARNING PATH

Background story

- Stop the background story at this point: "your motion, in a while is constant and in a while accelerating; it is the same in physics, Pico said." Ask for opinions: in what kinds of situations is motion constant, accelerating or decelerating (e.g traffic jams, skiing, running)? After pupils have stated their views, continue listening to the background story.
- After the story, ask pupils how to determine velocity (speedometer in a car, radar, runner in athletics)
- Ask pupils where they can use measured velocity.

Practical work

- The model section before the practical work should be read together. This will help pupils to focus on the essentials. After reading, pupils should be asked if there were any unknown terms and how these terms were used in the background story.
- Watch the animations together.
- Practical work on motion should be conducted in pairs. Practical work 1. Pairs discuss ways to produce constant velocity. It is important to ask one group to explain their observations and conclusions and get the other groups to add to their presentation.

—

Physics around us

- Pupils could be asked to evaluate how far a human being could run in ten minutes, and is it possible? How far can a slug get in five minutes?

—

Exercises

- Suggestions for homework:
- a pupil chooses one practical work to report.
- Exercises 1, 4, 6, 7

Figure 6.9 Excerpt of the learning path of the topic "motion"

6.2.3 Models and practical work

In the initial prototype of the learning environment, *Models* and *Practical work* were in separate modules (Section 4.2). It seemed that pupils, when engaged in research activities, ignored the theory. In combining them into one module, *Models and practical work,* pupils could easily refer to theory while doing research. This might offer a more realistic view of the nature of science than it did in the prototype. A prescriptive guide to conducting research could lean towards "discovery learning". Integrating *Models* and *Practical work* shows that scientific research is carefully planned. The researcher knows what to expect as well as how to start to explain results. In a similar way, a pupil may acquire knowledge about the phenomenon and, perhaps, be motivated to better understand motion (Section 3.1).

The theory section offers another version of a qualitative Newtonian model. It is expressed differently to the first one in order to avoid creating mantras that pupils repeat, but do not understand. Several different explanations of the same thing may help pupils to connect the model and phenomenon in multiple contexts. When introducing qualitative models, the *Background story* as well as *Models and practical work* propose external conflicts for pupils to discuss in small groups (cf. Bennet & al., 2004).

According to the Finnish National Framework Curriculum, experiments have a significant role in the teaching of physics. Every topic contains several practical work and the learning path suggests the basic ones. Practical work could be conducted with simple equipment. The pilot test showed pupils' enthusiasm for this kind of work. They had quite a lot of autonomy in the classroom and conducted the practical work on tables, on the floor, in the corridor, or even in the school yard. However, the teacher was available when needed, and the teacher walked around, asking questions about how the pupils were progressing.

Models and practical work also includes a guide for pupils to research as well as a web-based form to report research results via e-mail. This is another example of how a teacher could integrate computers into education. Despite a low number of computers available for the whole class, pupils could use computers after the lesson to return their reports.

The limit test (Section 4.2) pointed out the need for representations and pictures . There are eight animations showing the phenomena in an idealised way and eleven series of static pictures. Altogether there are 98 pictures (not including the buttons). Many of the pictures and animations describe how Nano or Pico experience the phenomenon under discussion. Therefore, the pictures illustrate physical laws and principles in a concrete and contextual way, integrating physics into personal experience. In addition, it appeared that the texts were too long in order to be read on a computer display.

The pilot test (Section 4.3) showed problems that students had with making connections between physical knowledge and the physical phenomena around us. Therefore, items in the *Physics around us* module introduced in the learning path were integrated into *Modes and practical work*. However, they still have their own module. The teacher may print the *Models and practical work* module pages for pupils. If the *Physics around us* module were separated, pupils may not even see these. Perhaps this integration helps pupils to recognise similarities between the friction caused by a shoe on the floor and air resistance in a parachute.

In the end of the *Models and practical work* module, there are exercises intended for homework. Examples of exercises from the topic *Mass and inertia* suggested in the learning path are shown below.

> 3. What is the gravity, in Newtons, of a 1-kilogram weight?
> 5. How does catching a baseball differ from catching a tennis ball?
> 6. A bus turns into a crossroads at a very high velocity. What do the passengers experience as a result?
> 9. What does the inertia of a body mean?

As these examples show, the exercises are not too trivial, cover a variety of subjects, and help pupils learn to explain common experiences with qualitative models. In addition, teachers need a learning environment that encourages pupils to work (Chapter 4.1). Exercises serve that need. Of course, sample answers for practical exercises are available in the teachers' training material.

6.2.4 Physics around us

Physics around us is an independent module, emphasising the importance of being aware that principles learned in the classroom are also valid outside of school. *Physics around us* introduces physical phenomena in a number of varied contexts (cf. Section 3.3.3). Perhaps there is at least one interesting item for every pupil in each topic. The hypothesis here is that when a pupil finds something interesting, it will be studied more keenly in the future, in order to better understand what is considered interesting. At the very least, the module introduces concrete examples in the context of physics, as teachers need (Section 4.1).

6.2.5 Additional information

The button *Additional information* is a hyperlink for teachers' training material. There is also a hyperlink for teaching method articles. In particular, practical work and interactive learning are relevant at the primary school level. There is also teacher material for Newtonian mechanics. Teachers need expert support (Section 4.1). These materials offer that support, as well as a support page with ask-an-expert web form, photos of the toolbox, and a list of frequently asked questions with their answers will be shown on the page. This *teachers' material* enables a teacher to be one step ahead of the pupils in subject knowledge. Peer support is a challenge. How will teachers find the page, and how can they form a community to share experiences? Currently, teacher support is organised during traditional in-service training (for example, for teachers who participated in the field test).

6.2.6 Games and exercises

Games are one kind of extra exercise (or a reward) for the pupils, and an easy way to adopt computers in education. Regardless of connotations of extrinsic motivation, games may well increase the positive atmosphere in a physics learning environment. Games ask questions and this might facilitate pupils to find out answers. At the very least, games help pupils to review what they have studied.

There are questions for every topic. For example, in the first game, *Formula one*, the players have to answer a question correctly to receive some petrol. Wrong answers decrease the amount of petrol. Thus, mouse-button clicking for game play was limited (Section 4.2) After a few laps, the player has to visit the pit stop and answer further questions to acquire more petrol. Other games have similar principles: correct yes or no answers win or lose points. There are four games. The first, second, and fourth ask questions which are either right or wrong, and the third is a classic hangman-style game.

There is one very practical argument for simple games. Class size could be over thirty and there could be special-needs pupils in the class. The teachers needed something relevant for pupils to do (Section 4.1). Playing games may prevent these pupils from disturbing others.

In the *Games and exercises* module, the content of *Models and practical work* is available in an easy-to-print PDF format.

6.2.7 Gender equality in the design solution

Section 3.4 explicated several objectives for gender fairness. The basic gender-fair characteristics of this learning environment are male and female characters in the background story, and co-operative learning methods for both boys and girls, offering an equal opportunity to interact with other pupils and the teacher. The gender-equality of the learning environment is very difficult to measure. Therefore, policymakers tend to use the term segregation, which is easily measured. Here, a simple content analysis of the learning environment is presented in order to evaluate how well gender-related objectives have been met in terms of desegregation.

To be sure of the equal participation of female and male characters, all pictures and text were analysed. Each figure was checked for whether feminine or masculine characters were present, and who was the active character, where "active" meant that a character does something. For example, Figure 6.1 illustrates a situation in which both characters are active participants. Nano and Pico conduct a pushing experiment in space. In Figure 6.5, Nano and Pico play billiards, and the female character of Nano is active. Table 6.2 shows the total number of pictures in each topic, as well as the participation of female and male characters in all pictures in the learning environment. Table 6.3 shows the number of pictures in the basic contents suggested by the learning path.

Table 6.2 Total number of pictures in the topics.

Topic	Total number	Female present	Male present	Female active	Male active	Both active
Force changes motion	22	10	8	8	4	2
Motion	12	2	4	0	3	1
Force constraining motion	19	5	6	2	5	1
Gravity and balance	35	10	16	2	11	5
Mass and inertia	9	2	6	0	4	2
Total	97	29	40	12	27	11

Note. The home page is not included in any topic

Table 6.3 Number of pictures in the topics following the learning path

Topic	Total number	Female present	Male present	Female active	Male active	Both active
Force changes motion	14	9	5	7	2	2
Motion	11	2	4	0	3	1
Force constraining motion	10	3	4	1	3	1
Gravity and balance	15	5	8	1	6	2
Mass and inertia	5	2	5	0	3	2
Total	59	22	27	9	17	9

Frequencies in Tables 6.2 and 6.3 show that a male character is present more often than a female. This is true for all the material, and for the basic information suggested in the learning path. Examining the topics, the female is present more often only in *Force changes motion*. At the beginning of the project, the gender issue goals were clearly in the minds of the designers. It is possible that during the design research process, the designers forgot to check that female and male characters are present in equal numbers in all the pictures, and that they are equally active.

However, the situation is not so simple. The first topic includes perhaps the most important content concerning the main principles of Newtonian mechanics. It would be useful to check the pictures there for the presence and activity of female and male characters.

Pictures have been inductively classified into four categories: 1) practical work settings, 2) theory illustration, 3) situational illustration, and 4) decoration. Pictures of practical work settings show the equipment needed and procedures to conduct the practical work. Theory illustrations clarify physical theories, models or principles. For example, in Figure 6.4, the text describes the principle of force and action. Above it, Nano pushes a screen and force arrows can be seen. A situational illustration clarifies the context and the situation in the text. Decorative figures have only a loose relation to the text, without any explicit reference. Tables 6.4 and 6.5 show how female and male characters are present in the pictures. A similar result is apparent: female characters appear more often than male characters only in the illustration of theory.

Table 6.4 Total number of the pictures in a picture category

Category	Total number	Female present	Male present	Female active	Male active	Both active
Practical work settings	25	3	5	2	4	1
Theory illustration	25	9	7	5	4	3
Situational illustration	13	6	11	1	8	3
Decoration	35	12	18	4	11	5
Total	98	30	41	12	27	12

Table 6.5 Number of pictures in a picture category following the learning path

Category	Total number	Female present	Male present	Female active	Male active	Both active
Practical work settings	14	2	3	1	2	1
Theory illustration	12	5	2	4	1	1
Situational illustration	10	5	8	1	6	2
Decoration	23	10	14	3	8	5
Total	59	22	27	9	17	9

The criticisms toward gender-unfair instruction materials mentioned in Section 3.4 focused on the relationship between pictures and narrative texts, and especially the active participation of females and males in those story texts. In order to evaluate gender fairness, texts in the learning environment need to be analysed.

The modules *Background stories*, *Models and practical work* and *Physics around us* were used for text analysis, using analysis categories based on the objectives set in Section 3.4. Analysis looked for the following:

- A feminine character is present
- A masculine character is present
- A feminine character is active
- A masculine character is active
- Gender-biased language
- Stereotypical gender role
- Non-typical gender role

Analysis was conducted using a paragraph as a standard analysis unit. Altogether, there were 140 analysis units. Not every unit contains a gender perspective. Following the radical feminist critique, that science as such is male-biased, and therefore, every text unit should be classified by the same sort of bias-code. In this case, the analysis used a more liberal ideal that focuses on participation of woman and men in science. Overrepresentation of men in science creates the view of science as male-powered. (Keller, 1987)

According to the content analysis, there were 50 units containing a gender perspective. A female character appeared in 35 units and a male character in 42 units. Female characters were active in 26 units, and male characters in 16 units. Table 6.6 shows the appearance and activity of female and male characters in the topics of the learning environment. Table 6.7 shows female and male participation in basic topics. Even the implicit appearance of female and male characters has been recognised. Appearance is implicit when the narrative is gender-neutral, but it refers to pictures with an obviously female or male character. The total number of implicit references to female characters appeared in 32 units and to the male in 35 units. The explicit presence of female and male characters was quite equal.

Table 6.6 Appearance and activity of female and male characters in the topics.

Topic	Female present	Male present	Female active	Male active
Force changes motion	4	10	6	4
Motion	4	6	4	2
Force constraining motion	7	7	6	2
Gravity and balance	11	13	5	6
Mass and inertia	7	6	5	2
Total	35	42	26	16

Table 6.7 Appearance and activity of female and male characters in the basic topics suggested in the learning path

Topic	Female present	Male present	Female active	Male active
Force changes motion	5	7	5	4
Motion	4	6	4	2
Force constraining motion	6	6	5	2
Gravity and balance	6	8	3	3
Mass and inertia	5	5	5	2
Total	26	32	22	13

One of Zittleman and Sadker's (2002) main criticisms towards science textbooks was a cosmetic bias where women are decoration in pictures, but invisible in narratives. The analysis shows that regardless of the more frequent appearance of male characters (Pico and some others), than female characters (Nano and Sara), the female characters were more active.

Another critique towards textbooks was reinforcement of traditional occupations and gender roles. The narrative in 11 units implies a stereotypical gender role, and nine units imply a non-typical gender role. Analysis of the units implying stereotypical or non-typical gender roles were only in background stories. In the background stories, characters demonstrate plenty of stereotypes to point out that they are not accurate. For example, at the beginning of the story, Sara claims that she does not understand levers, wheels, and other “boys’ things”. However, several times during the story, she praises how much fun it is to study physics. In the second story, Pico wonders how a girl could know the term “average velocity”. Sara responds indignantly: “I am not so dull, even I could catch something!” In addition, there are occasional sentences offering a model of a self-confident physics learner. Sara was happy. In the third story, she says: “Great! You are superb, now I know a lot about friction”.

According to my analysis, it seems that the most problematic gender-role situations were mention about Nano’s body as a thin model-like body and Pico’s muscles. There is a risk in that despite their humorous tone, such comments could reinforce the view that a girl should be very thin, and a boy should be athletic However, female participation is not a curiosity or amusing anecdote, only natural.

As previous shown: categorisation and gender-fairness are highly dependent on the way things are interpreted. However, it is reasonable to say that the learning environment meets the criteria of gender-fair instruction material to a satisfactory level. It shows girls and women as active participants in the same way as boys and men. In addition, it offered a role model for girls to have the equal right to understand situations and demand explanations.

6.2.8 Physics in different contexts

Research literature shows interdependence between the context where physical concepts are met and pupils’ interest in studying physics (Häussler & Hoffman, 2002). There is also an interdependence between context and and student achievement in physics (McCollouhg, 2004). The structure of the learning environment modules implies that during the design process, contexts have been taken into consideration. The design team participated in a large survey considering student interest to study physics in different contexts (Juuti, Lavonen, Uitto, Byman, & Meisalo, 2004). Therefore, the idea of presenting the same physics concepts in several contexts was at least implicit.

A simple content analysis can evaluate how well the learning environment shows physics in different contexts. To clarify contexts, the pictures and text were analysed. The categories come from Juuti, Lavonen, Uitto, Byman, & Meisalo, (2004) (cf. Section 3.3.3). The analysis can be called deductive content analysis (Kyngäs & Vanhanen, 1999)

In the content analysis of contexts, an analysis unit is a theme. A theme can be one sentence or one paragraph. The criterion is that the text constructs a context. Again, learning paths were left out of the analysis. Furthermore, not every analysis unit presents physical concepts or principles, such as story blocks which only build the narrative. To look more closely at the context of pictures, the same classification was used. Tables 6.8 and 6.9 show frequencies of the contexts.

Table 6.8 Frequency of contexts

Context	Learning path	Additional
Ideal: Space, cosmology	6	7
Ideal: Units, constants	-	6
Ideal: Models, laws	28	22
STS: security	7	6
STS: home and environment	13	5
Equipment: principle	10	5
Equipment: as example	17	12
Human: Human process	6	3
Human: Experience, act	27	24
Human: History	-	1
Practical work: laboratory equipment	2	2
Practical work: Home-made equipment	8	13
Practical work: Kinesthetic	7	7
Technology design and construction	3	9
Comment	14	6

Table 6.9 Frequency of context in pictures

Context	Learning path	Additional
Ideal: Space, cosmology	1	2
Ideal: Units, constants	-	-
Ideal: Models, laws	-	2
STS: security	1	2
STS: home and environment	1	1
Equipment: principle	1	-
Equipment: as example	9	7
Human: Human process	2	1
Human: Experiences, act	30	14
Human: History	-	1
Practical work: laboratory equipment	1	1
Practical work: Home-made equipment	8	7
Practical work: Kinesthetic	3	1
Technology design and construction	1	-
Comment	1	-

During content analysis, it seemed appropriate to classify context in more detail, as shown in Tables 6.8 and 6.9. They show that by following the learning path, the most frequent contexts in the texts are the ideal context, the human being context, and the technical application context. In the pictures, the most frequent context is human being (performing an action or experiencing something). The absolute number of contexts is not so important, but it is interesting to compare the relative number of contexts, and compare them with each other. The ideal, technical application, and human being contexts appear at about the same frequency. In pictures, the human being context appears about three times as often as the technical application.

According to frequency of context, the learning environment emphasises the human being context. Therefore, the learning environment answers to the critique concerning context where physics is encountered (cf. Juuti, Lavonen, Uitto, Byman, & Meisalo., 2004). Especially pictures show physics and human beings in close relation. It seems that physics is really something to be experienced.

6.2.9 Combination of virtual and real aspects

The design solution helps teachers to integrate ICT into their teaching. There is no tradition in Finland in the teaching of physics in primary school. A new subject and new materials together create a teaching tradition right now. Therefore, the integration of computers into the learning environment makes computers a natural element of physics teaching.

To reach a clear structure, the topic view of the learning environment follows a simple version of the conventional frame structure (see Section 3.5). The topic view contains links only on the left and item buttons on the bottom, except for the copyright hyperlink. The first five topics contain six item buttons briefly described in Table 6.1. Items open in the front of the topic view, so the topic view is a beginning point for studies. Teachers have emphasised the usability (Section 4.1). Pilot testing, concentrating on usability, showed that the learning environment is satifactorily usable. It is also possible to use the design solution as an encyclopaedia. The glossary and the index lead to the appropriate topic.

An important aspect of usability is the possibility for redesign. The way teachers teach vary, and facilities available in different schools are not identical. Therefore, it is important that the design solution is flexible. A teacher creates the learning environment and a novice needs more support than a more experienced colleague. A teaching path is just one suggestion.

Teachers worry about the lack of equipment for science education. Practical work have been designed in such a way that they can be completed using very simple and inexpensive tools, as shown in Figures 6.7 and 6.8.

7 FINAL DISCUSSION

The original research questions of the design research project were related 1) to analysing the project leading to the design solution, 2) to describing the properties of the designed learning environment, and 3) to evaluating student learning concerning Newtonian mechanics.

The present thesis reported on one design research project in order to better understand primary-level physics teaching. The thesis also introduced the idea that the learning environment could be adapted to improve the quality of teaching in physics.

The research demonstrated that qualitative-level models using stories with lively characters and detailed research offer good potential for physics learning and, in a more general way, might improve the results of primary-level physics teaching. In addition, design research showed the importance of user attention, testing in real contexts, and continuous re-design while designing. The research also indicated the properties of primary school physics learning environment.

In this chapter, I will discuss the research according to the theoretical outcomes of the principles of design research: Domain theory (Section 7.1), design methodology (Section 7.2) and design framework (Section 7.3). In addition, Section 7.4 analyses the reliability of the design research and, finally, Section 7.5 states the same implications for the future.

7.1 Domain theory

According to the distinction made by Edelson (2002), design research provides two kinds of *domain theory*: 1) *contextual theory,* as described in the section 7.1.1, and 2) general, *outcomes theory*, extending the problem analysis (Section 7.1.2).

7.1.1 Contextual knowledge

Context theory characterises the challenges and opportunities of the design context. The present research project is very closely related to the renewal of the Finnish National Framework Curriculum. The learning environment has been designed in accordance to the framework curriculum process. Therefore, this research offers the chance to evaluate the curriculum as well. The Finnish National Framework Curriculum (FRAME, 2004) does not prescribe in very much detail to what extent movement and force should be taught in physics classes. However, the evaluation criteria seem quite ambitious. According to the framework curriculum, "a pupil

- "know how to investigate forces, such as gravity, friction, and air and water resistance, and how to recognize different types of motion
- "know how to investigate how force changes the motion of an object, and how to apply scientific knowledge in traffic or moving about
- "know how to describe danger situations in traffic and other everyday environment"

(FRAME, 2004, p. 187).

To investigate force, pupils have to be able to recognise physical forces, and it is not an easy task, as this research showed (Section 4.4). Let us consider gravity as an example. Is it enough that pupils are aware that objects fall because of gravity, and that objects fall with constant acceleration, or do they have to explain why objects fall with constant acceleration? This research suggests that it should be enough if pupils are aware that there is interaction between the Earth and falling objects, and pupils have experienced first-hand and learned the fact that every object (in the correct set of circumstances) falls with the same acceleration. Another reasonable objective could be for pupils to understand that in Newtonian mechanics, constant velocity is the basic state of the object, change of velocity (change of motion) is the phenomenon requiring explanation, and forces (friction, collision, gravitation, air resistance, etc.) cause it. However, Newton's laws in their qualitative form, as described in Section 3.1 are still very ambitious goals at primary level.

During the empirical problem analysis (Section 4.2), it appeared that pupils have difficulties with transitions from one activity to another. Von Aufschnaiter and von Aufschnaiter (2003) posited that a time span of less than 30 seconds is best. If pupils cannot combine two facts or pieces of information in that amount of time, they are less likely to understand how they relate to each other. However, a teacher might also explain content too quickly, or a teacher could integrate too many aspects within too short a time. Another time span emphasised by von Aufschnaiter and von Aufschnaiter (2003) is five minutes. If pupils cannot solve a given subtask in five minutes or divide them into subtasks solvable in such time, they will drop the task. This may explain difficulties in starting practical work. If pupils do not have a clear idea of their research objectives, increasing the amount of information in their instructions may not be a solution, because more information requires a longer time to understand it. More time for teacher-directed co-operative discussions before the practical work could be a viable solution. In such a situation, there is enough time to integrate purpose with qualitative models, and divide practical work into subtasks of five minutes or less.

7.1.2 Outcome theory

Problem analysis started with a description of the pupils' understanding and conceptualisation of change of motion. The main idea was that during learning, pupils formulate models about the phenomena to be learned. They obviously need simple theoretical models to describe and explain phenomena. If they understand the relationship between their experiences and the given model, they might formulate far less compromise models.

In this design research project, the models were cause–consequence models presented verbally. Vosniadou, Ioannides, Dimitrakopoulou, and Papademetriou (2001) used cardboard vectors to represent force and yellow stickers to represent energy. It is important to recognise the meaning of the representative model: is the representation an explanation of the phenomenon or is it the phenomenon itself? It could be argued that young children have difficulty in differentiating between a phenomenon and a model. If teaching concentrates too much on representations, there is a risk that pupils learn the model, and not the phenomenon. In Finland, quantitative-level explanations (mathematical models) have been traditionally blamed for that (cf. Kurki-Suonio & Kurki-Suonio, 1994).

Pupils evaluated the designed learning environment very positively. Modules and topics of the learning environment were thought to be important, easy, pleasant, interesting, and learning supportive. Research literature indicates several possible reasons why pupils evaluated the learning environment so positively. The environment seemed to promote their interest. During the practical work, pupils had the freedom to determine the progress of their own learning, background stories provide vivid situations with space characters in a familiar context, and the stories also provide relevant information before the *Models and practical work* texts are introduced (cf. Schraw & al., 2001). In addition, the learning environment included most of the interest-promoting aspects that Hoffman (2002) and Häussler & Hoffman (2002) described. In the background story, space characters helped pupils to marvel at movement and its explanations, and connect movement and force to their prior experience, science in society, technical applications, and the human body. Direct connections to physical knowledge were made in the *physics around us* modules, then measuring velocity gave a hint of the quantitative level of physics.

School students are not equally interested or uninterested in physics. Girls tend to be more sensitive to contextual change. For girls, find it most interesting to learn about physical phenomena in the human being context, in which a human produces or experiences physical phenomena, or they are related to human physiological processes. For boys, the most interesting context is technical applications. In that context, application functions are studied or seen in practical examples. However, the technical application context is less interesting to girls (Juuti, Lavonen, Uitto, Byman, & Meisalo, 2004). Content analysis of contexts (Section 6.2.8) showed that the human being and technical application contexts were both taken into consideration. This then demonstrates one gender-equal aspect of the designed learning environment. Juuti, Lavonen, Uitto, Byman, and Meisalo. (2004) emphasise that gender-equal learning environments provide physical phenomena in versatile contexts.

Another viewpoint could be the *self-determination theory*. Pupils evaluated learning as quite easy; in other words, they felt a sense of *competence*. Pupils had plenty of time to decide amongst themselves how to share tasks during learning. Especially during the investigations, pupils had the chance to practise *autonomy*. The background story and small group work under the guidance of a teacher constituted a learning community serving the basic need of *relatedness* (Ryan & Deci, 2004).

The pilot and field tests suggested good potential for the use of background stories in physics teaching. On the one hand, pupils learned Newtonian mechanics, and on the other, they seemed to recognise the importance of the background stories for motivating the investigation work. This has been previously recognised as a problem in education (Hodson, 1996). The most undesirable situation is that pupils only perform hands-on practical work. Their classroom investigations might be fun and perhaps their skills in this area increase, but their conceptual understanding might not benefit. When pupils are aware of the objectives, practical work might better engage student minds as well. Then it is possible to reach Hodson's (1996) three goals of investigations.

This research was not focused on narrative, but ensuring the successful teaching and learning of Newtonian physics. However, narratives using background stories appeared to show novel, non-traditional, features which benefit the learning of physics.

In science education, stories and narratives have been used to teach the nature of science. These stories typically tell something about the lives of great physicists, or are anecdotes to offer pleasant asides in learning (i.e. Solomon, 1999). Narratives or stories in science education do not typically include how ordinary people experience and understand phenomena. This research reported one initiative in helping pupils to connect their experiences outside school with those inside school. Characters in stories should be credible enough so that pupils can better relate to the characters' Newtonian world. If writers have to consider every possible stereotype, the result would be more like a committee report than a story with an interesting plot and characters.

This research showed three possible roles for stories: 1) stories help teachers introduce concepts to be taught according to curriculum; 2) stories offer pupils explanatory models with which they can conceptualise physical phenomena; 3) stories mediate personal experience to help pupils interpret their own experiences.

Finnish primary school teachers have very limited physics knowledge and very limited experience in physics teaching. Characters in a background story introduce the basic concepts to be learned. Listening to the background story, a teacher has time to become familiar with basic concepts. Then the teacher can continue teaching via the learning path.

The background story introduces a physical phenomenon to pupils and offers explanatory models at the qualitative level to explain phenomena. Background stories reflect the typical pupil's conceptualisations – compromise models – and describe why pupils may think that way. The story then provides a qualitative explanation model for the phenomenon. After the story, a qualitative model provides a guide by which to approach practical work. Even students notice how the background story helps (Section 4.3). Perhaps the background story promotes a pupil's intention for conceptual change. The background story starts the discussion about the meaning of physical concepts intended to understand and explain better movement phenomena. Then it might be easier to continue this discussion in small groups when conducting classroom research. In addition, the results indicated that the pupils who listened to the background story learned the concepts of Newtonian mechanics better compared to the pupils who did not. There were no gender differences to this result (Section 4.4).

7.2 Design methodologies

This research project provided a simple model for the design process. The model, described in Figure 5.2, tries not to cover the whole design process, but two essential aspects of it. Firstly, a design process, through a cycle of design, production, and testing, is iterative. Secondly, the model emphasises listening to the intended user. Other aspects of the design process have been described in the Chapter 5. In spite of this description, much of the design effort remain tacit. Many decisions are based on intuition and they might or might not work.

This was a non-profit design research project, few of the designers received a salary for their design work, and no one really owned the project as a whole. The project was conducted through a network which began with three partners (the University of Helsinki, the City of Helsinki, and the Finnish Technology Industry Association) with shared goals. One important feature of the process was consensus in the intended communication between partners. Lavonen and Meisalo (2002) used a similar process in their *Seven-stage research-based process for designing sponsored learning materials.* Consensus offered successful ways to cooperate with industry, teachers, educational administration, and so on.

Consensus required that designers subject their preconceptions of high-quality instruction materials and experiences as science teacher educators to a reflective discussion. It was necessary to clearly state the reasons for every design decision.

The project showed that tests conducted in the very beginning of the project offer great possibilities for re-design of the original solution. Testing was limited to only four hours, plus some preliminary work in the classroom. In this research, the main data gathering method was classroom observation from the point of view of the intended teaching–learning process and an inductive classification of actions. Fortunately, there was a reasonable time for an inductive data analysis. If there had been only a very limited time to analyse test data, one possible approach could have been reflective discussion after testing that is based on instant impressions and use of the learning environment. This method was also used in this research. Teachers tend to be reluctant to adopt and evaluate learning environments and educational innovations (e.g. Rogers, 1996). In the field test phase, in-service training was used as the method of approach: teaching and learning in the designed learning environment.

The proposal here is that using the described design model should help designers to ensure that user opinions are taken into consideration. This approach forces designers to consider the most crucial factors of the implementation of the educational innovation: characteristics of the innovation, local characteristics, and external factors (Fullan, 1991).

Evaluating the benefits of the design model (Chapter 5), it may be the most suitable for prototype design or for non-commercial instructional design. Another benefit of the model is that anyone who starts an educational design project – for example, a mentor – could, in one snapshot, perceive the main ideas of the design process. The opposite (complicated) example is the 3-space design strategy (Moonen, 2002). However, the 3-space design strategy emphasises the role of the end user. Lowyck (2002) emphasised that the interplay between teachers and designers is crucial in pedagogical design. The first phase in developing a teachers and designers' working community is to engage teachers in in-service training and launch a participatory project to further design the learning environment.

7.3 Design frameworks

During the research project, teachers and student teachers were asked to write essays and do an interview. Teachers participated voluntarily in an in-service training course. Pupils were observed and videotaped while learning, as well as interviewed about their opinions on the learning environment. The conceptual understanding of the students was measured before and after their learning experience. This section, *Design framework*, discusses the research results from the point of view of the properties of the learning environment.

The results demonstrated the properties of a successful learning environment for physics education. As a summary, these properties are: 1) contains concrete illustrations, including examples for the classroom; 2) activates pupils cognitively and inspires their practical work; 3) contains physically and pedagogically meaningful contents; 4) has a clear structure and user interface and 5) supported by peer and experts. Chapter 6, *Design solution*, described the approach to realise these properties.

It is clear that teachers require a concrete and illustrative learning environment. A primary school teacher instructs in (almost) every subject, so does not want (or does not have enough time) to produce much learning material. Teachers mainly use textbooks while teaching. *Illustrative* means that the contents help teachers visualise abstract concepts so that primary school pupils are able to understand these concepts. The contents should be contextual and from the children's world. Stories and narratives could be one solution to introduce abstract scientific concepts or complicated natural phenomena. *Concreteness* relates to activating pupils in their practical work at a qualitative level. Primary school teachers demand that the most important thing for their students is that they personally experience the phenomena. Illustrative elements may be figures, videos, animations, photos, and so on. However, such illustrations may cause oversimplification. And concretising abstractions is no easy task. For example, Figure 6.4 uses a force arrow model to illustrate force and action. In fact, in the arrows are in a wrong place in the figure. They should be in the figure on the left, where Nano touches the screen. In the figure on the right, there are no forces between Nano and screen. There are a few similarly incorrect figures in the learning environment. To design concrete and illustrative learning material requires knowledge, not just of physics, but how people learn about physics. It is crucial to know how pupils perceive phenomena – pupils' initial schemas – and how to avoid a representation that reinforces compromise models.

The learning environment should inspire pupils to learn. It should support teachers in such a way that they feel their pupils have something meaningful to do all the time. Pupils could think about the essential aspects of the phenomenon being studied, perform practical work, or complete written exercises, and so on. This suggests how important task versatility is in the learning environment. When a few pupils have finished the practical work, their teacher could guide them to written tasks and the remainder of the class could continue with practical work before a joint closing discussion.

Despite the fact that texts are much shorter than those used in the initial versions of the learning environment, there seems to be a need to still do something more with them. When pupils read about models, their interest seems to vanish. An audio presentation presenting models could be one solution. Read aloud, model items might be more appealing and aid concentration.

It is clear that teachers demand meaningful contents in learning environments. These contents should be both scientifically and pedagogically meaningful. To put it bluntly, primary school teachers need more meaningful subject knowledge and subject teachers need more pedagogical arguments. In this research project, pedagogically meaningful content was a design based on qualitative models to explain Newtonian mechanics as described in Section 3.1. Further, the designed learning environment followed the guidelines of the Finnish National Framework Curriculum.

This thesis reported on a design research project to design and develop a learning environment for teaching and learning Newtonian mechanics in primary school. The principles shown here were used in the design of learning environments for teaching electricity and electronics, heat and energy, and chemistry.

Learning environments must have a clear structure. The specific content topic should be easy to find. When the structure is clear, pupils can use the material themselves. The teacher simply asks pupils to go to the computer lab and became familiar with some topic, such as friction. Pupils could easily find material on friction and the related tasks. In general, design of the user interface follows knowledge about human perception and physiology. In addition, tradition is a very important element for users to feel comfortable using an interface (Nielsen, 1993). A classic example is the difference between the order of the numerical buttons on a calculator and a telephone.

Teachers' needs assessment (Section 4.1) showed that primary school teachers who instruct in the physical sciences sometimes feel very isolated. The teacher may be the only one in the school who thinks that chemistry and physics are important. There is no one with whom to discuss issues or plan. Therefore, it is important that the learning environment includes access to a community where there are experts who answer problems regarding subject knowledge and pedagogy, and peers who struggle with similar problems.

A teacher network in connection with an expert could improve the quality of teaching. They could collaboratively develop several learning paths for different classrooms and different teachers. Thus, through the support, it is possible to show several ways to teach physics at the primary level.

One problem for teachers was to divide the classroom into two groups: one in the classroom, and another in the computer lab. Pupils seemed to need more detail guided when required to work independently. Perhaps it is not useful to write detailed instructions, but instead guide the teacher to manage classes. Even if an experienced teacher knows how to manage a class in different situations, an inexperienced teacher or teacher who is not confident in physics education needs tips to start.

At the very least, background stories and co-operative learning methods need a good argument to back up their use if they are to be introduced effectively into the Finnish classroom. Listing the tasks that must be done in the classroom it is not enough for Finnish teachers.

The education of Finnish schoolteachers emphasises *pedagogical thinking*. Pedagogical thinking means that the teacher is aware of her or his own decisions in the classroom. In addition, teachers based teaching not only on tradition, but on research-based knowledge as well (Kansanen, Tirri, Meri, Krokfors, Husu, and Jyrhämä, 2000). Finnish teachers need robust arguments for every task required in the classroom.

7.4 Reliability

This research mixed qualitative and quantitative research methods. This mixed-method approach is natural for design research. Mixing methods offers several benefits for reliability. According Greene (2001), mixing qualitative and quantitative methods provides several benefits:

- Triangulation (coherence of results),
- Complementary (overlapping and distinct facets of the phenomena),
- Development (previous method helps to develop next),
- Expansion (extend breadth and range of the inquiry),
- Initiation (provoke fresh insights, new concepts, and imaginative interpretations).

Greene stated that mixing qualitative and quantitative methods provides *different ways of knowing*. In this research, this appears as the focus on research questions. A research question (or objective of testing) determines the method. For example, in the field test, statistical methods were used to evaluate pupils' learning.

Design research is not methodologically orthodox; it does not take a strict methodological stance. Design research treats methodical choices from a pragmatic point of view: whatever works is used. In this research, the methodology is mainly qualitative. Furthermore, the whole design research project can be considered a qualitative project. Therefore, in this design research project, it appeared to be useful to evaluate the research using the criteria introduced by Lincoln and Guba (1985). They use the term *trustworthiness* to evaluate the quality of the research. Research can be considered trustworthy if it achieves *credibility, transferability, dependability and confirmability*. (Lincoln & Guba, 1985; Eisenhart & Howe, 1992)

The main principle of trustworthiness is that the research design and methods provide the information that is relevant to the design of a learning environment. The researcher was a member of the design group, thus had opportunity to engage in *persistent observation,* a method to improve the possibility of finding answers to the research problems (Lincoln & Guba, 1985). There is a danger of making superficial conclusions. However, engaging in a long design process (from November 2001 to autumn 2003), I had the opportunity to become familiar with phenomena concerning the design processes. Thus, a long-lasting membership in the project ensures credibility.

The challenge then is to provide a critical and detailed description of the design processes and evidence (problem analysis results, usability testing results etc.) that led to the design. There is a question to answer: can the results of this particular research be transferred to another context? According Lincoln and Guba (1985), a researcher is the best expert of the context described and he or she must describe it in detail so that a researcher from another design context could follow the arguments and decide on the meaning of it in his or her own design research project. This thesis describes the project, and the design solution can be seen in the Internet (www.tvopas.com/astel). Thus, a reader is able to evaluate how well the research results fit in her or his context.

There are still two ways to demonstrate trustworthiness. Lincoln and Guba (1985) use the term *audit* as an analogy from business companies. This research project can be seen to be open and yield a detailed description of the problem analysis – design – evaluation – re-design – evaluation process to design a learning environment for primary school physics teaching. The designers' tacit knowledge became visible through this design research process.

The empirical problem analysis contains a reasonable number of original quotations. However, there are no high abstractions of the data, just description and categorisation. Thereby, a reader is able to follow the argument from the explicit research results to the design solution implicit in the results. Thus, the research processes can be seen to meet the *dependability* and *confirmability* criteria.

Chapter 2 summarises reliability criteria for design research. The main reliability criteria are *novelty* and *usefulness*. The design solution is a novel approach to teach mechanics at primary school level. It follows research conclusions and the Finnish National Framework Curriculum (FRAME, 2004), in particular the integration of narratives (background story), qualitative-level models to explain movement phenomena, and practical work to provide the novelty criterion. This project provided three kinds of benefits: 1) knowledge about the way pupils learn mechanics; 2) design principles for a successful design solution, and 3) a design solution for primary level physics. The design solution has particularly good potentials to be very useful to primary school teachers in their efforts to start physics teaching. One argument supporting its further use is that teacher educators in another university (University of Joensuu) have adopted the designed learning material for in-service training. The academic year 2004 – 2005 is the second year they will be using this learning environment.

Another criteria for the reliability of design research is that it must be *convincing*. Design research, typically, has many parties participating. The researcher must convince all those in the design team and the readers of the research report of the accuracy of the research. Therefore, phases of the design research are results of consensus-intended work. Thus, there have been some compromises in intentions of the parties in the resource framework and some other constraints. There are not enough resources to do everything. From the research point of view, time is the most crucial constraint. Fortunately, this design research project was a non-profit project without an overly- demanding time schedule. Thus, the design team had a reasonable time in which to conduct testing. The reader should evaluate testing phases keeping in mind the time constraint. One aspect to ensure trustworthiness of the testing (Chapter 4) is that the research team has reported its results. I discussed results with fellow researchers. Further, research results have been presented in international conferences and the obtained feedback has helped to finalise the research report.

The third reliability criterion for design research is the improvement of teaching (see Section 2.3). The field test provided hints for speculating about the third criterion. Teachers who participated in the in-service training tested the learning environment and many of them adopted it. If it is reasonable to assume that teachers have not taught physics until now, the learning environment has been a facilitator, helping teachers start to teach physics in primary school. Therefore, in one sense, it can be argued that the design research process reached the teaching and learning *improvement* criterion.

7.5 Implications

The nature of design research is iterative. Reflection on previous versions provides initiatives for further design. In accordance with that, every phase of the design research provides future research challenges.

The design research project focused on Newtonian mechanics. Therefore, it would be interesting to study what effect the understanding of Newtonian mechanics has in action. It would be interesting to clarify the connection between Newtonian mechanics and physical education; what effect initial schemas of movement have on students' ability to learn gymnastics, sports, or athletics, for example. Krist (2000) studied how pupils drop an object from a "wheelchair" moving with constant velocity. He found that most 12-year old pupils drop an object at the appropriate moment, but younger children dropped the object too late. He concluded that initial schemas influence the actions.

As well as pupil and teacher thinking, action and affect play important roles in the teaching–learning process. It would be interesting to study what effect the confidence of a teacher has on pupils' learning. The hypothesis could be that the background story and learning path encourage teachers, and so their confidence increases. Thus, a teacher is more confident and, thereby, pupils are more confident with physics as well.

The Finnish National Framework Curriculum, national standards in the USA, syllabuses in Sweden, and the curriculum in England focus not only on conceptual understanding, but practical work as well (Standards, 1996; Syllabus, 2001; Curriculum, 1999). The development of pupils' practical work skills needs more research. One interesting aspect could be pupils' views about the nature of science, and rationales for the practical work. The research indicated that pupils found practical work to be pleasant (Section 4.3) Still, the interdependence between the interest to study physics and practical work needs to be studied in more detail.

There is quite a lot research about student interest in physics. However, it seems that research has been concentrated at secondary-level (over the age of 12). This design research indicated that pupils enjoy studying physics. It would be interesting to follow a group of pupils from the beginning of fifth grade to the last (ninth) grade of the compulsory school to evaluate changes in their interests.

The main outcome of this research is that the learning environments designed for the project gave an opportunity to research how primary school teachers start teaching physics and how pupils start learning physics, when they have only a limited experience of physics. In particular, the learning environment for primary school physics offers a novel phenomenon in the Finnish primary school: physics teaching and learning.

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