Faculty-Based Design-Oriented Research on Digital Learning Materials: Defining Project Goals

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Abstract: Advance of information and communication technology inspires faculty to search for new goals in higher education. In several universities, faculty members in natural and engineering sciences invest efforts in design, realization, implementation, use and evaluation of interactive digital learning materials. Defining the goal of such a project implies finding a valuable and feasible match between demands of faculty and students on the one hand, and possibilities of digital learning materials on the other hand. This article is inspired by a series of such faculty-based projects. Reflection on these projects raises awareness of a number of decisions with respect to project goals. Decisions that are related to the focus of innovation of such projects are strategic decisions. This article describes a six-fold classification of faculty-based design-oriented research projects based on the focus of innovation and relates this to implications for the type of project activities and required resources.

Introduction

A major part of the teaching tasks of faculty goes into the design of teaching-learning activities and learning materials. From the contents of learning object repositories and referatories such as Merlot (MERLOT 2007) or Globe (GLOBE 2008), one can conclude that in a number of universities, faculty members invest efforts in design, realization, implementation and use of digital learning materials. Many of these learning materials are purely presentational but many are also interactive. Digital learning materials are often realized in what we will call 'faculty-based' projects. In these projects, faculty or chair holders within university departments and the students in their courses are the primary problem-owners and stakeholders. Designing learning materials for undergraduate and graduate students requires deep understanding of discipline-specific subject matter. Designers of digital learning materials for university education should have a background in the relevant subject matter knowledge domain. Usually they will have a position within the relevant chair group. Sizes of faculty-based projects may vary considerably.

This article is inspired by experience in a range of faculty-based projects on design, realization, implementation, use and evaluation of digital learning materials in natural and engineering sciences. In the remainder of this article, these projects will be referred to as 'FBT projects'. At the start of the series, FBT was the acronym for Food and BioTechnology. However, now the scope of the FBT projects includes many fields besides Food and Biotechnology. The FBT projects were intended to be design-oriented research (DOR) projects. In this article, DOR is defined as research that primarily aims to produce an innovative design, applies typical concepts of design methodology and contributes to a knowledge base, not only in terms of artifacts but also in terms of scholarly publications. The latter distinguishes DOR from ‘design’ (Hevner et al. 2004; Peffers et al. 2007). The aspect ‘innovative’ implies here that a result should be a synthesis of knowledge from different sources and not the result of a straightforward derivation from a theory. Moreover, 'innovative' refers to projects in which one cannot yet rely on a body of directly relevant and coherent scientific literature. The term ‘innovative’ as used in this article does not refer to ‘reform’. In particular, the FBT projects were not intended to reform any curriculum, nor to reform courses or to reform the mindset of professors. Rather, they were intended to enable faculty in articulating and realizing their (often implicit) goals and intentions and embedding these in digital learning materials.

Faculty-based DOR as defined here, implies the following research questions:

(1) what are, in a specific real university 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?

Within many disciplines, there are design-related research approaches. Well-known examples of design-related research approaches in education are ‘development(al) research’ (Gravemeijer 1998; Lijnse 2003; Reeves et al. 2004; Richey et al. 1996; Richey et al. 2007; van den Akker 1999), ‘design-based research’ (Bell et al. 2004; Design-Based Research Collective 2003) and ‘design-experiments’ (Brown 1992; Cobb et al. 2003). Later, the term ‘educational design research’ (EDR) was introduced for reference to these approaches (van den Akker et al. 2006). EDR approaches tend to aim primarily at improving the researchers’ understanding of teaching and learning in real classroom contexts and to provide guidelines for the design of interventions. Most EDR has been carried out in primary and secondary education. EDR approaches are ‘more interventionist’ than faculty-based projects. Some design-related research approaches in information systems (IS) research are described in (Hevner et al. 2004; March et al. 1995; Peffers et al. 2007). In these approaches, ‘improved understanding’ is not excluded but less prominent and the primary goal in such research is coined as ‘utility’ (Hevner et al. 2004). In this respect DOR would fit these approaches. In contrast to design research approaches in educational and information systems disciplines, DOR is not intended to fit within one discipline. Rather, DOR should be acceptable to range of researchers in subject matter disciplines in natural and engineering sciences.

Lawson (2006), proposes a model of design, that is based on constraints. In this model, design requirements are a special class of constraints. Lawson distinguishes four classes of constraint generators: legislators, users, clients and designers. Often, a constraint is implicitly or explicitly modeled as a relation (in the mathematical sense of the word) over the domains of a set of variables (e.g. Gross et al. 1988; Kuchcinski 2001; Ohlsson et al. 2006). Here, the domain of a variable is the set of its possible values. The variables may be qualitative or quantitative. The domains of these variables define a Cartesian product. The constraint defines a sub set of this Cartesian product. In this model of design, a design goal is defined in terms of a set of constraints (and thus, also a set of variables). In practice, the set of constraints will be very large. The variables span a design space and define the dimensions in the design space. A design goal is defined by the set of all constraints. This set includes the design requirements.

In projects on innovative design of digital learning materials, articulation of design requirements and formulation of the goal go hand in hand. This is not surprising against the background of views in requirements engineering literature (Lamsweerde 2001). It is also related to the means-ends analysis character of DOR for digital learning materials. This also implies that the well-known linear ADDIE (analyze, design, develop, implement, evaluate) model from classical instructional design literature is not applicable (Merriënboer et al. 2002; Visscher-Voerman et al. 2004). Changing requirements are changing constraints. Requirements may also be added or dropped. Thus, the design goal and its articulation is output rather than input of the project. Nevertheless, some of the strategic decisions are often made quite early in the project.

A goal (i.e. the set of constraints that defines the goal) can be innovative in many ways. A new goal may incorporate new variables, new values for variables, new constraints (i.e. new requirements and/or new other constraints) or new combinations of those. A sub set of the constraints may refer to variables that are directly related to learning objectives. These learning objectives may be well-established or quite innovative. Another sub set of the constraints may be only indirectly related to learning objectives. Examples are requirements with respect to the average level of students’ motivation, or student and teacher satisfaction.

In several of the FBT projects, there was a tendency to select rather implicitly a focus for innovation quite early in the project. Often, the primary focus for innovation has important implications for the type of project activities and required resources. Furthermore, these implications are different for different types of learning goal or target competency. This article aims to raise awareness of a number of these implications. In particular, six types of faculty-based DOR projects on design, realization, implementation, use and evaluation of digital learning materials in natural and engineering sciences will be discussed. Table 1 summarizes this discussion.

	Focus innovation on LOD sub set (learning objectives are innovative)	Focus innovation on NLOD sub set (learning objectives well established)
Understanding concepts, methods et cetera	1.Articulate learning objectives 2.Design and realize interactions based on existing interaction types e.g. (QTI 2.0) 3.Combine interactions in a case 4.Use quantitative simulations as foundation for interactions	1.Design and realize new interaction types e.g. based on manipulation of three dimensional objects, or based on quantitative simulations 2.Map available operational definitions of learning objectives onto digital closed questions. 3.Build adaptive systems for heterogeneous target populations, realize well defined motivation level
Whole task overview	1.Analyze overall task class 2.Build virtual task environment 3.Design authentic cases in this environment	1. Provide automated guidance by structured approaches to problem solving. E.g. environment that guides students in design/development/running of models
Whole task competency	1. Realize Just In Time (JIT) presentation of procedural information 2. More part task practice 3. Follow "Ten steps to complex learning"	1. Use professional task environments e.g. Matlab Mathematica, MathCad, SPSS, SuperPro Designer or real wet laboratory 2. Realize integrated learning experience 3. Provide performance support. 4. Enable low-cost part task practice. 5. Enable computer-based assessment of task

Table 1. A six-fold classification of projects on digital learning materials with some examples.
A project goal is defined as a set of constraints. Two sub sets are distinguished. The LOD sub set defines learning objectives. The NLOD sub set defines objectives are not directly related to learning objectives.

Two Major Distinctions

A project goal is a set of constraints. In this article, two sub sets are distinguished. The first set will be called the Learning Objectives Defining (LOD) sub set (see left hand column in Table 1). The second sub set is the set of all other constraints. Examples are constraints that define intended levels of student motivation, intended levels of teacher satisfaction, study load, scheduling constraints, infrastructural constraints, and capacity constraints. This second set will be called the Non Learning Objectives Defining (NLOD) sub set (see right hand column in Table 1). The two sub sets also define two sets of variables or two partial design spaces. The intersection of the two sets of variables will in general not be empty. In general, the two partial design spaces overlap. Throughout this article, the reader should keep in mind that a project will always involve both constraint sets. Satisfying the constraints in one sub set without satisfying the other constraints does not make sense. At the same time, focusing innovation on both sub sets is likely to be too ambitious in faculty-based projects. Thus, focus of innovation is our first major distinction. The second major distinction is based on the scope of the project in relation to learning tasks. We distinguish three 'scopes' based on the following questions. Is the innovation aimed "to support students in acquiring 'deep understanding' of concepts, methods, theories and the like (see row 1 in Table 1), or to support students in acquiring an overview of a whole and authentic task within a field (see row 2 in Table 1), or to support students in becoming competent to carry out a complete professional task?" (see row 3 in Table 1).
These two distinctions suggest a six-fold classification of projects on the design, realization, implementation, use and evaluation of digital learning materials. The remainder of this article discusses and illustrates each project type.

The Horizontal Dimension: New Learning Objectives or New Other Objectives

Focus on a New Learning Goal and Corresponding Assessment

One type of the recurring challenges for faculty in university education is to define new learning goals. In university education, it is to be expected that the growth of knowledge induces new learning objectives in related curricula. For instance, in this decade, molecular life sciences have been entering a new phase. Focus has shifted from individual genes and their products to networks and whole systems. This induces a need to introduce new learning objectives in life science education. These objectives involve that students learn to apply quantitative tools in molecular life sciences (e.g. Aegerter-Wilmsen et al. 2005a; Aegerter-Wilmsen et al. 2006). In addition, the genesis of a new discipline such as Nutrigenomics will give rise to corresponding new learning objectives in university curricula (Busstra, et al. 2007b). Finally, new technological developments may enable us to incorporate certain learning objectives in a course that could previously not be accommodated in this course. For instance, several courses that were supported by the FBT program provided little opportunity to acquire design competencies. Thus, a range of FBT projects aimed to complement these courses with respect to design competencies. Five FBT projects (Aegerter-Wilmsen et al. 2003; Busstra et al. 2007b; Diederen et al. 2006; Sessink et al. 2006; Wilmsen et al., 2002) focused on the design of experiments. Two FBT projects (Busstra et al. 2008; Busstra et al. 2007a) aimed to support learning aspects of designing an epidemiological study and the design of a questionnaire respectively. In (van der Schaaf et al. 2003) the focus was on the design of an industrial purification line. In (Aegerter-Wilmsen et al. 2005a; Aegerter-Wilmsen et al. 2005b; Aegerter-Wilmsen et al. 2006; van der Schaaf et al. 2006a; van der Schaaf et al. 2006b), the focus was on the design of qualitative and quantitative models.

In summary, progress in most research fields will imply that faculty will yearly be confronted with challenges to define new learning objectives. Apart from this, there is often a range of learning objectives that have been suggested by faculty for many years, but that were actually never part of a course and exams. These objectives may come within reach due to new developments in ICT. A major challenge in projects aiming at support for achievement of new learning objectives is the definition of assessments that operationally define the objectives (Anderson 2007; Hartog 2008). Even when there is an initial formulation of the new learning objective, such a formulation is only a starting point for further articulation, definition of corresponding assessments and design of corresponding learning materials.

Focus of Innovation on Parts of the Design Space that are Not Directly Related to Learning Objectives

A project aiming at established learning objectives does not require efforts for the task of defining and articulating learning objectives and designing assessments. This will enable faculty to focus on other goals, i.e. other combinations of requirements. For instance, the project could aim to cast existing assessments into the form of digital assessments. Such an assessment might be a set of digital closed questions, but it might also be more advanced. In fact, a whole class of innovative design goals is defined by the field of computer-based assessment (Hartog 2008).

ICT in education provides many innovative design opportunities that, at least in principle, do not imply new learning goals. Examples are goals that are formulated in terms of a life long learning attitude, levels of motivation, learning efficiency and support of distance learning. In particular, distance learning becomes more relevant every year. Here distance learning means that the students are not physically present in any of the buildings of the university. Further articulation of this design goal might imply that students should achieve the same learning goals in the same study time as in a setting that requires on-campus attendance. This naturally suggests research into virtual environments as one of the research goals. For instance, we are currently designing and realizing virtual microscopy experiments for this purpose (Hartog et al. 2010). This implies that students acquire the skills of using microscopes and interpreting microscopic images by carrying out tasks with a virtual microscope.

Another innovative design goal related to 'old' learning goals might be to provide students with a completely integrated learning experience (Helic et. al. 2001; Sessink et. al. 2007). Here, ‘integrated learning experience’ is defined as a learning experience that does not involve any form of cognitive load due to switching between different tasks or between the uses of different media.

Locating the Centre of Gravity of Investments on the Map of Knowledge Domains

A project aiming at digital learning materials in higher education is likely to involve research that is relatively generic, once it can start with established and well defined learning goals. The relationship with specific subjects in discipline specific education such as biotechnology education, molecular biology education et cetera is still there, but it tends to be an indirect relationship. This subsection, will illustrate that in projects aimed at established and well-defined learning objectives, the 'centre of gravity' of the efforts tends to shift into the direction of computer science and knowledge management or even into other directions. At the same time the discipline specific education knowledge and/or pedagogical content knowledge will still be essential in the project.

For instance, in process engineering education a new requirement might be to avoid any cognitive load involved in switching from reading a text to setting up a set of linear differential equations (e.g. van der Schaaf et al. 2006a). Alternatively, in the context of learning to apply a psychological theory about nutrition behavior, we might want to avoid any cognitive load involved in switching from reading a text to defining a questionnaire (e.g. Busstra et al. 2007a) In both examples there is some relationship between the design requirement for the digital learning support system (i.e. no extraneous cognitive load due to switching between activities) and the subject matter. However this relationship is very indirect in comparison to the relationship between a learning goal and the subject matter. Moreover, avoiding cognitive load related to switching from reading a text to mathematical modeling or to designing a questionnaire will imply a different technical challenge. This illustrates that the design goal of 'providing an integrated learning experience' will not be related to the subject matter in the same way as a learning goal is related to subject matter.

The same applies for 'supporting low-cost updating of learning material'. If the learning material is purely text based, such support will be very different from supporting low-cost updating of learning material that relies on three-dimensional visualization. Within many social science disciplines, purely text based learning material can often be satisfactory. Within many engineering disciplines and natural science disciplines such as chemistry, there is much need for three-dimensional visualization (see for instance Schönborn et al. 2006). Thus, the relationship between low-cost update functionality and the subject matter discipline is still there, but it is an indirect relationship.

DOR that aims at the combined design goal to provide an integrated learning experience to students and low-cost update functionality will require relatively little knowledge of the subject matter domain and relatively much expertise in domains of computer science and related knowledge domains. In most contexts in which the digital learning materials will operate, it will also be necessary to have or acquire expertise on eLearning standards such as SCORM 2004 (ADL, 2006) and QTI 2.0 (IMS, 2005).

More generally, the centre of gravity of investments of a project aiming at an innovative 'other' constraint sets (i.e. a project in the right hand columns of Table 1), might shift inadvertently into knowledge domains that are more related to computer science, such as knowledge and information management technology. However, also a tool or environment that has a tight relation with the subject matter and of which the development is desired by the faculty, can be much more generic than one might expect. For instance, a virtual microscope and some corresponding digital cases were designed and realized (Hartog et al. 2010). On the one hand, the primary faculty involved in this project were cell biologists. On the other hand, a virtual microscope can actually be incorporated in many other courses as well. Design and realization of a virtual microscope and corresponding digital cases will be partially generic, partially a matter of discipline specific education. Within the discipline, the quality and the functional scope of the virtual microscope should be determined by operational design requirements that articulate the learning goals. This is because here, most weight is carried by the subject matter discipline. In addition, the primary needs will be the needs felt by students and lecturers in that discipline. Across faculty-based projects in different subject matter disciplines, other design requirements such as requirements that define possibilities for reuse and a generic approach to low cost implementation in different courses and faculties will carry more weight. Realization of these requirements tends to shift the centre of gravity of investments towards software engineering, information and communication technology and knowledge management, or towards the domain of contextual organizational knowledge.

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The Vertical Dimension: 'scope' of what will be supported by the digital learning materials

The second dimension of the classification of faculty-based DOR projects on digital learning materials is defined by the 'scope' of what will be supported by the digital learning materials. We distinguish three 'scopes' each related to one of the three rows in Table 1. The distinction can be matched with the 'Ten steps to complex learning' approach (Merriënboer et al. 2007). The authors define 'learning tasks' as "authentic whole-task experiences based on real-life tasks that aim at the integration of skills, knowledge and attitudes" (Merriënboer et al. 2007 p. 14). We will call this goal 'whole-task competency'. This textbook presents a model for instructional design based on four components: 'Learning Tasks', 'Supportive Information', 'Procedural Information' and 'Part-task Practice'. 'Supportive information' is relevant for the non-recurrent aspects of the learning task. For instance, balance equations and their meaning typically constitute 'supportive' information in many sciences. 'Supportive information' should enable elaboration and help to acquire understanding. 'Procedural information' is relevant for the routine aspects of the learning task. The information on how to insert a specific unit operation in a flow sheet in a design environment such as SuperPro Designer (Intelligen 2007) is procedural information. 'Part-task Practice' aims at the routine aspects of the task and at achieving a very high level of automation. Complete application of the ten steps approach in a university context is often not possible because the aim of university teaching at the level of a specific course is not always 'whole-task competency'. In the FBT projects selected aspects of the four component model and ten steps approach were applied. In particular, the idea of using 'authentic tasks' both as starting point and framework for learning in higher education is much wider supported (e.g. Herrington et al. 2000).

Aiming to Support Learning and Understanding of Concepts, Laws, Theories and Methods

Activating digital learning material that is intended to support learning and understanding of a range of concepts, laws and methods in natural and engineering sciences, often consists of computer simulations (based on a quantitative model) and digital exercises and questions with feedback. Computer simulations that are based on a quantitative model provide opportunities to inquiry-based learning (e.g.Wieman et al. 2008). However, it is still difficult to articulate what guidance should be provided (Jong 2006). In particular, activities that rely on visualization and manipulation of screen objects are likely to support understanding (e.g. Busstra et al. 2005; Hsin-Kai Wu et al. 2004; Sadler et al. 1999; Schönborn et al. 2006).

Sometimes it is possible to incorporate digital exercises and questions in one or more digital cases. A digital case is a combination of a situation, an assignment and a role for the student. Technically, many of the FBT cases were constructed as networks of interactions, were the interaction types were comparable with those defined in (IMS 2005). A digital case illustrates the relevance and some possible uses of concepts, laws and methods that the students need to learn and understand. However, often it is not possible to design a case or set of cases that provides adequate opportunity to support all learning objectives of a course or a topic. In those cases, that primarily provide a context for a cluster of exercises and questions, the task represented in the case is not the primary learning goal. The primary learning goal is an aggregate of the learning objectives that are defined by the exercises and questions. The exercises and questions enforce active learning and should stimulate induction (in particular, generalization and discrimination) and elaboration (Merriënboer et al. 2007). Elaboration refers to a cognitive process of connecting pieces of information to each other and to prior knowledge. This is believed to be the best way to increase the student's memory for new information (Merriënboer 1997). Moreover, digital exercises and questions provide opportunities for the student to display that (s)he can use supportive and procedural information in performing tasks for which it is relevant. This gives us information about the extent of their understanding (Simon 2001). Thus, digital exercises and questions can be part of the operational definition of the project goal.

For generic concepts, the range of exercises and contexts that are intended to define 'understanding' can be very wide. Being able to apply a concept in a task and/or context that is very different from previously executed tasks and/or contexts, is called 'Far Transfer' (Walker 1990). Perkins & Salomon (1989) argue that such transfer requires "intimate intermingling of generality and context specificity". For instance, we might define 'understanding of the Reynolds number' as (i) being able to calculate the Reynolds number for a set of combinations of geometrical form, fluid parameters and velocities, and (ii) being able to characterize the corresponding flow situations and (iii) being able to identify flow situations in which the Reynolds number is actually not defined. Defining such concept specific understanding and trying to represent this in terms of available interaction types would primarily be a task of subject matter experts (see upper left cell in Table 1). Defining such concept specific understanding in terms of innovative interaction types, that still have to be realized, would also be mainly a task of subject matter experts. The size of the software engineering effort necessary to realize such new interaction types would depend on the interaction type. Moreover, innovative interaction types give rise to a number of questions with respect to evaluation of student responses. Much research with respect to assessment still has to be done (Bransford et al. 2003 p. 20).

Aiming at Acquisition and Understanding of Overviews of Authentic Tasks

In many courses in higher education, the learning goal is to acquire insight in the main structure and characteristics of certain authentic tasks in research and in the role of specific concepts, laws and methods in these tasks. For such learning goals a number of digital cases were developed in the FBT program. A few examples are: a 'Mixing and Oxygen Transfer' case, a 'Membranes' case and a 'Heat Transfer' case (Sessink et al. 2007b), a 'Personalized Diets' case, an 'Obesity' case and a 'Leptin Pills' case (Busstra et al. 2007b), a 'Downstream Processing' case (van der Schaaf et al. 2003), a 'Brain' case and a 'Light Induction' case (Aegerter-Wilmsen et al. 2003). Such cases are highly streamlined and stripped of almost all details. Understanding of concepts, laws and methods is still relevant but more relevant is their role in the authentic tasks. Operational definitions of learning objectives that articulate this 'task overview' goal, should therefore be much more tightly related to the case than operational definitions of learning objectives that articulate the 'understanding' goal. Actually, the case defines the learning goal.

Aiming at Whole Task Competency

Whole task competency is here defined as the competency to carry out a specific task completely, i.e. including all its details. Usually 'whole task competency' in higher education requires more than understanding. A whole task might include formulating a research question, designing an experiment in order to answer this research question, planning and carrying out the experiment, analyzing and interpreting the results and writing an article that presents this work. The main distinction between whole task competency and having knowledge and understanding of an overview of an approach to an authentic task is that the former requires also that the student has adequate routine on recurrent demands of the task. Digital learning materials enable students to carry out tasks with a high degree of authenticity. In this context a high degree of authenticity, means that the task is largely the same as a task in real life. Such tasks are in practice always composed of many sub tasks. Also the environment in which the tasks will be carried out is an environment that is normally used in the corresponding professional context. Examples of such environments are SuperPro Designer (Intelligen 2007) in a process engineering context or SPSS (SPSS 2008) in an applied data analysis context. Examples of learning materials that come somewhat in the neighborhood of supporting the acquisition of such whole-task competency are described by (Busstra et al. 2008; Busstra et al. 2007a; Sessink et al. 2006). Even these examples provide relatively little exercise aimed at routine. All in all most FBT learning materials aimed to support the acquisition of concepts and understanding in the context of a whole task and to provide insight in whole tasks, but did not aim at building routine on recurrent cognitive skills in the context of an authentic task.

Aligning the Virtual environment, the Learning task and Assessment

Focusing on learning goals that are strongly related to a whole authentic task such as in described above, has important consequences for the operational definition of the learning objectives and thus for the final assessment. The challenge is not only to align learning tasks, intended outcomes and assessment (Biggs et al. 2007), but also the virtual learning environment that enables the learning tasks. Many learning processes as well as assessment processes in higher education will require the student to execute a set of tasks. In an often used paradigm, the student is said to be supported by ‘scaffolds’ during a sequence of tasks and successive tasks have to be carried out with less and less scaffolding (Collins et al. 1989; Merriënboer et al. 2007). Means for scaffolding are for instance, sequences of guiding questions, analogies, particular problem formats, or constraints on the number of options provided to the student. The learning goal is often that the student can carry out the task with a well-defined maximum set of scaffolds in specified conditions. Alternatively, the learning goal is often that the student is able to carry out the task without any scaffolding. This line of reasoning implies a definition of an assessment and therefore a definition of a set of design requirements. In order to make these requirements operational, we distinguish two main approaches.

One approach is to ask the student to carry out the task in the digital learning environment such that the performance can be reviewed by an expert panel and/or to submit the results to an expert panel. Then, the expert panel has to decide if the performance and or the results are satisfactory. This approach rests on the digital learning materials or digital learning environment, but the actual assessment is not incorporated in the environment. The current state of performance assessment is still far from enabling such incorporation (Sluijsmans et al. 2006). On the other hand, this first approach requires the availability of very much expert capacity. For many subjects in natural and engineering sciences, availability of expert capacity is very limited.

The second approach is to specify requirements with respect to the students’ performance or with respect to the results of the students’ performance. For some tasks, this can be formalized in advance. For instance, one can ask the student to design a purification process in a given virtual environment and define a set of specified requirements for the design that the student has to deliver. One can also set requirements on the students' path in the design space. For instance, one might require that certain types of mistakes are never made or not made more than once. Or one might require that certain sub tasks never take more than a specified amount of time. Thus, for a task like this, it is at first sight possible to define the learning objectives operationally before the student takes the exam. For a task like this, it might also be possible to realize computer-based assessments. This would be an item on the research agenda.

The main questions to be answered would then be: (1) how to define student behavior in terms of variables that can be monitored effectively and efficiently, (2) how to define scoring rules for student behavior based on these variables, (3) how to define scoring rules for student results, and (4) how to define the boundary between satisfactory score and unsatisfactory score. The first question will involve some software engineering efforts. The other three questions require that knowledge of assessment in education and psychometrics is combined with topic-specific subject matter knowledge and/or topic-specific pedagogical content knowledge. As to defining scoring rules for student results, wide availability of innovative closed-question types might suggest that at least for these question types the discussion about scoring rules has been concluded. However, recent research shows that even for multiple-response question types the theoretical justification of scoring rules is incomplete and far from trivial (Boxel et al. 2007). Finally, computer-based assessment will also involve the question on how to organize secure web-based exams (Sessink et al. 2004).

Concluding Remarks

This article describes a six-fold classification of faculty-based DOR projects and project goals aiming at innovative digital learning materials in higher education in natural and engineering sciences. A conscious allocation of the focus of innovation to one of the six classes helps to prevent the project side-slipping into a class that does not match well with the available resources. In particular, a project with a focus of innovation in the upper left hand cell of Table 1 will require considerable investment of efforts of the primary stakeholders. Here subject matter experts will have to invest considerable effort in articulating learning objectives and operationalizing these objectives in terms of available assessment technology. When the focus of innovation is closer to, or inside, the lower right hand cell in Table 1, the centre of gravity of efforts is likely to shift towards knowledge domains that are usually not covered by the subject matter discipline. In particular, focussing innovation on a digital environment that enables an integrated learning experience of heterogeneous student populations in whole academic tasks (i.e. a shift towards the lower right hand corner of Table 1) will still require efforts of subject matter experts. However, such a shift tends to require considerable software engineering efforts and interfacing with other knowledge domains besides the subject matter knowledge domain. Moreover, such a shift would actually imply a shift from learning materials to more generic systems. Such systems would be the successors of the current generation of learning management systems. In particular, new learning management systems would enable more adaptivity (e.g. GRAPPLE 2008; Sessink et al. 2007a) and/or support knowledge management approaches that can capture communications of students and experts and use this to enhance learning materials (e.g. Heinrich et al. 2000; Maurer 2003). Apart from this, such systems are also likely to be based on new architectures (see for instance OKI 2008).

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