A Holistic Approach to Instructional Design for Technology-Supported Engineering Courses.

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ABSTRACT

In engineering education research, many methods have been presented to support curriculum design. Courses, however, need to be designed as well. While designing a course, attention must be paid to the subject matter, pedagogical aspects and technological factors, for example. New teaching technologies further widen the potential solution space. This results in a complex design challenge for the teacher. The teacher's ability to design the courses has a direct impact on how successful learning will be.

The purpose of this literature review is to clarify what methods currently exist for the systematic design of courses in engineering education. We focus on the following research questions: 1) What methods, tools and processes currently exist to support the design of courses? 2) What are the key concepts, models or theories they are based on? 3) What is the role of information and communications technology (ICT) in these methods?

The literature review shows general instructions, with central affecting factors, are available. Current approaches present some aspects—for example, student motivational factors or the role of teacher instructional skills. However, the systematic or more holistic method, which supports a study module design including ICT aspects, is not currently available. This study's results contribute to an educational design research project that is aimed at developing a systematic design method for ICTsupported courses within the engineering education context.

1 INTRODUCTION

'We will not meet the needs for more and better higher education until professors become designers of learning experiences and not teachers' [1]. The students often live in the moment; the studying process will become concrete through the courses taught at each stage of the study. Hence, courses are key elements employed to prepare students for the demands of workplaces. While students study using the courses, the know-how will cumulate and be fully effective with the accomplishment of all the courses related to the degree. So the teacher constantly acts the crucial role when designing courses. However, should this design be made?

Knowledge about course design is the most significant bottleneck in better teaching and learning in higher education [2]. In light of current research information, the teacher is often seen as a designer of learning, where the design methods and the control of design tools are emphasised. The traditional approach to the planning of the course, in which the contents to be taught direct the planning, has been found to be inadequate [2]. In addition, constructivist-oriented teaching has added challenges to the design of courses. Many teachers experience difficulties with constructivist-oriented pedagogies because they tend to be in conflict with their pedagogical practices [3]. The use of technology on campuses has been one of the most significant movements in higher education over the last decade [4]. Advanced teaching

technologies have, however, brought not only more possibilities but also challenges to the design, and integrating information and communications technology (ICT) into classroom teaching and learning continues to be a challenging task for many teachers [5].

To address the challenges, a recently developed theoretical framework designed to guide research in teachers' use of ICT is the technological pedagogical content knowledge [6]. For teachers, the design of ICT-integrated lessons for 21st-century learners can be challenging, as they need to keep up with the rapid proliferation of ICT tools [3].

Different methods have been developed to support the course design. Newell (1983) describes the method with four statements [7]:

1. It is a specific way to proceed.
2. It is a rational way to proceed.
3. It involves subgoals and subplans.
4. Its occurrence is observable.

The objectives of these methods have been to intensify designing and help align teaching according to the theoretical premises of the methods. Learning outcomes, teaching and learning activities and assessment are seen as sections which are tightly intertwined and not as unconnected pieces of the design of courses [6]. It is a challenging task to fit educational principles and contents into the design so the learning outcomes, which are the starting point for the design, can be reached.

The purpose of this literature review is to clarify what methods exist for the systematic design of courses in engineering education. We focus on the following research questions: 1) What methods, tools and processes currently exist to support the design of courses? 2) What are the key concepts, models or theories they are based on? 3) What is the role of ICT in these methods? The point of view regarding ICT concerns its possibilities to support teacher and student work before, during and after the teaching and learning activities.

The rest of the paper is structured as follows: Section 2 discusses the research method used, focusing on the search strategy and data sources. Section 3 introduces the results of the literature review. Section 4 discusses the findings and validity of the study. Finally, Section 5 concludes the paper with future directions and final remarks.

2 RESEARCH METHOD

The amount of research information in the world is constantly increasing; this is especially true for the field of engineering education. If an engineering education researcher (or a teacher as a researcher) wants to be conscious of the present state of relevant research, he or she must continuously follow new research results.

The research method of this study is a literature review. The purpose of a review is to provide a holistic understanding of the topic of interest [8]. An integrative literature review is used in this paper. Integrating literature review is a good research method when one wants to describe all the aspects of a phenomenon [9]. Using this approach, it is possible to combine different methodologies to review the literature and provide a summary for a more holistic understanding of the phenomenon [9]. Integrative literature reviews represent the broadest type of research review methods, and they are distinctive for combining diverse data sources, such as experimental and nonexperimental research or theoretical and empirical literature [10]. Integrative

literature review neither selects nor separates a research material as carefully as a systematic literature review, but if well done, it is able to present the state of the science and contribute to theory development [10]. An integrative literature review entails problem identification, formulation of inclusion and exclusion criteria, literature research and evaluation and analysis of data [11].

2.1 Search strategy and data sources

Searches were conducted in March and April 2019 using electronic database search engines (Scopus, EBSCOhost and Wiley Online Library) to find literature which could answer the research questions. Attention was focused on books, specific book chapters, PhD theses and peer-reviewed articles, but all scientific accepted forms of literature were considered. The first method used was searches with phrases connected with Boolean terms. After these basic searches, the amount of relevant literature was rather small, so we used a snowballing method to supplement results. Snowballing refers to using the reference list or citations of a paper to identify additional literature [12].

2.2 Inclusion criteria

In the first inclusion stage, the aim was to find books, book chapters and PhD theses of good quality that answer the research questions. Because engineering education is part of a higher education field, we decided to accept literature from an area of higher education if it contributed to course design. The search criteria included the literature was published after the year 1999 and the language of the publication being English. The main reason for limiting the search by year is outcome-based education became more common in this century, and this form of education has significant effects on course design. The search words were a combination of the main concepts of course design. Many test searches were required to find a suitable combination of terms. The keyword combinations always included the word ‘design’ to direct the searches to the right content. The word ‘course’ has many synonyms, so it was necessary to use all possible alternatives. Word searches including ‘study module design’, ‘course design’ and ‘teaching strategy design’ were used in combination with the term ‘higher education’. These searches often led to many duplicates. Examples of the results of the first stage of the literature research process are presented in *Table 1*. *Table 1.* First-stage search results (examples)

Date	Search engine	Search words	Restrictions	Keyword hits in search
4.3.2019	EBSCOhost	‘Course design’ AND ‘higher education’	2000–; Books	33
11.3.2019	Wiley Online Library	‘Course design’ and ‘higher education’	2000–; Books	112

In the second inclusion stage, the aim was to find articles of good quality that answer the research questions, focusing on only engineering education. The search criteria included the study was published after 2013, with the full text available, the study was peer-reviewed, and the language of the publication being English. Hence, it

was possible to ensure that the information was up to date. Examples of results from the second stage of the literature research process are presented in *Table 2*. *Table 2.* Article search results (example)

Date	Search engine	Search words	Restrictions	Keyword hits in search
2.4.2019	Scopus	'Course design' OR 'study module design' AND 'engineering education'	2013–; peer-reviewed articles	478

2.3 Exclusion criteria

The inclusion stage led to an extensive amount of literature. During this stage of the literature review, the aim was to delimit the literature to only studies which have relevant content. For that purpose, titles, abstracts and tables of contents were examined, and the studies that did not meet the criteria were ignored. Only the books which processed the design of the courses in higher education were accepted to the final review. If the focus was on curriculum design, the book was rejected. After this exclusion process, six books were accepted. In the case of articles, only those which processed the design of the courses in engineering education were accepted to the extension. Articles focusing on curriculum development or innovation in classroom instruction were not included since these topics were out of the scope of this research. After this exclusion process, nine articles were accepted. Using these 15 sources for the snowballing method, we added two books and two articles to the final analysis. Overall, after all searches and the inclusion/exclusion stage, we accepted 8 books and 11 articles for the purpose of a detailed analysis.

3 RESULTS

To get the answers to the research questions, the accepted literature was carefully analysed. An important focus was to find out what role ICT plays in the selected design methods. The role was divided into three stages: before, during and after course implementation. This role was evaluated from the perspectives of the teacher and the students. Simultaneously, it was possible to notice what main tools and processes were used and what kind of theoretical foundations or models were present in the background. This analysis was mainly performed by the first author. An overview of the results of the analysis is presented in *Table 3*.

Table 3. Overview of design methods, tools, processes and the role of ICT

Method	Main tool(s)/process(es)	Theoretical foundation/model	Role of ICT			Context
			Design	Action	Asses.	
Traditional course design [13]	Content sequencing	Behaviourist	-	-	-	HE

Integrated course design [2]	Course development worksheet; taxonomy of significant learning	Constructive	-	T+S	-	HE
Constructive alignment [14]	Structure of the observed learning outcome taxonomy	Constructive	-	T+S	T+S	HE
Backwards course design [15]	Content priorities; diagram clarification	Constructive	-	-	-	HE
Idea-based learning [13]	Course design document template	Constructive	-	T+S	-	HE
Designing and assessing courses and curricula [4]	Form for establishing the need for the course design process	Constructive	-	T+S	-	HE
Course design [16]	Flexible modes of content delivery	Constructive	-	-	-	HE
Content assessment pedagogy model [17]	Concept map; assessment triangle	Constructive	-	-	-	EE
Effective course model [18]	Course assessment matrix	Constructive	-	-	-	EE
Product development model [19]	Stage-gate process diagram	Constructive/ product development	-	-	-	EE
Method	Main tool(s)/process(es)	Theoretical foundation/model	Role of ICT			Context
			Design	Action	Asses.	
Intrinsicmotivation course design [20]	Intrinsic-motivation process diagram	Self-determination motivation theory	-	T	T	EE
Design thinking in course design [21]	Evolution 6^2 model adapted for instructional design	Design thinking	-	-	-	EE

Competence-oriented didactics [22]	Competence-oriented didactic course flowchart	Klafki's theory of education	-	-	-	EE
Gathering feedback [23]	Conflict cards	Constructive	-	-	-	EE
Theory-based course design [24]	Process with focus on engineering sciences and employed learners	Constructive/motivation	-	-	-	EE
Consensusbased course design [25]	Fishbone diagram integrating the rule for implementing cat	Consensus-oriented decision	-	-	-	EE
Working process course design [26]	Six steps to organising teaching	Constructive	-	-	-	EE
Gamifying educational process [27]	Gamification methodology algorithm diagram	Gamification	T+S	S	-	EE
Lean principles course design [28]	Value stream mapping; Kaizen; 5 Whys; quality function deployment	Continuous improvement	-	-	-	EE

*Abbreviations: Asses. = assessment, T = teacher, S = student, HE = higher education, EE = engineering education.

3.1 Research question 1

What methods, tools and processes currently exist to support the design of courses?

We can argue that there are many methods which support course design. The first column of *Table 3* gives a basic illustration of founded methods. All the theories include different kinds of tools and processes. The main tools and/or processes are illustrated in the second column of *Table 3*.

3.2 Research question 2

What are the key concepts, models or theories they are based on?

Every design method uses concepts when constructing the structure of the design process. The main concepts are learning objectives/goals, instruction/delivery and assessment. Under these main concepts, there are several method-specific subconcepts. The most used theoretical foundation for the design of courses is constructive learning theory (*Table 3*, third column). The other theories or models originate from industrial backgrounds or design research. For course design, it is possible to categorise the relevant theories into three types: learning theory, assessment theory and instructional theory. However, a more exact analysis is not the goal of this research.

3.3 Research question 3

What is the role of ICT in these methods?

In *Table 3* (fourth column), there is an illustration of the role of ICT in the methods. A few of the methods emphasise the possibilities of using ICT to support the teacher and the students' teaching and learning activities (T+S in the 'Action' cells). However, the design and the assessment phase are mostly abandoned. Some guidelines are presented on how to implement ICT in teaching processes, but there are no specified directives on how to take educational technology into account when it is time to make design decisions.

4 DISCUSSION

Research on engineering education course design are characterised by a relatively small number of studies that provide a general overview and a large number of works, mainly articles that focus on specific elements of study module design. A short article or report which describes and evaluates the effectiveness of innovation in course design is one of the standards of higher education literature [29]. Several higher education research projects and publications include evaluations of innovations introduced at the course level. Not surprisingly, these appear far more frequently in the form of journal articles than books [29].

One can argue that in the literature on course design in engineering education, the most used design methods are based on constructive alignment. The fundamental starting point for this principle is intended learning outcomes [14]. There are several iterations of this principle, but the fundamental thought is the alignment of the assessment and the teaching and learning activities to support the learning outcomes. Methods such as backwards design and effective course model emphasise the stages of the planning process in a different manner and offer different tools for design. It is recognised that courses are designed by and for people, and the process is more of a holistic and organic one than is usually acknowledged [16].

It is important to notice that the design of courses can be divided into three elements: the design of learning objectives (learning outcomes and core content), the design of assessment (assessment techniques, tests and surveys) and the design of instructions (lectures, laboratory assignments and used instructional technology) [18]. These elements comprise the core of the design. Elements are intertwined and affected by many situational factors—for example, the number of students who will participate in the course, knowledge level of the students, status of the students (full time or part time) and the teacher's prior experience in the subject matter and knowledge and skills of the teaching process [2]. Attention must be paid at a very early stage to instructional techniques because they affect, in many ways, the student assessment procedures.

How student learning is designed, assessed and delivered immediately impacts one of the main 'customers', the students [29]. Nevaranta (2012) emphasised a course as a modular service product of which its customers are students [30]. It is possible to approach design tasks as a product development job and use widely adopted product development methods from the industry [19].

The impact of technology on teaching and learning is widely recognised. Technology significantly not only increases the instructional options available to

faculties but also has a negative impact on two areas that are often neglected: institutional budgets and the ways in which students study and learn [4]. Technology has an impact on how students approach the entire learning experience. Currently, faculties are reporting decreasing attendance in classes, more students multitasking during lectures and difficulty in getting students to devote to their assignments the amount of effort and time required for quality work [4].

The theoretical framework designed to guide research in teachers' use of ICT is the technological pedagogical content knowledge [6]. However, it seems that the framework is not applied in connection with course design systematics at the moment.

Similar to all studies, this study has certain limitations. The number of articles related to general course design, in the context of engineering education, turned out to be small. Studies focusing primarily on course design are rare. However, this study managed to capture the representative sample of the relevant literature and, consequently, synthesised the form of the big picture.

5 CONCLUSIONS

Many distinguished researchers have thought about the complex challenge of course design. Methods and tools developed during research aim to facilitate and systematise design. In the background, there are many limiting factors. These are, for example, the researcher's view of life, teaching and learning theory and the context for which the model has been developed. Due to many variables, it is probably impractical to develop a universally applicable method. Every study, however, has its own value. The methods and tools, at best, bring systematics to design and make repeatable, efficient processes and the constant improvement of quality possible.

The constraining time resource drives teachers into a situation where it is not possible to maintain present learning results without efficiently utilising technology. Particularly assessment is a time-consuming stage of course implementation. Using technology to help formative and summative assessment is one promising application area. Students receiving instant feedback on their progress will provide good support for learning and make assessment more sustainable and instructive.

A design method for course design which pays attention to the efficient use of technology is not currently available. In light of this fact, more attention must be paid to the systematic design methods which offer practical tools for the intensification of teaching and learning processes with educational technology. The results would contribute to an educational design research project that is aimed at developing a systematic design method for ICT-supported courses within the engineering education context.

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