The FBT programme
Looking back and looking forward

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Abstract

The primary context of the research described in this report was the Food and Biotechnology program (FBT program) at Wageningen University. The FBT program involved design, realization, implementation, use and evaluation of digital learning materials for specific subjects and aimed to share relevant aspects of the resulting knowledge in the form of digital learning materials and in the form of publications. This report presents a view on digital learning materials. Next, the report gives an overview of the FBT program and presents a first indication of the methodological issues that emerged during the program.

Chapter 1 Introduction

Learning materials are specifically designed and realized in order to support learning processes of learners and to support the achievement of learning goals. At Wageningen University (WU) a series of projects has been carried out that were aimed to deliver digital learning materials and to share knowledge about these learning materials in corresponding publications. Many of these projects were part of the Food and BioTechnology (FBT) program (http://wmmrc.nl). They combined design, realization, implementation, use and evaluation of digital learning materials in realistic settings in higher education with the intention to capture knowledge of the learning materials and their use in publications. This raised a number of practical and methodological issues. In many fields, in particular in education, information - and knowledge management, and in management sciences, the literature on methodology with respect to activities in which design and research are strongly interrelated, has been growing [1-29]. The growth of literature **about** design-related research approaches in itself might be regarded as an indication that many academics recognize a need for articulation of methodology in design-related research activities. For a number of methodological questions that became apparent in the FBT program, in particular questions raised by scientists with a natural science background, we were not able to find a practical answer, i.e. an answer that is useful without further articulation, in the literature.

In this report, we will first describe main concepts that are directly related to digital learning materials. These concepts are *learning scenarios*, *learning materials*, *digital learning materials*, *learning objects*, and *learning management systems*. Next, we will give a comprehensive description of the FBT projects and indicate some of the methodological issues that arose in the FBT projects and how they are related to the context in which they arose. Finally, we will formulate a small set of research questions with respect to methodology. In the remainder of this report, we will propose and articulate answers to these research questions. We will call the resulting approach Design-Oriented Research (DOR).

Chapter 2 Learning scenarios

We define a *learning scenario* as a scenario aimed to support students in learning. A learning scenario defines roles for all actors and for all learning materials; in addition the scenario may define which activities and actions are planned and in what order. Typical well-known categories of learning scenarios in universities are lectures, laboratory work, tutorials, project-based learning, problem-based learning, report work, group discussions, field work and excursions. In addition, students also devote considerable time to studying textbooks and lecture notes in preparation of exams. At WU, most study programs (curricula) apply a wide range of different learning scenarios. Even within a WU course, it is quite usual to apply several different learning scenarios.

The view that a learning scenario should enable learners to construct knowledge using the actual state of their knowledge is now quite generally adopted [30]. Moreover, there should be sufficient opportunities for learners to be involved in *inquiry* [31, 32]. Hofstein et. al. [32] define *inquiry* as referring to "diverse ways in which scientists study the natural world, propose ideas, and explain and justify assertions based upon evidence from scientific work. It also refers to more authentic ways in which learners can investigate the natural world, propose ideas and explain and justify assertions based upon evidence and, in the process, sense the spirit of science."

In universities, one might label report work and many of the problem-based learning and project-based learning activities as inquiry-based or inquiry oriented learning scenarios[1]. In practice, this will often be **guided** inquiry. Many other learning scenarios in universities, including laboratory work, involve even more guidance. In particular in laboratory work that is not part of report work, the degree of guidance tends to be such that there is little or no opportunity for inquiry anymore. The question what degree of

[1] As to inquiry activities that are not guided, one might conclude from 33. Broek, A.v.d., F. Wartenbergh, I. Wermink, R. Sijbers, M. Thomassen, M.v. Klingeren, and L. Hogeling, *Studentenmonitor 2006*, ed. M.v. OC&W2007, Nijmegen: ResearchNed. that many study programs of dutch universities leave time for such activities. However, it also seems that students on average prefer to allocate this time to activities that are not directly related to the curriculum of their choice.
One could relate this to the fact that the link between such efforts and assessment 34. Biggs, J. and C. Tang, *Teaching for quality learning at university*. 3[e] edition 2007, Maidenhead Berkshire England: Open university Press. is often unclear. One could also see this as a challenge to make curriculum related 'unguided' inquiry more attractive.

guidance is desirable and can be consistent with inquiry is a topic of debate [35, 36]. It is still difficult to find a balance between direct instruction and inquiry [37].

Guidance implies a direction and a direction implies a goal. One of the challenges in a learning scenario is to align teaching-learning activities, guidance and the goal of the learning scenario with *Intended Learning Outcomes* (ILO's) of the course and curriculum and with assessment [34]. A related challenge is to operationalize a statement such as "real-life tasks should be the driving force for complex learning" [38][2].

Guidance will be based on assumptions with respect to the prior knowledge of the student. A classical quote is: "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" [p vi 39]. Of course this statement still has to be operationalized. In Science Education literature it is applied in particular to preconceptions [see for instance 40]. On the other hand, the constraints implied by the context of a learning scenario in a university do often not allow the teacher to ascertain adequately what the learner already knows and what conceptions the learner already has. Answers to questions about type and degree of guidance will mostly be curriculum, course and topic specific. In addition, practical answers have to satisfy practical constraints such as scarce expert capacity or constraints of available infrastructure[3].

2.1 Information and communication technology in university education

Over the last decade, Information and Communication Technology (ICT) has become an integral aspect of research in many disciplines to such a degree that much of this research can only be done using ICT. A natural consequence of this is that ICT also will be an integral aspect of the study in these disciplines. By its very nature, this holds for computer science education. Other examples of sciences in which ICT is naturally and deeply integrated are bioinformatics and geo-information systems, decision sciences and sciences

[2] Note that not all real-life tasks of a graduate can be categorized under inquiry, or to put it in another way: inquiry is not for every aspect of every real-life task the best term to characterize that aspect.

[3] Jonassen 41. Jonassen, D.H., *The Vain Quest for a Unified Theory of Learning.* Educational Technology, 2003. **43**(4): p. 5-8. highlights that different conceptions and theories of learning can be relevant in different contexts and urges us not to select one single theory as the ultimate truth.

that rely heavily on simulation models or large databases. For these sciences, education necessarily has to take into account an important ICT component.

Secondly, ICT has become important in everyday life of practically every student and teacher. In many countries, almost every student who now enters a university has already been using ICT intensively. Consequently, ICT has become a part of the mindset of almost every student. For instance, many students are used to on line access to digital resources, on line communication and a high level of interactivity. As such, this aspect of the student's mindset has to be taken into account in learning and instruction.

Thirdly, in many countries, almost every university now supports education with facilities and services such as Learning Management Systems (LMS’s), Local Area Networks (LAN's), internet access services and computer rooms or laptop lease programs for students. These facilities are used in more and more courses in university education.
A *learning management system* is an information system that at least:

- supports authorized management of digital learning materials;
- provides authorized access to these materials;
- supports electronic communication and collaboration

Most web-based learning support is based on a learning management system such as Blackboard, Moodle or Sakai to mention only a few of the more than hundred well-known LMS's.

In practice, most professors in university education by now at least make their presentations, lecture notes and course information available ‘on’ an LMS. Actually, most LMS’s have much more functionality. For instance, most LMS's support authoring and management of quizzes consisting of closed questions such as multiple choice questions, multiple response questions, ordering questions et cetera [42]. More advanced web-based learning support systems support the possibility to use electronic communication for enhancement of web-based learning materials [43-45]. Approaches like this can also be viewed from a knowledge management perspective: communication between students and subject matter experts can be related to specific topics, concepts, issues et cetera. Moreover, the recorded communications can be restructured, recombined and made reusable (see below). Many other developments in learning support and learning management are beyond the scope of this introduction. For this introduction, the primary relevance of learning management systems is that they support large-scale management of, and easy authorized access to digital learning materials. This is one of the conditions for large-scale use of digital learning materials.

2.2 Resources for teaching and learning

Teaching implies among other things, supporting learning processes by allocating human and material resources to these learning processes. The most obvious and well-known resources at university level are students, professors, learning materials, publications in scientific journals and resources on the worldwide web and infrastructural resources such as laboratories, lecture rooms, computer networks and learning management systems.

The tools that are used in research and academic professions form a special class of resources. Examples are spectrometers, autoclaves, pumps, heating and cooling devices, computer algebra programs, spreadsheet programs, computer simulations and project-management programs. Sometimes these tools can be used to develop dedicated learning materials. Students naturally use tools like these because they are necessary in the professional task execution for which they are being prepared. Moreover, students are often required to learn the basic concepts underlying these tools. As such, these tools are resources that are used in learning processes and in general, their use by students is intended to support their learning process.

Chapter 3 Learning materials

Most of the resources in the previous section are not specifically developed for a learning goal or class of learning goals and a target population and as such we do not classify these as learning materials.

The most well-known learning materials are textbooks. Kuhn [46] states that "The objective of a textbook is to provide the reader, in the most economical and easily assimilable form, with a statement of what the contemporary scientific community believes it knows and of the principal uses to which that knowledge can be put." Kuhn also warns that "…, though texts may be the right place for philosophers to discover the logical structure of finished scientific theories, they are more likely to mislead than to help the unwary individual who asks about productive methods." It is likely that this quote still applies to many currently available textbooks. Like almost any resource in almost any task, textbooks as well as other learning materials, have important limitations. In particular, certain text-based learning materials may not adequately connect to the actual state of knowledge of the student in such a way that the text guides students through a process of conceptual change. Such a connection supposes that developers of learning materials or authors of textbooks have knowledge of the relevant prior knowledge of the students who will use the material in the future. In general, authors of textbooks and other learning materials will make assumptions about prior knowledge of students based on their own expertise in teaching and on feedback that they received from students and peers on their teaching and previous productions. Thus, knowledge of teachers may be embedded in learning materials. Because this knowledge is often rather tentative, we often prefer the term 'assumptions' instead of 'knowledge'. We will come back to these issues in several places and in particular in our discussion of interfaces and our discussion of the role of knowledge management.

In practice, because resources tend to have limitations, most university level learning scenarios will require a combination of resources. In particular, most scenarios require allocation of scarce teacher capacity. One function of learning materials in university education is to compensate for lack of such capacity or to leverage scarce subject matter expert capacity.

We distinguish two major classes of learning materials.

(1) *Presentational Learning Materials* (PLM), such as video recordings of lectures, instructional movies, animations, lecture notes, textbooks, and (digital) slide presentations [see for instance 47, 48].

(2) *Activating Learning Materials* (ALM), such as instructional laboratory set-ups and digital learning materials that require the student to make decisions, enter data, make combinations, define variables, design models or systems, investigate the behavior of systems, et cetera.

For some students all learning material and all learning resources induce active behavior. However, in this report the term ‘activating’ is reserved for learning materials that require the student to take conscious actions. Thus, a textbook with assignments is not labeled as ‘activating’.

Digital learning materials require the student to use a digital computer. For this reason, they can also be called *computer-based learning materials.*

3.1 Digital learning materials

In comparison to traditional non-digital learning materials such as lecture notes, textbooks, audios, videos and animations, digital learning materials may enhance the palette of learning materials and learning activities in a university by providing **additional possibilities** to:

- invite or provoke decision-making and call for action;
- evaluate user actions and provide corresponding feedback on actions of the user;
- enable learning activities such as designing, developing, adjusting and running qualitative and quantitative computer simulations [47, 49-56];
- provide experiences that would otherwise be too dangerous, time consuming , expensive or impractical and enable virtual experiments [56-58]; environments that enable the student to do virtual experiments are called *virtual experiment environments*.

Virtual experiment environments allow for a certain degree of inquiry. However, it is important to be aware that virtual environments incorporate considerable 'hidden' guidance. This guidance is often not so easy to capture in natural language and is thus not so apparent in publications. This is a good reason to link web-based access to learning materials [59, 60] to the publications on these learning materials [53, 56].

With respect to costs of design, realization, and use of learning materials, digital learning materials provide additional possibilities to:

- reduce the staff/student ratio and relieve academic staff from some repetitive and labor-intensive aspects of their teaching task; [see for instance 61];
- design and develop digital multimedia material at much lower costs than non-digital multimedia material; a good instance of low cost realization of digital multimedia is the realization of screen-recordings [48, 62, 63];

In addition, ICT infrastructures enable us to

- adapt, to a certain extent, access and presentation of learning material to specific characteristics and actual state of knowledge of the individual student [64-67];
- manage and make available multimedia materials at lower costs than non-digital multimedia material; in particular, the costs to make information just in time (JIT) available in an adequate form and the costs of providing worldwide access to learning materials have been reduced considerably in the last decade;
- collect data about students and student behavior; this offers opportunities for educational research as well as for incremental improvement of learning materials;
- manage knowledge implied in interactions between students and their peers, and between students and their professors when they are using the learning materials; for instance, it is possible to log these interactions, and to link them to relevant locations in the learning material; in this way the learning material can be enhanced in order to improve the match between the learning material and students in a specific target population [see for instance 45, 68].

3.1.1 Learning objects

An important category in the literature about digital learning materials is the category of learning objects. *Learning objects* are reusable pieces of digital learning material aimed to support the achievement of 'atomic' learning objectives, i.e. learning objectives that we have not been able to decompose in other learning objectives. Many other definitions and many other terms with more or less the same meaning such as *reusable content object* (RCO) or *unit of learning material* (ULM) are used in literature.

One of the ideas underlying this concept is that the same 'piece' of knowledge is often necessary and useful in different contexts. For instance, the concept of exponential growth is relevant in the context of compound interest, in the context of cell growth and in many more contexts. It seems a waste of resources to redesign learning material for all these courses. One could imagine that there might be just one or a few pieces of learning material that can be used by anyone who teaches or learns the concept of exponential growth. In case of digital pieces of learning material, we use the term *learning object*.

Of course, this ideal is partly inspired by the success of reusable components in almost any hard- and software industry. In particular, in software engineering, a concept of object classes that allow for specific instantiations that fit specific contexts has been very successful[4]. At the same time, the need for something like *learning objects* becomes visible in the common practice of many university teachers. Many professors compose slide presentations from objects such as tables, diagrams, quotes et cetera. This illustrates also the reusability of these objects. Also, many professors compose so-called 'readers' from objects such as sections and chapters of different textbooks or articles, using so-called 'boxes', diagrams tables et cetera as well.

If we were successful in realizing a learning object that adequately helps students to acquire the concept of exponential growth, millions of teachers and students could use this learning object in different contexts. Such large-scale use would free considerable resources for raising the quality of such a learning object.

An important condition for such large-scale use is that any teachers or student can search and find the right learning object at the right time. This requires metadata. Metadata are data about the learning object that can be used in search queries. Consequently, much effort has been invested in metadata standards.

[4]One of the most well-known object classes is the window class. Most desktop users and laptop users are familiar with instances of this class.

3.2 Learning materials and learning scenarios

We already mentioned that a learning scenario can require more than one resource. For instance, a learning scenario might require a professor, one or more textbooks, as well as a virtual experiment environment and access to library facilities. Alternatively, a specific resource can often be used in more than one learning scenario. This applies also to learning materials. For instance, a virtual experiment environment might be used in a project-based learning scenario, a problem-based learning scenario, an instructor-led group discussion or a collaborative learning scenario.

Chapter 4 The Food and BioTechnology (FBT) program

This chapter provides a comprehensive overview of the FBT program. This program was the context in which the need for the research on methodological issues. This report provides an introduction to the formulation of these methodological issues and an introduction to research into a new design-oriented research methodology.

In 1997, WU founded four educational institutes. Each of these institutes was responsible for a subset of the bachelor and masters programs that were offered by the university. This organizational effort went hand in hand with increased attention for education. Against the background of developments with respect to ICT in education and increased interest in new learning scenarios for higher education, two innovative parallel efforts were initiated.

The first was a program to stimulate and realize problem-based learning scenarios [69]. The second was the FBT program introduced at the start of this Report. Initially, this second program was aimed at Food and BioTechnology (FBT), but soon the FBT program covered other areas as well. Because the acronym already lived a life of its own, we continued to use the acronym. The FBT program aimed to explore possibilities for ICT in education.

4.1 FBT Stakeholders

The parties who invested in the program were the key stakeholders. These key stakeholders were the educational institute of technology and food, the departments to which the involved chair groups belonged, the respective chair groups, the chair of applied information technology and the rector magnificus of WU. Students were represented in the board of the educational institute as well as in the committees that defined the curricula. The infrastructural ICT facilities department was naturally a stakeholder but except in the early preliminaries of the program, this department did not invest in the program.

In January 1998, a workshop was organized with all faculty involved and soon afterwards the author of this report was invited to be program manager. All in all, the projects in the program were going to be primarily *faculty-based*. In such a faculty-based project, faculty would search for a feasible match between opportunities offered by new information technology and needs recognized in their direct educational context. Because we had no experience with such projects, they were considered 'pilot' projects and because they were intended to be the start of a sustainable process (i.e. a process of ongoing design-oriented activities) they can also be considered 'bootstrapping' projects. Thus, the projects would have to enable us to free, generate or acquire resources for continuation of the activities[5]. The initial frame of reference of such a faculty-based project is its direct educational context.

4.2 Major decisions and implications

At the outset of the FBT program, we distinguished two main functions for ICT in education. On the one hand, there was a growing interest in what we will call the Learning Management – Learning Object paradigm and calls to produce digital learning materials to populate Learning Object Repositories such as Ariadne [70]. On the other hand, there was worldwide a growing interest in Computer Supported Collaborative

[5] In the next chapter we will shortly review related research.

Learning (CSCL) and a promise of web-based environments that promoted and supported inquiry-based activities [71, 72].

CSCL projects and projects aiming at other more abstract functions of ICT such as automated capturing of knowledge of students, professors[6] and communities would initially require focus on infrastructure and corresponding investments in infrastructural design and realization. This was difficult to match with the fact that the centre of gravity of investments of the FBT projects was not in the central administration or the infrastructural facilities department. Thus, learning scenarios, that would primarily require investments in more advanced infrastructural support were out of scope of the FBT projects. Secondly, learning scenarios with a strong communication and collaboration component would, for natural and engineering sciences, require more than natural language as major representational formalism. Support for such formalisms, such as MathML [73] and Chime [74] was in the years of the FBT program still in an early stage of development. Thirdly, in terms of research interest, it would not have been natural for chair groups to invest in efforts on the advancement of infrastructural learning management and learning support systems[7]. Finally, initial experience with communication between professors and students by means of e-mail and discussion forums in early LMS's suggested that the teacher entries were not reusable. In other words, the results of the efforts invested by teachers in such discussion forums seemed to 'evaporate'. On the other hand, 'condensation' in learning materials was expected to enable sustainability and sharing of some teaching experience.

For the chair groups it was more attractive to focus on digital learning materials and to gain experience with their use in suitable learning scenarios given available learning management facilities. At the outset of the FBT program, many of the digital learning materials were presentational learning materials. At the same time, all stakeholders shared a belief in learning materials that would promote 'active learning' i.e. that would prompt and enable students to carry out activities, take decisions, answer questions etcetera. For the chair groups the step from presentational learning materials to more activating learning materials was not too abstract. In addition, the creation of activating digital

[6] This term includes associate and assistant professors or lecturers

[7] However, it should be noted that in a later stage some limited work on extending infrastructural facilities became part of the FBT program. This reflects how the weight of certain arguments tended to change over time.

learning materials was a possibility to ‘capture’, or ‘condensate’ elements of subject matter related teaching experience of the respective professors.

4.3 Quality and large- scale use

A second position taken was that learning materials should not be too 'university specific'. In general, we believe that lecture notes and presentations that never leave the university and are never scrutinized by faculty of other universities, are likely to be of lower quality than textbooks that are available worldwide and exposed to external reviews[8].

In general, we also believe that a lecturer who is co-author of a textbook is likely to invest more time in the creation of this learning material than a lecturer who makes lecture notes for a number of students in the range of thirty to fifty students per year. In case of the former, (s)he will usually also work in a team supported by a publisher aiming at an audience of thousands of students a year. Moreover, a publisher can contribute to the quality of the process and product by making available considerable knowledge and resources that would otherwise not be available. Extending this view to learning materials in general implies that the capacity of resources that can be allocated to the design and realization of learning material tends to increase with the number of users of this material. In other words, we assume that for learning materials economics of scale are important in the same way as they are important for many industrial products and software products. We assume that achieving sustainable high quality of learning materials requires large-scale use.

4.4 View on digital learning material in a globalized world

The globalization trend of the last decades and the new possibilities of modern ICT enable matching a student anywhere in the world with authors and experts anywhere in the world. Every year it becomes easier to make worldwide connections between students and

[8] Exceptions are lecture notes that can be tuned to a specific homogeneous target population. Such tuning to a homogeneous target population would require at least three conditions. The first is that the actual state of knowledge of students in successive cohorts attending a specific course changes little over the years. Secondly, each cohort must itself be relatively homogeneous in this respect. Thirdly, the lecturer should be in a position to build up experience with this target population.

experts with a common interest. The worldwide web enables us to link more potential students to a *Subject Matter Expert* (SME) in a specialized field[9]. The number of biotechnology or food-technology students in the Netherlands may be small, but the number of students interested in these fields worldwide is much larger. Many publishers and universities operate already a long time from the perspective of serving students worldwide. Wageningen University and Research centre (WUR) in particular, serves students from more than 100 countries [75].

This view on globalization in higher education led to four related propositions in the FBT program defining an ideal situation as follows.

(1) Whenever a university has specific core competences and claims to be leading in specific fields, this university should be the source or at least a major contributor to learning materials in this field.

(2) These learning materials should be exposed to reviews worldwide.

(3) A student anywhere in the world who wants to study this field should want to have access to reviewed learning materials from such a renowned source.

(4) Lecturers from universities anywhere in the world should at least consider using those learning materials in their courses that have been created by experts and have been reviewed with satisfactory results.

Furthermore, not only learning materials should be exposed to criticism from experts but also experience with the design, realization, implementation, use and evaluation.

4.5 Aiming for sustainability

The FBT program was completely funded by Wageningen University. Moreover, for the fields that we categorized under the FBT program, we could not find examples of comparable programs. Thus, our primary concern was how to realize sustainability.

[9] We use the term Subject Matter Expert here in order not to refer only to professors and assistant and associate professors but also to specialized technicians and to experts in industry.

Our assumption was that satisfaction of key stakeholders in university education would be essential for sustainability. For sustainability of investments by faculty, we believed it to be essential to deliver useful products that matched their goals. The learning materials should enable good practice and had to be valued by students as well as by peers within the subject matter discipline. In addition, we believed that it would be important to realize synergy between the efforts in the FBT program with research interests and publication efforts of faculty [cf. 76, 77, 78]. After a few successful small faculty-based projects on digital learning materials, it was decided to start PhD projects on design, realization, implementation, use and evaluation of digital learning materials for a number of subjects. If successful, such projects should lead to recognition, not only by students but also by peers within the discipline. Such recognition was believed to be crucial for sustainability. Indeed, several years after the conclusion of the FBT program, all materials except one digital tool set for systematic model design [49] are still in use and considered satisfactory by the professors who use the materials. Moreover, based on these experiences, several more projects have been initiated in order to create more digital learning materials and to invest in evaluation activities. Thus, until this moment we have been able to realize continuation of the type of efforts that started with the FBT program. From a 'basic research'[10] perspective, taking into account requirements derived from the practical aspects of sustainability might be viewed as a restriction on scientific ambition. From a design-oriented perspective as described in the succeeding chapters, we consider satisfaction of students and faculty and actual continuation of efforts after conclusion of the FBT projects a valid component of a research goal. Possible successes could be starting points for other types of research on ICT in education in specific fields. Thus, the level of ambition of the FBT projects was considered inherent to the ‘bootstrapping function’ of the projects.

[10] Here we refer to an interpretation of basic research as suggested for instance by 79. OECD, *Frascati Manual: Proposed standard practice for surveys on research and experimental development* 2002, OECD Publication Services: Paris. or 80. Bush, V., *Science: The Endless Frontier.* Transactions of the Kansas Academy of Science (1903-), 1945. **48**(3): p. 231-264. that is widely known. It should be noted though that the term 'basic research' is interpreted in several other ways as well.

4.6 Innovative materials but no intention to 'reform'

The intention of the FBT program was to design and realize a body of digital resources for teaching and learning within existing courses. This also implies that the activities would not be aimed at the curriculum but rather at parts of courses. The existing curriculum was to be part of the given design context.

The FBT activities seemed natural advances for many chair groups who were already used to make presentational learning materials such as lecture notes and slide presentations. In the FBT program, the aspect ‘innovative’ referred to the fact that a result should be a new synreport of knowledge from different sources. Such a synreport would be new in the sense that it was not the result of a straightforward derivation from a theory. Moreover, in particular at the outset of the FBT program, the process of design, realization, implementation, use and evaluation of digital learning materials for the specific topics could not rely on a body of directly relevant and coherent scientific literature.

The aspect ‘innovative’ did not refer to ‘reform’. In particular, the program was not intended to reform any curriculum, nor to reform courses or to reform the mindset of professors but to enable faculty in articulating and realizing their (often implicit) goals and intentions.

4.7 Design, realization, implementation, use and evaluation of digital learning materials in the FBT program

Each of the PhD projects consisted actually of four to five sequential subprojects. Most subprojects involved the actual design, realization, implementation, use and evaluation of digital learning materials for a part of a course and in a corresponding publication in a suitable peer-reviewed scientific journal. In addition, a few digital tools that extended the possibilities of digital learning materials were designed, realized and implemented. These were relatively generic software designs and products [see 64, 81, 82-86]. The functionality of these software products was derived from requirements that surfaced during the projects.

Given the exploratory nature of the research projects and the expectation that much of the engagement of anyone person in the projects would go into a learning process most procedures, methods and techniques described in standard information systems development methodologies and project management methodologies [87, 88] were considered not to be directly applicable. In practice, many information systems development approaches tend to seek flexibility (some rather implicitly) in flexible delivery moments. Exceptions are methods such as the Dynamic Systems Development Method [DSDM 89]. In such a method, time is fixed and flexibility must be realized by relaxing constraints on other variables such as functionality. In this respect, our approach matched methods such as DSDM.

There were several reasons to fix time in our faculty-based projects. The first reason is that we did not want to loose too many opportunities for evaluation in a realistic setting. Thus, the time of delivery of the learning material was fixed within the first instantiation of the course in which the material was going to be used. Because most of the courses at WU are given only once a year, any flexibility in delivery of the learning material would imply that the next opportunity to use and evaluate the material would be a year later. Flexibility in time in a PhD project of four to five years with only one opportunity per year for evaluation in a realistic setting was considered undesirable. Secondly, in our university environment most faculty is used to invest considerable efforts in preparing the details of the first upcoming instantiation of a course. Spreading the efforts over a much longer period would not match the habits of most faculty. Thirdly, technology changed rapidly. We believed that interleaving subprojects[11] instead of sequencing subprojects would complicate discussions about adoption of new technology.

In each subproject, we aimed to deliver digital learning material that was evaluated as satisfactory in the first realistic setting in which it was implemented and used. These evaluations were essentially summative in intention. The set-up of the program was (1) to achieve a goal in each subproject, (2) to contribute to the growth of knowledge in relation to this goal in publications and by providing access to the learning materials and (3) to move on to the next goal related to another topic in the next subproject. This approach fits

[11] With 'interleaving subprojects' we refer to an approach where the subprojects would be executed over a longer time period and where the capacity of the researchers in time-slots of a week would be allocated to several subprojects.

the primary tasks of many faculty in higher education. We recognize this in many publications in discipline-specific education journals[12], journals of software engineering, information systems research and knowledge management and journals in the field of ICT in education or instructional technology. In these journals, many publications can be found that - to a certain extent - reflect the design-oriented and goal-achievement oriented intention of the FBT approach.

Insofar an evaluation did reveal shortcomings of the material or the implementation, these shortcomings almost never indicated that underlying assumptions and applied theory would have to be adjusted or that the basic architecture of the learning material had to be adjusted. The case studies for evaluation of the materials were not primarily intended to provide supporting evidence for a theory or to inspire adjustments to a theory.

Most of the time, the PhD candidates were the core designers. The most important required qualification for each of these core designers was that this designer would quickly be able to acquire a deep understanding of the subject matter of the course and to be able to discuss and elicit course goals with the responsible professors. In the FBT projects, the core designers had been students in a related master program within the university. Thus, their background was not only fitting from the perspective of the primary research field, but they had also experience as a student in a bachelor and master program that was very much the same as the programs for which they would design digital learning materials. This implied that they still had certain relevant knowledge of usual learning scenarios, schedules and many of the practical issues that are important for students.

Faculty responsible for the courses were the major sources of knowledge with respect to the subject matter, the primary research field, their own goals, desired project goals, course goals, curriculum goals, experience with previous cohorts of students in the course and course context.

The FBT program manager[13] acted as a broker[14] with respect to many other sources of knowledge and with respect to required services. This involved among other things, the

[12] Examples of such journals are 'Chemistry Education Research and Practice', 'Advances in Physiology Education', 'European Journal of Engineering Education', 'Biochemistry and Molecular Biology Education'.
[13] R.J.M. Hartog

task of balancing (at many moments during the program) the state of art of ICT based learning technology and learning support with actual availability of corresponding facilities. More generally, this involved throughout the program the task of eliciting and balancing a shared perception of the actual needs of the projects with the available project resources and balancing short term needs with sustainability of the intentions of the program. The problem of deciding how much project capacity should be allocated at a certain moment to searching and incorporating specific knowledge in a design process is a core problem in the type of research that characterized the FBT projects[15]. This problem was part of the more general problem area of methodology and acceptability of activities, evaluations and publications. As different disciplines have different norms and values with respect to methodology and evaluation [see for instance 91], finding an approach that was acceptable to the most directly involved discipline (i.e. the discipline 'of the subject matter') was considered an important challenge in particular for the project manager. This challenge is also recognized in the literature on scholarship of teaching and learning [92]. In particular, this challenge gave rise to this report. More will be said about this at the conclusion of this report. First, we will give a comprehensive overview of relevant domains of knowledge for projects such as the FBT projects.

4.8 Relevant knowledge domains and knowledge sources

In the following (sub)subsections we will present a short overview of the most relevant knowledge domains and for each domain a number of issues and factors that were relevant for the design processes. Note however, that the knowledge domains as we describe them are not per definition disjunctive.

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[14] Gasson 90. Gasson, S., *A genealogical study of boundary-spanning IS design.* European Journal of Information Systems, 2006. **15**(1): p. 26-41. describes the designer as an implicit knowledge broker crossing organizational and knowledge boundaries and IS design as a "collective negotiated process within a specific political and social ecology".

[15] During the projects many other persons with a variety of competencies were involved in carrying out specific tasks (software engineering, programming, screen recordings, making drawings, photographs, animations, realizing voice-overs, managing servers, developing questionnaires, et cetera) or consulted in relation to relevant knowledge domains (see next subsections).

4.8.1 The Subject Matter Knowledge (SMK) domains

All stakeholders as well as peer reviewers in the FBT projects believed that for the design of digital learning material for a specific learning goal or target competency within a disciplinary course in a university curriculum deep subject matter knowledge (SMK) is essential. This should include deep understanding of the relevant subject matter and of the corresponding primary research field as a whole. Above, we already indicated that this element has been crucial in the selection of the PhD students for our projects.

4.8.2 Information and communication technology including learning technology

A major assignment of the program was 'chair group side' exploration of ICT in education. Thus, a relevant knowledge domain was the domain of learning management systems, learning support systems, learning technology standards and developments with respect to more general infrastructural ICT opportunities and facilities. During the greater part of the duration of the projects, learning technology standards such as SCORM [93], QTI [94] and LD [95, 96] were still in development. After their final specifications came out, these were not immediately de facto standards. In addition, in several of the FBT projects, it was difficult to match project intentions with constraints implied by SCORM2004 [83, 85]. Studying, implementing and exploring possibilities and constraints of QTI2.0 turned out to be a challenge far beyond the possibilities of the FBT projects. For this, we succeeded in setting up and carrying out a separate project [97]. Moreover, the interfaces of actually available learning management systems at WU and the interfaces of the organizational units that were responsible for the infrastructure within WU underwent a series of changes[16].

More generally, design and realization of digital learning materials naturally involved a range of issues in the domains of software engineering and management of technology. In particular, at a detailed level, assessing the stability of specific technologies such as Javascript, Flash, Flex, PHP and Java in relation to a range of web browsers and defining a suitable match with project goals that were still being articulated, required attention

[16] (1) functionality of actually available learning management systems at WU, (2) technical constraints on learning objects and (3) services provided by organizational units of WU, all changed over time.

throughout the lead-time of the projects. The same holds for matching changing requirements with changes in availability of technology. Finally, throughout the FBT program, the problem of assessing which needs would rather require infrastructural solutions and which needs would legitimate chair group based investments in ICT required attention.

4.8.3 Pedagogy and learning

Digital learning materials that will be used by students in universities will have to be based on assumptions with respect to university students. Much more will be said about this in the remainder of this report. Some assumptions may refer to generic properties of human learners such as drives that are related to motivation, learning styles or limitations of human information processing capacity. There is a huge body of literature in educational research, learning and instruction and cognitive science that constitutes a source for generic assumptions about human learners and corresponding theoretical underpinnings or evidence. In addition, there are textbooks and reports that aim to inform SME's of views on teaching and learning [see for instance 30, 31, 34, 98, 99-103]. At the same time, as learning requires the use of what the learner already knows, specific assumptions about the actual state of knowledge of the student are crucial. In relation to this, much knowledge on teaching and learning is less generic and highly related to content (subject matter) and the actual state of knowledge of the student. A term that has received much attention over the last twenty years is *Pedagogical Content Knowledge* (PCK).

The term Pedagogical Content Knowledge (PCK) was introduced by Shulman [104] as one of the categories of teacher knowledge as follows:

> "….that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding;"

The introduction of PCK generated much research and over the last two decades, a family of interpretations of PCK has been spawned [see for instance 105, 106]. In particular, PCK has received much attention in Science Education Research in secondary education contexts, but the scope of the concept is not by itself limited to science education or to secondary education [107-109].

The concept of PCK has been called ‘elusive’ [110]. Note however, that pedagogical content knowledge is not exceptional in this respect and that more generally in knowledge management literature the concept of 'knowledge' has been called 'elusive' as well [see for instance 111]. Not surprisingly, the body of literature on PCK has been called "much less tidy than the SMK literature" [105]. Nevertheless, we believe that literature on PCK highlights a set of important knowledge domains and identifies teachers as essential sources of knowledge in these domains. At the same time, elusiveness, lack of tidiness and lack accepted procedures on how to make use of the concept of PCK suggests that in faculty-based projects a pragmatical interpretation of this concept is to be preferred.

4.8.4 Pedagogical Content Knowledge domains

We propose to make a clear distinction between using the term PCK in order to reference a set of knowledge domains (such as 'epidemiology PCK', 'molecular biology PCK', '(bio) process engineering PCK' et cetera) and using the term PCK in order to reference actual knowledge in those knowledge domains. As to the latter, relatively much of the knowledge in PCK domains is considered *tacit* or *personal knowledge* of teachers [112, 113].

As to the former, several authors have proposed interpretations of the term PCK that include a set of categories of knowledge. These categories contribute to an interpretation of PCK knowledge domains. For instance, for science teachers, Van Driel, Verloop, & De Vos [114] described PCK as having the following key elements: (1) knowledge of student conceptions with respect to a domain or topic, (2) understanding specific student learning difficulties in that area, (3) knowledge of representations of subject matter for teaching, (4) knowledge of instructional strategies incorporating such representations.

Alternatively, Magnusson et. al. [115] distinguished the following five components: (1) orientations toward teaching science, (2) knowledge of science curricula, (3) knowledge of students’ understanding of science, (4) knowledge of assessment in science, and (5) knowledge of domain -specific[17] and topic-specific strategies. As to the latter, de Jong et. al. [116] also distinguish domain-specific PCK, which focuses on a particular domain (such as chemistry) and topic-specific PCK (e.g. focused on stoichiometry), which is the most distinct level of PCK.

Attempts to denote components of PCK might provide some insight in PCK or enable us to make some of the knowledge of teachers explicit, but essentially all this knowledge will work 'in concert' when it is actually applied [cf 117].

The recognition of PCK spawns in a natural way several streams of research. A first is research aimed to elicit PCK of experienced teachers [116, 118, 119]. A second stream is research aimed to compare PCK of experienced teachers with novice teachers [120]. Another stream is research aimed to contribute to PCK and to the further development of PCK of teachers [see for instance 114, 115].

The relationship between design, realization, implementation, use and evaluation of digital learning materials and PCK is twofold. Firstly, our point of departure is that digital learning materials in higher education can and should embed knowledge of professors. In general, this knowledge comprises not only SMK but PCK as well. Secondly, it is likely that a university professor who dedicates attention to design, implementation, use and evaluation of teaching strategies or (digital) learning materials, develops his/her personal PCK as well.

If the design of certain (digital) learning materials could be based on literature describing relevant domain-specific PCK or topic-specific PCK, this literature would be a valuable source of knowledge in the design process. However, the body of literature on PCK of university teachers is much smaller than the body of literature on PCK of science teachers in secondary education [107-109]. In particular, we did not find literature on PCK for university teachers on epidemiology, nutrition behavior, nutrigenomics, bioprocess engineering, food chemistry, and molecular biology, which were the domains that where relevant for the FBT program. More specifically, we also have not found literature on topic-specific PCK on the topics on which the projects in the FBT program came to focus.

We conjecture that in general, the PCK of a university teacher is likely to be quite different from PCK of a science teacher in secondary education. Some factors that are

[17] Actually, the authors use the term 'subject-specific' where the subject refers to 'science' as being a subject in secondary education.

likely to be relevant are the following. First, the level of abstraction of the related university-level SMK will be relatively high. Second, university teachers have often invested less time in acquiring knowledge of pedagogy than teachers in secondary education. Third, interaction of university teachers with their students is likely to be different from interaction of science teachers in secondary education with their students. The number of occasions of personal contact between a university teacher in a regular course and a student is often rather limited. This holds in particular for large enrollment classes. Moreover, such occasions of personal contact may be restricted to one semester. Alternatively, contact might be fairly intensive during report work.

4.8.5 Knowledge about the knowledge of students

The body of implicit and explicit assumptions about the actual state of knowledge of 'the' student in the university (i.e. knowledge about the actual state of knowledge of university students) might also be regarded as a knowledge domain[18][19]. For teaching, it is important to have knowledge of or to make assumptions about the relevant prior knowledge and conceptions of students [30, 39, 121]. In science education at the level of secondary education, there is since long considerable interest in students' prior knowledge, preconceptions and 'misconceptions' and conceptual change. [see for instance 122, 123, 124]. In a recent discussion of conceptual change theory and practice, Duit et. al. [125] state that "Quality of instruction is always due to a certain orchestration of various instructional methods and strategies. Hence, conceptual change strategies may only be efficient if they are embedded in a conceptual change supporting learning environment that includes many additional features." and "that there seems to be ample evidence in various studies that these[20] approaches are more efficient than traditional approaches dominated by transmissive views of teaching and learning."[21][22]

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[18] Recall that knowledge domains may overlap. This is particularly true for the domain of knowledge about knowledge of students and PCK domains.

[19] When the teaching and or the learning materials are based on the English language, it is also relevant to have knowledge of the students' mastery of the English language.

[20] i.e. the conceptual change approaches

[21] Note that the authors also warn that "what works in special arrangement does not necessarily work in everyday practice."

However, in university education, relatively little work has been done in terms of investigating and understanding relevant prior knowledge and (possible) conceptions of students. In particular, in university education relatively few specific problems with conceptual understanding are being identified that are experienced by professors as particularly challenging, due to the relatively larger distance between teachers and students and less attention for basic learning problems of students. Moreover, the origin of problems of conceptual understanding often turns out to be in the students' secondary education.

While we recognize these points, we believe three other points to be at least as important in relation to the intentions of the FBT program and problems of conceptual understanding. First, the student population within the courses that were considered in the FBT program was increasingly heterogeneous. Second, the learning materials were ultimately intended to be useful in courses of other universities as well. Thorough research into the actual state of knowledge of a sample of a student population may provide valuable insights if this population is fairly homogeneous and if the actual state of knowledge of students in the population in the near future is not likely to change[23]. However, if many students in the target population for the learning materials have different histories in education[24], such sample knowledge is likely to have less value. Terms like 'common sense notions' or 'every day language' or prior knowledge of 'the' students, should be reconsidered if the sample is small and/or not random[25]. Third, the

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[22] Note that , while we did not exclude direct presentation of information to students, we certainly do not consider the FBT results to be 'dominated by a transmissive view of teaching and learning' . Thus this comparison cannot be regarded as a comparison with FBT like approaches. Moreover, the FBT program was aimed at learning materials that could be used in different learning scenarios. A specific learning object was not the only component in the 'orchestration'.

[23] Dutch university teachers are often not even well informed about the prior education of the students who enter their courses. Moreover, not all their students will have had the same prior education. In parallel with the FBT program, a tool was being developed that would provide university teachers a quick though limited insight in the educational history of those students in their course who had attended Dutch secondary education 126.
Bodegom, P. and M. Folkerts. *Vakinhoudelijke aansluiting met ICT*. [last accessed. www.sobit.nl/site/Interknowledge/hva.ppt .

[24] Recall that this is to be expected in a globalizing world and in particular at university level. Note furthermore that any team of authors and editors of a textbook aimed at a worldwide audience already had to cope with this limitation of sample knowledge.

[25] It would be different if measurement instruments such as the 'force concept inventory' 127. Hestenes, D., M. Wells, and G. Swackhamer, *Force concept inventory*. The physics teacher, 1992. **30**: p. 141 - 158. would be available for concepts related to the learning objectives that were central in the FBT projects AND if large-scale measurements with these instruments would reveal that the same misconceptions would prevail across the whole target population

topics, concepts and learning goals that were selected for the creation of digital learning materials in the FBT projects were quite specialized and often chosen precisely because we thought that there was little or no experience in their teaching. Thus, we soon suspected that adequate literature on students' actual knowledge, understanding and **common** conceptions in relation to the specific topics, concepts and knowledge domains of the FBT program would be difficult to find. These considerations contributed to decisions to allocate relatively little capacity of the design teams to investigate **common** prior knowledge of students entering the respective courses. More about this type of decisions will be said in Chapters 2, 3 and 5. Often, we made assumptions for which little or no supporting evidence could be provided. It should be noted however, that the question how to design learning materials for a worldwide population is not new. Every author of a university level textbook aiming at a worldwide audience meets the same challenge [see for instance 128]. This is the challenge of making at a detailed level a connection with the actual state of knowledge of 'the' student. For learning **material,** this challenge is different from the challenge to make this connection in **teaching**. Many issues are related to the former challenge. These are issues of limitations of learning materials, defining the functions that learning materials have to support, establishing assumptions about their operating context and implementing learning materials in a learning scenario. The latter also implies defining the role of the learning material in a learning scenario. Moreover, it also makes sense to pay attention to adaptivity and/or adaptability of learning materials, teaching experience of professors and automated knowledge elicitation and knowledge management. The latter two issues have not been covered in the FBT projects.

4.8.6 Knowledge of relevant courses and 'direct contextual knowledge'

With the term 'direct contextual knowledge', we refer to knowledge of the possible contexts in which learning materials will have to be realized and might be implemented. This implies knowledge of typical forms of university organization, course scheduling, the contexts in which university students and professors work, usual learning scenarios, et cetera. Part of the knowledge of the courses in which the learning material might fit well can also be considered to be 'direct contextual knowledge'.

Thus, terms that from the viewpoint of reformers are used to indicate 'barriers to change', such as management (barrier), coordination (barrier), faculty (barrier), curriculum (barrier), accreditation (barrier) [129] should from the viewpoint of the FBT program rather be regarded as referring to domains of knowledge with respect to the context in which the learning materials should function.

While the intention was to design and realize materials that could be implemented in different courses of other universities, we tended to focus initially on objectives and requirements of one or more WU courses and curricula. Practical knowledge of the course and the curriculum and of key players in the curriculum was often incorporated by involving key players.

4.8.7 Assessment

Along the duration of the FBT program, assessment in higher education and the possibilities of information and communication technology for supporting assessment became more and more a very relevant knowledge domain for the design of digital learning materials. We consider assessment important, as it should operationally define learning objectives and design requirements for our learning materials. Many scholars in education highlight the importance of alignment of assessment and learning [30, 34, 98, 130-132]. At the course and curriculum level, such alignment will usually pose the challenge to provide assessment tasks that have a high degree of authenticity [see for instance 133]. While the intention of calls for authenticity is probably clear to most educators, it is still difficult to arrive at an operational definition of 'degree of authenticity' even in a context of vocational education [134]. In particular in the FBT projects, attaching performance objectives and realizing alignment and authenticity for learning activities related to the digital learning materials covering only some of the learning objectives of a course turned out to be a major challenge.

Finally, exploration of the possibilities of ICT in higher education will usually include investigation of *interaction* types and the use of interaction types. An *interaction* is a combination of a user gesture and a system response. During the FBT program, a set of interaction types was defined and these interaction types were used in many of the FBT learning materials. In the same period a specification for Question and Test Interoperability [see for instance 135] was being developed under auspices of IMS. Again, there is a huge body of literature on assessment but literature on assessment and digital learning materials that incorporated relevant SMK and PCK was difficult to find. Besides, in a university context, the challenge to match means as defined by the QTI specification, with ends as defined by alignment and authenticity requirements, is not straight-forward. These challenges led to a limited extent to the incorporation of relevant QTI knowledge in FBT learning materials. Instead, funding was acquired to initiate a separate project that was dedicated to the design and development of digital closed questions in higher education [42, 97].

4.8.8 Information and knowledge management

The boundary between information management and knowledge management is not always clear because the distinction between information and knowledge is not well defined [111]. Sharing information and knowledge is essential in the mission of a university. In particular, this involves publicizing and teaching. More information and knowledge can be shared by eliciting knowledge (SMK and PCK) of professors, representing this knowledge in digital learning materials, and making these widely available. Much of PCK is tacit, but Shulman [104] stresses that one of the aspects of teaching is precisely the challenge of representing knowledge. This particular aspect may enable ways of making explicit some PCK that are different from well-known knowledge engineering methods and externalization approaches [136, 137]. For instance, an author of a textbook is likely to make explicit some PCK himself and so is a teacher who is involved in the design of digital learning materials. Note, that digital learning materials also provide ways to capture certain knowledge that cannot be easily captured in a regular textbook. For instance, knowledge that is embedded in interactions of the learning material with students or knowledge captured in computer simulations is less natural to capture in a text in a textbook.

Another knowledge management perspective could have been the more pragmatic perspective of automated reuse of information that is entered into the system [111]. Examples of such entries that become available in the system are e-mails and contributions to discussion forums. Such an approach would also fit what Schütt [138] calls: "the real question of knowledge management" i.e. how to increase the production of knowledge workers. From this viewpoint, in university education, knowledge management should focus on the question how to support professors and other SME's who are involved in teaching specific topics in a course. If, in the FBT program, the ICT facilities department would have been a primary investor and key stakeholder, and if there would be a critical mass of such communication-based resources, such an approach would have made sense. Such an approach might help to bridge between actual prior knowledge of students in heterogeneous populations and the learning material. It also can enable us to enhance the learning materials 'on the fly'. For faculty-based projects such as the FBT projects, such an approach would be more difficult to realize. Besides, within WU, many students prefer to communicate 'live' with each other and with their teachers. Thus, within WU, there is no critical mass of resources that have been generated in electronic communication such as e-mails, chat logs or contributions to electronic discussions. This would of course be different in a distance learning setting.

4.8.9 Human-Computer Interface and usability

Since the outset of the FBT program, the diversity in the body of literature on Human-Computer Interfaces (or user interfaces for short) and Human-Computer Interaction (HCI) has been growing [139-149]. This also holds for literature on usability, accessibility and web-design [150-159]. At the same time, the technology for user interface design and web design became much richer and the costs of programming rich user interfaces are now much lower than ten years ago. Moreover, on the user side, better hardware, in particular high-resolution computer screens and more bandwidth became available. The rapid progress of the technology implies that a number of constraints on the design (such as for instance constraints on what can be presented on one computer screen) are relaxed. However, in the process of design and realization of materials, one has to find a balance between potential benefits of new technology and additional costs of evaluating and learning this technology. This holds in particular for the use of better development tools and the incorporation of better software components. Moreover, with respect to user interface design, many detailed decisions have to be taken for which available guidelines in the literature are not specific enough. The problem is that we were and are not able to balance the costs and benefits of investing additional project resources into such a detailed decision and its consequences.

4.8.10 Generic and specific design knowledge

One of the core tasks in any FBT project was always 'design'. At the same time, one of the core problems in the FBT program turned out to be the fact that we had no shared conception of 'design'. Design is a concept with many aspects. Different disciplines understand and discuss 'design' in different ways, using different examples and attaching different meanings to aspects of design. Even within one discipline, conceptions of design can differ [160]. As digital learning materials, and in particular learning objects, must be viewed as information systems, one disciplinary perspective is to frame our understanding of 'design' in terms derived from the domains of IS design and development and from software engineering [see for instance 161, 162]. Another disciplinary view could have been based on the use of the term 'design' in instructional design literature [163-165]. In particular, in parallel with the FBT program, a growing body of literature in education reflected a search for research methodologies in which conceptions of design would play a more prominent role. In addition, ICT and education literature as well as HCI and usability literature displayed an increasing interest in *design patterns* [151, 166-177]. A *design pattern* is a reusable configuration of basic components or activities (including parameter settings), which fits a partial design problem. The concept originated in architecture [178] and was taken up in software engineering in the early nineties [179]. However, throughout the FBT program, also a range of other engineering knowledge domains became relevant. For one thing the new learning goals that emerged in the projects were often related to design knowledge and design skills in typical engineering fields such as bioprocess engineering [see for instance 180]. Throughout the FBT program, it turned out to require considerable effort to arrive at a shared understanding of 'design' that fitted the intentions of the FBT program.

4.8.11 Research methodology

In the introduction of this report, we explained our need to find and/or articulate a research methodology that would fit the intentions of the FBT program. In particular, the question what output the program should generate in terms of growth of knowledge, products and publications required considerable attention. In addition, we explained some aspects of the faculty-based character of the FBT projects including the primary intention to satisfy stakeholders and to solve practical problems or grasp opportunities. On the one hand, research methodology is one of the knowledge domains relevant for faculty-based design-oriented projects for digital learning materials. Therefore, we incorporate research methodology in our overview of relevant knowledge domains. On the other hand, one of the two main foci of this report is precisely our attempt to formulate an initial framework for a research methodology that fits such projects. We will come back to this below.

4.8.12 Final remarks on relevant knowledge domains

We do not claim that the list of knowledge domains that are relevant for the design of digital learning materials in higher education is complete. Many more knowledge domains, for instance project management, requirements engineering et cetera could have been listed as well. We already mentioned several domains that are subject to research in Science Education but many other knowledge domains are relevant. For instance, Duit [181] considers Science Education to be a "a genuinely inter-disciplinary discipline" in which "science is a major reference discipline" and competencies from the reference disciplines Philosophy of Science, History of Science, Pedagogy and Psychology are needed and further reference disciplines such as Sociology, Anthropology, Linguistics and Ethics are also relevant. All these disciplines might contribute to knowledge that is relevant for the design of digital learning materials in specific courses in higher education.

Chapter 5 Disciplinary visibility in FBT outputs

Boundaries of disciplines are traditionally important in what we will call 'basic research' but 'design-oriented research' requires us to 'cross' these boundaries or to rely on interfaces if such interfaces are available. As any project will have finite resources, additional consumption of resources of boundary crossing efforts will imply a reduction of disciplinary depth. Consequently, such projects may result in output in which the applied knowledge does not reflect the importance of several reference disciplines as viewed from a 'basic research' perspective. Indeed, in all FBT project outputs, there will be many disciplines that might be considered insufficiently visible from a disciplinary viewpoint. Often, this can be contributed to the fact that - given the design goals in the FBT projects - it was difficult to find literature that was directly relevant for these design goals. For instance, leading Science Education research journals such as 'Science Education', 'International Journal of Science Education' and 'Journal of Research in Science Education' devote relatively little attention to university teaching [182], even less to learning materials and even lesser to digital learning materials. Moreover, in these journals we did find little research output that was directly useful in relation to FBT subject matter such as bioprocess engineering, molecular biology, food technology, epidemiology, nutrigenomics and nutrition behavior. These fields are also not mentioned by Laws [183] in a review of undergraduate science education research. Also with respect to Knowledge and Information management it was difficult to find research output in important journals such as 'IEEE Transactions on Knowledge and Data Engineering','Data & Knowledge Engineering', 'Knowledge and Information Systems', the 'ACM Transactions on Information Systems' or even 'Multimedia Systems' that was directly useful in FBT projects. An exception is the 'Journal of Universal Computer Science', which pays more attention to learning support. In case of the second example of low disciplinary visibility an important factor was the fact that most research in Knowledge and Information management is directed at the infrastructural level, whereas for the FBT projects infrastructure was part of the design context.

5.1 FBT publications and Intended audiences

The FBT output consisted of digital learning materials, software tools and software applications and publications describing initial experience with implementation and use of the digital learning materials and software.

For university education, descriptions and output of **actual** instructional design activities or actual design of learning materials are usually published in journals of the subject matter discipline. For instance, some of the FBT results were published in 'Trends of Biotechnology', 'PLOS', 'eSPEN', 'The American Statistician', 'Bioprocess and Biosystems Engineering'. These are the journals that are read by researchers who are the peers of the SME’s (i.e. SME's in molecular biology, epidemiology, process engineering, food chemistry, et cetera, …) who can also understand the subject matter and evaluate the learning materials and many of the underlying assumptions. These peers can also evaluate if the applied educational approaches fit their own research and education. These researchers are also the most natural primary target audience for publications on learning materials in their field. Apart from this, the publications might also raise their awareness of possibilities to realize synergy between their research and their educational tasks.

Secondly, a number of FBT articles were published in journals like 'Chemistry Education Research and Practice', 'Advances in Physiology Education', 'European Journal of Engineering Education', 'Biochemistry and Molecular Biology Education'. We assume that these journals reach an 'education interested' subset of the audience of the SME's that we want to reach. We will call these journals, which have the name of a discipline and the term 'education' in the title "discipline-specific education" journals or DSE journals for short[26][27].

Thirdly, a number of FBT articles were published in more ICT-technologically oriented journals. These range from journals on the intersection of ICT and science education such as the 'Journal of Science Education and Technology', 'Journal of Computers in Mathematics and Science Teaching', to journals with a wider scope such as 'Technology, Instruction, Cognition and Learning', 'Journal of Interactive Learning Research', Journal of Educational Technology and Society', and the 'Journal of Universal Computer Science'. We assume that these journals reach an audience that is more knowledgeable about and interested in the growth of knowledge with respect to using information technology in education.

[26] Other candidates for a generic label to attach to these journals were 'Content Specific Education' journals, 'Subject-Related Educational' journals, 'Subject-Specific Educational' journals or 'Subject Matter Didactics' journals or SMD journals. In the glossary we say more about the term 'Subject Matter Didactics'.

[27] The 'D' in 'DSE' may refer to any discipline and is not limited to the disciplines that are considered science disciplines in science education journals.

Chapter 6 Methodological issues in the FBT program

6.1 Intentions

The PhD projects in the FBT program involved design, realization, implementation, use and evaluation of digital learning materials for specific subjects and aimed to share relevant aspects of the resulting knowledge in digital learning materials and publications.

We believe that writing articles with the intention to submit these to peer-reviewed scientific journals would help to involve faculty more actively in thinking about their education and upcoming possibilities of ICT. Moreover, such a way of aiming at synergy between the research task and the education task of faculty might provide a counter balance to incentives of the academic reward system that tend to create a tension between research and teaching in higher education[28].

In addition, we decided to share knowledge not only in the form of digital learning materials but also in the form of corresponding publications. This decision rests on the insight that both contribute something different to the body of knowledge on digital learning materials for the pertinent subject matter, on the process of designing such learning materials and on the resulting design of the learning materials.

Internally we looked upon our research as being 'design-oriented' i.e. oriented towards the delivery of a design and 'goal-oriented' i.e. oriented towards the achievement of a goal [see 165]. However, throughout the FBT program, we still had difficulty to articulate the meaning of this term. This is not surprising against the background of many parallel developments with respect to design-related research approaches. For instance, van den Akker et. al. [12] wrote quite recently with respect to educational design research approaches: "clearly we are dealing with an emerging trend, characterized by a proliferation of terminology and a lack of consensus on definitions."

As it turned, out relatively much time had to be dedicated to discussions on the methodology of such design-oriented research in general and its application in the context

[28] In particular it was Terry Anderson who provided this argument in a talk at the EdMedia 1999 conference. See also 76. Anderson, T. *Utilizing Disruptive Technologies in the University: Confessions of an Agent Provocateur*. in *World Conference on Educational Multimedia, Hypermedia and Telecommunications 1999*. 1999. AACE.

of design, realization, implementation, use and evaluation of (digital) learning materials in higher education in particular. This included discussions within the projects and with researchers from other universities as well as correspondence with reviewers of journals.

6.2 Issues

Firstly, these discussions unveiled a need for a framework and a corresponding terminology for DOR that would be based on a shared conception of 'design'. Such a shared conception could not be realized directly on the basis of literature in one of the well-known engineering disciplines such as software engineering, chemical engineering, (bio)process engineering, civil engineering, electrical engineering, architecture or in instructional design literature. An attempt to realize such a shared conception on the basis of Herbert Simon's seminal work 'The sciences of the artificial' [184] was unsuccessful. There was a strong need to clarify the semantics of terms like ‘object system’, ‘ inner environment’, ‘outer environment’, ‘form’, ‘context’, ‘interface’, ‘modularity’, ’component’, ‘minimal dependency’, ‘design space’, ‘constraint’, ‘requirement’, ‘guideline’ and 'iteration'. The fact that much literature on design does not consistently use design terminology was one of the factors behind this need. While certain concepts in design literature might be quite generally accepted, terminology and definitions are not used consistently across many disciplines. For instance, what one author coins as ‘guidelines’ is by another author coined as ‘ requirements’ and by yet another author as ‘criteria‘ and by yet another author as ‘principles’ . What one author calls ‘context’ is called by another author ‘outer environment’. Thus, there was a need for a shared vocabulary.

Secondly, most involved faculty were used to aim their research efforts towards growth of knowledge within their own discipline. Within the FBT program, both faculty as well as the PhD students who did most of the actual work of design and realization of the digital learning materials, tended to have a view on research that is often associated with the term 'basic research'. In certain respects, this view was difficult to match with a primary design orientation. In particular, the fact that it is practically impossible to arrive at clear relationships between 'independent' and 'dependent' variables seemed to be beneath the surface of many discussions. Throughout the FBT program, the question if we should do comparative studies kept being posed.

A third issue was always the pressure to allocate more project resources in order to get more insight in just a few variables and relations instead of allocating the project resources in a balanced way over all variables[29]. The latter of course was necessary in order to achieve a design goal that reasonably well matched the demands of the stakeholders.

Fourth, but related to the previous issue, a set of recurring questions concerned what we should evaluate and how we should evaluate and how to arrive at an acceptable balance between investments in evaluation and investments in design, realization and implementation of digital learning materials.

Fifth, we had to ask ourselves what publication output can reasonably be expected from design-oriented research. Is it sufficient if research contributes to 'shared knowledge' or should the contribution be a contribution to 'theory'? The answer to this depends on what one considers as 'theory'. When 'theory' has only relevance within a discipline, 'contributing to theory' will have a different meaning in different disciplines. Our position has usually been that DOR aims to contribute to 'shared knowledge' but we have usually hesitated to claim that we contributed directly to 'theory' in a disciplinary sense.

In addition, throughout the FBT program, a second strand of issues was related to technological developments in the direct and indirect context[30] of the projects. Many decisions had to be made with respect to conforming or ignoring the actually available infrastructural facilities, technology and services. Many of other technology related issues concerned decision-making with respect to conforming to or ignoring learning technology specifications that soon might or might not become standards. Moreover, not only technical specifications where in fact nascent during the greater part of the FBT program, but also a range of technical implementations of languages and software components underwent rapid developments. Ignoring upcoming technological

[29] For instance, it would be nice to know a relationship between type of learning objectives, interaction types and achievement of learning objectives. However, it seems not likely that research into this would be sufficiently interesting for faculty of a specific subject matter discipline to invest their time in this.

[30] i.e. the context provided by WU respectively the context provided by worldwide developments in information and communication technology and learning technology.

developments would reduce the innovative aspect of the projects. Thus, many decisions had to involve an assessment of upcoming technological developments and relate this to the available capacity and competences in the project. In these decisions, we had to balance the risk of choosing a 'wrong' technology or complying to a 'wrong' specification against intentions to be innovative.

Chapter 7 Design-oriented research

We define *design-oriented research (DOR)* as research that primarily aims to produce an innovative design and applies typical concepts from design methodology and contributes to a knowledge base not only in terms of artifacts but also in terms of scientific publications.

The primary research questions in design-oriented research are:

1. what are, in a specific real life context, goals that make sense and why;
2. how can these goals be articulated in terms of measurable quantities;
3. is it possible to achieve these goals;
4. if so, how?

One of the typical outcomes of a design-oriented research project can be a set of requirements that define a goal that matches demands of stakeholders as well as realistic possibilities. Another example of a typical type of outcome of design-oriented research is a proof of feasibility.

Chapter 8 Looking forward

In contexts of design, realization, implementation, use and evaluation of digital learning materials in faculty-based projects in higher education such as described in the previous sections, the FBT programme has generated the following questions with respect to DOR:

- What is a potentially useful perspective on design and what are corresponding design concepts?

- What can be a methodological framework for design-oriented research that gives adequate structure to a DOR project on design, realization, implementation, use and evaluation of digital learning materials in higher education and in particular defines relevant output-classes?
- What is a comprehensive set of concepts and terms?
- Can concepts and terminology in this framework be illustrated with examples from existing literature and from publications that resulted from the FBT program?
- What can be ‘handles’ for evaluation?

8.1 For whom should these questions be relevant?

Assuming a scholarship of teaching and learning stance [185, 186], these questions are primarily relevant for those SME's who are directly involved in faculty-based projects on design, realization, implementation, use and evaluation of innovative digital learning materials for higher education in particular, but not per se exclusively, in natural and engineering sciences. By being more conscious of particular aspects of design and design-oriented research, members of this audience should be able to share their knowledge in their own disciplinary journals as well as in DSE journals. Combining design and realization of (digital) learning materials with additional efforts to present the results to a scientific community might improve the quality of the designs. Moreover, combining educational duties with research efforts in a way as described in this report allows the individual staff member to increase the benefits of these educational duties.

Secondly, the methodological questions of which we became aware during our FBT programme are also relevant for educational support teams who support faculty in educational innovation projects. In more and more universities, these teams include educational technologists (ET’s) who support the realization of digital learning materials. Transforming the work of these teams and team members into design-oriented research as described in the subsequent chapters and publishing the results might raise the quality of the work because such publication requires reflection. In particular Shulman [78] makes a strong point of this.

For these first two audiences the answers should provide handles for evaluation in design-oriented research, propose output-classes and argue why manuscripts that cover one or more of these output-classes can be valuable contributions to a knowledge base for the design and realization of digital learning materials in higher education.

Thirdly, the questions and theire answers might interest researchers in computer science and knowledge and information systems research, in particular those researchers who are involved in learning technology research. For these researchers the answers might provide insight in the relative importance of different perspectives on learning technology for faculty-based projects in higher education.

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