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**THE POTENTIAL OF PROBLEM-SOLVING OPTIMISED INSTRUCTIONAL DESIGN
METHODOLOGY IN DIGITAL CONTENT DEVELOPMENT**

Theses for doctoral thesis (PhD)



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1. Topic and the framework of the PhD thesis

The aim of my dissertation is to investigate instructional design features that enhance learning effectiveness as elements of problem-solving optimized digital learning materials. In this context, I first introduce the principles of problem and problem solving that still dominate today's thinking on instructional design.

Effective problem solving is a major area of psychological research. Research has investigated the impact of problem incubation and of different emotional factors on problem solving. In the area of cognitive load theory, there have also been significant recent findings on the influence of different sources of load on working memory during problem solving on problem solving efficiency. In my dissertation, I present in a separate chapter the principles and research findings related to the psychological aspects of problem solving.

The OECD (2015) sees problem solving as an integral part of the everyday life of 21st century people, so in chapter four I will show how, approaching it from the perspective of labour market needs and expectations, we arrive at the conclusion that the different teaching-learning processes necessarily have to reflect the goal structures that determine the thinking about educational design. In the process of teaching, the learning process is organised in such a way as to produce the most effective growth of knowledge. Theories that view the teaching-learning process as a system have been developed to this end. In my dissertation, I present the most important models of instructional design, with a focus on their elements dealing with problem solving.

In order for learning to be effective, an appropriate learning environment must be created for the learner. We are developing e-learning environments as an effective learning environment. The digital technologies present in the learning environment allow us to make learning available in every area of life, at any time of life. In the fifth chapter of my dissertation, I present the characteristics and learning management tasks of teaching-learning processes in ICT-enabled environments. For successful online learning, well-designed and organised learning materials are necessary, and I will present theories and findings on four key features of these materials: the texts, the required and expected features of visual elements, the possibilities for supporting learners, and the length of materials for independent learning.

In my dissertation, I will review the models of instructional design related to problem-solving instructional design that have been developed to formulate the

target structure of problem-solving instructional design, with a special emphasis on the questions that arise as a result of the analysis of various research studies and the recommendations of practicing instructional designers.

In the sixth and seventh chapters of my dissertation, I present the research hypotheses, strategies, methods, tools and results of the research on the potential of a problem-solving optimised instructional design methodology in digital content development. Based on the results of the research, I will make recommendations for digital content development and further research, taking into account the limitations of the present research.

2. Literature background

In its 2015 publication, the OECD states that problem solving is an integral part of daily life and work (OECD, 2015). Solving non-routine problems is one of the most important skills of the 21st century (Zhang, Yu, Li and Wang, 2017).

Citing Mayer's definition from 1990, the OECD defines problem solving as a cognitive process from an initial situation to a target situation, in which there is no obvious method for solving (OECD, 2015). In effective and efficient problem-solving, the individual must be able to add new information to the knowledge of the context and be able to search for, interpret and organise it in the problem situation using tools that enable him or her to communicate and access information electronically.

In this dissertation, I deal with the solution of ill-structured problem types, where the starting point and the goal state, as well as the available tools, are not fully defined (Funke, Fischer and Holt, 2018). Ill-structured problems lack a prototype case, general principles and rules, and action metrics that would provide clear guidance for solving. In the solution process, it is necessary for the problem-solving individual to express his or her views and make decisions through the motivational and cognitive components (Jonassen, 1997).

Knowledge of the behaviour and psychological state of the problem-solving individual - the learner in terms of the learning process - is also of crucial importance in educational planning. In addition to cognitive factors in the problem-solving process, emotional and behavioural aspects of the individual have also been investigated by researchers in the field (Muis, Chevie and Singh, 2018; Di Leo et al., 2019). In psychological research on problem solving, the incubation phase, in which the individual puts the problem aside, context switches or relaxes, is a key

element in the solution process, leading to a positive effect (Gilhooly, 2016; Talandron-Felipe and Rodrigo, 2021). The effectiveness of problem solving is influenced by the level of cognitive load from several perspectives: excessive demands on working memory make it difficult to correctly interpret and process information (Leahy and Sweller, 2019). A noteworthy finding on emotions is that, contrary to previous research, the impact of frustration and stress in the problem solving process is not clearly negative, as recent research suggests.

Educational design and development is nowadays in many cases designed to meet the educational needs of market organisations, and therefore different educational design models, and improved versions of them, have emerged in recent decades. The processes described in these models combine pedagogical principles with professional development work. There are clearly defined development objectives and target systems, adapted to individual content, and creative solutions that can be applied to the objectives in an LMS. The subject matter expert plays a significant role in the design of curriculum content (Williamson, 2019; Sengupta, 2020). Curriculum developers transform content into learning materials that incorporate learner activity and feedback. An essential element of the development process is the revision phase, in which the course or curriculum is revised in terms of the skills and competences to be acquired.

Digital content development should also take into account the specificities of the online learning environment (Komenczi, 2021), as well as the characteristics of learning in this environment (Dávid et al., 2016; Faragó, 2016). Other aspects to be considered when designing learning materials include research on text formatting adapted to visual interfaces (e.g. Murphy, 2000; Eóry, 2006) and the use of visual elements (Ollé et al., 2016; Walia, 2020). In this dissertation, I also presented and compared two recent models of digital content development optimised for problem solving: the Nexius model's problem-solving curriculum schema (Ollé et al., 2016) and Singkaew and Chaijaroen's model (2021). A review of instructional design models for e-learning environments suggests that instructional design should ensure that the learner has access to the widest possible understanding of the problem and the information needed to identify and analyse the problem. The learner's task should be to plan the phase of analysing, organising and evaluating the information, as well as the analyses, summaries and conclusions to be drawn from the information.

3. Purposes and hypotheses

In my literature review, I have focused on theoretical approaches and empirical research in which problem solving, or more narrowly, real-world problems of professional practice, are the central organizing element of the curriculum. As a research question, I have formulated which of the instructional design model elements that have proven to be effective in the classroom environment can be incorporated into digital learning materials designed for independent learning, and whether they can measurably increase the efficiency and effectiveness of learning.

Based on the literature review, previous own and research group learning material developments and related pilot research, the hypotheses developed in this research relate to learning with learning materials optimised for problem solving, as well as the logical structure, visual and linguistic design and layout of learning materials.

In the course of the research, I tested two hypotheses about the impact of the existing online learning experience on the characteristics of learning and on the learning experience during the period of time the student perceived as effective.

- H1: Prior online learning experience does not predict the effectiveness of learning with a learning material optimized for a differently designed problem-solving interface.
- H2: Learning is more effective for learners who learnt online in the time of day considered to be the most effective with digital learning materials optimised for problem-solving for self-directed learning than for learners who learnt in other times of day.

With my H3 and H3/a hypotheses, I used the studies of Jonassen (1997), Likourezos and Kalyuga (2017) and Sharma (2017) to investigate whether the prior introduction of the solution(s) to the problem(s) and the analysis of possible wrong ideas and solutions during learning can influence learning effectiveness and learner interest.

- H3: Learning with problem-solving-optimised digital learning materials for independent learning is more effective if the presentation of the solution to the problem is presented at the beginning of the learning material, after the problem has been introduced, than if the learner is only introduced to the problem situation to be solved at the beginning of the learning material.

- H3/a sub-hypothesis: Learning with digital learning material for independent learning is more effective if the good solution to the problem is presented at the beginning of the learning material and then the bad solutions are analysed, than if the learner only learns the problem to be solved at the beginning of the learning material.

On the basis of theories about the visual and textual representation of learning material, I hypothesized a difference between the versions of learning material that contain concise texts and those that contain an outline structure, and between the effectiveness of learning material with different types of visual support.

- H4: In the case of problem-solving-optimised learning material designed for self-study in an online interface, a measurable difference in performance during learning is the presentation of text that does not present a continuous text in sentences but rather in syntactic links that highlight the main points.
- H5: Significantly better learning outcomes can be achieved with learning material optimised for problem-solving and designed for independent learning if it contains a majority of images that represent the real-world context of use of the information content, rather than if the material contains only drawn but also contextualised images.
- H5/a: Learning is more effective with problem-solving-optimised, self-paced learning material if, in the initial phase of the learning process, simpler information graphics are used, and in the subsequent phase, pictures of the real environment are used, compared to if the learner sees pictures of the real environment from the beginning of the learning material.

Various forms of supporting learners in the learning process have been proposed by researchers and curriculum developers (e.g. Nehme, 2010; Pléh and Faragó, 2016; Bao 2020). In this research, I investigated the effectiveness of using written and spoken forms of supplementary explanations available from the curriculum in the MOODLE interface, using the H6 hypothesis:

- H6. Learning is more effective when an individual learning with a self-paced, problem-solving optimised learning material designed for online learning listens to the explanation of terms that are unfamiliar to him/her, rather than just reading it.

In the description of the Nexius model (Ollé et al., 2016), the authors suggest that irrelevant information for the learner to solve the problem should be included

in the learning material. Based on the results of research on older learners' learning in an online interface, Ahmad et al. (2022) point out that irrelevant content should be avoided as it may distract older adult learners (I define older learners as those aged 40-59 years, older adults and the elderly¹). My hypothesis is as follows:

- H7. It has been shown that if the help and information provided to solve a problem in digital learning material contains not only the necessary but also distracting information that is not relevant to the problem, it leads to a decrease in learning outcomes in the older age group.

In psychological studies of problem solving, the interruption of student activity appears to have a beneficial effect on students' thinking and problem solving recognition (e.g., Barkóczi, 1999; Gilhooly, 2016). Based on this, I formulated the following hypothesis:

- H8: Learning with problem-solving optimised online learning material for independent learning will be more effective if the learning activity is interrupted by a task not related to problem solving, compared to if the learner is continuously progressing in the problem-solving process as determined by the learning material.

4. Research strategy of the study

In my research, I designed research materials based on the principles of problem-solving instructional design methodology and created them on a MOODLE platform installed on my own website, where the pre-learning and post-learning questionnaire and the glossary of terms were available to the research participants. After 254 volunteer students had completed the learning process, I analysed the data using statistical methods to assess the effectiveness of the methodological elements.

5. Methods

The research is a multi-sample curriculum experiment, in which several versions of the curriculum were developed for the same educational content. Each of them

¹ The classification of the age group is based on the KSH Demographic Research Institute's Glossary: <http://demografia.hu/hu/tudastar/fogalomtar/12-korosszetetel>

is optimised for the learning of the problem, but they differ in the elements related to each hypothesis. The baseline and final states are measured by questionnaires and knowledge tests, while the learning process data for the experimental learning materials are provided by the MOODLE interface.

The knowledge content of the experimental curricula is aligned to the curricula of the construction training, based on a real-life situation. Based on an instructional design methodology optimised for the problem solution, the curricula are designed in a baseline (baseline) and 7 experimental versions. The specificity of the ill-structured problems is that the context of the problems is the daily workplace or a specific field of expertise (Funke et al., 2018), therefore the problem situation used is a case in the construction workplace. This real-life situation is woven through the selected curricular content as a case study, motivating and supporting student engagement (cf. Ollé et al., 2016).

The curriculum content is structured around smaller units of content, which is in line with the Rimmer (2020) recommendation. The short content units are concluded with reflective questions, which are presented in the form of multiple-choice test questions. I have designed the length of the learning materials to allow approximately 20 minutes of learning time, based on the theoretical considerations introduced in section 5.4.4 and the length of the topic unit.

A Glossary extension is available in the MOODLE interface to ensure that learners can access the supporting information without exiting MOODLE.

A non-probability sampling was used, according to the possibilities and the subject of the research. For learning with the learning materials, I targeted adult-age students who were enrolled in or had completed their studies in a technical or university course in the field of construction. The sample consists of 254 students, with an average age of 28 years, a median age of 22 years, the youngest student aged 18 and the oldest aged 69.

The study was a cohort sample analysis, in which I examined students' responses to a questionnaire before and after learning the curriculum and their learning outcomes.

Prior to statistical analyses, the variables were classified on the type of scale (nominal, ordinal, interval, ratio). The vast majority of the variables used to test the hypotheses were measured on a nominal scale, with only age and the input and output outcome measures (and the numerical characteristics derived from them) being measured on an in-interval scale. For nominal variables, the descriptive statistics were the chi-squared statistics, and for interval scale data, the class

statistics. For normality testing, I performed Kolmogorov-Smirnov and Shapiro-Wilk tests using SPSS. Based on the normality tests, most of the baseline data are from non-normal distributions, so I performed a Wilcoxon signed rank test to test the significance of the learning outcomes.

6. Results and conclusions

Based on the results of the research, the following table summarises the instructional design considerations that can be implemented to increase efficiency and those that can be omitted because they do not increase efficiency:

	Methodological options	The location of the element in the inventory, including its proposed location if its location is inappropriate	Proposal based on research results
1.	present a solution to the problem raised	at the beginning of the lesson, following the presentation of the problem situation	there is no evidence of an increase in learning efficiency and therefore no justification for its use
2.	the solution to the problem raised and the misconceptions	at the beginning of the lesson, following the presentation of the problem situation	there is no evidence of an increase in learning efficiency and therefore no justification for its use
3.	text formatting with syntactic links to emphasise the point	throughout the whole curriculum	has been shown to increase learning efficiency, it is recommended to use

4.	images of real-life environments that correspond to the information content of the curriculum	throughout the whole lesson	increase the effectiveness of learning, it is recommended to use
5.	contextual diagrams that display simpler information	at the beginning of the lesson, at the initial stage of the learning process	increase the effectiveness of learning, it is recommended to use
6.	readable explanation of terms	on the first appearance of the concept on the course material page and in the learning interface in the form of a separate glossary	tendency to increase the efficiency of learning, it is recommended to use
7.	audible explanation of terms	on the first appearance of the concept on the course material page	tendency to increase the efficiency of learning, it is recommended to use
8.	irrelevant information not related to the problem presented	not specified	develops cognitive skills in problem solving, no reduction in learning efficiency can be demonstrated, recommended for use
9.	interrupting a learning activity with another task	not specified	a tendency to increase the effectiveness of learning, it is recommended to use

7. Limitations of the interpretation of the results, further research directions

The present research was planned in the period before the COVID-19 pandemic, and the research materials were prepared in the second period of the pandemic. I started recruiting participants in January 2022, and I tried to be representative in terms of age and education in the field of construction professionals. As a result of the surveys, 254 people were successfully recruited, mainly from the higher education population. As the educational subjects are unique and specific, I did not reduce the number of experimental subjects, but assigned the registered students roughly equally to each subject. This number of elements divided by the eight types of curricula distributed meant that the number of pupils assigned to each curriculum could be just over 30. Consequently, for some hypotheses, the results are indicative of a tendency towards a more relaxed period, it would be worthwhile to continue the research with more participants and a higher number of participants in a larger study with (public) funding, in order to confirm the emerging trends.

It is likely that the incentive I offered for learning and for the fact of completing the questionnaires resulted for some students in a superficial "click-through" rather than serious, in-depth learning. By verifying the results on a larger sample, such student behaviour could be detected and more reliable conclusions drawn.

In the case of technical terms and expressions that were identified as unknown and in need of explanation, it was possible to include a hyperlink to the glossary in the H5P MOODLE extension, which would turn the word into blue. This made the term highlighted in otherwise black letters - indicating that it was a hyperlinked word - which would not necessarily have been highlighted given the content of the page. It is likely that for some learners the highlighting was confusing, indicating materiality, and so may have altered the meaningful emphasis of the page. I did not find a solution to this problem in the pilot lessons, but I think it would be useful to address the issue in the future.

The suggestions for instructional design and content development formulated on the basis of the research results should be tested on other curricula in other subject areas, optimised for problem solving. My aim was to design general specificities and to measure their effectiveness, but the scope of the present research did not allow for the simultaneous treatment of one or more non-construction topics in a similar curricular structure. Concordant results from studies in different

disciplines would provide more reliable evidence of the learning effectiveness of the solutions described in each proposal.

It would also have been worthwhile to add short video films to the research teaching materials, as these have been shown to increase learner engagement and support comprehension. It was not possible to produce the necessary videos within the framework of the present research, but if sufficient financial and organisational resources were available, it would be worthwhile to carry out studies on the learning effectiveness of editing video films of different characteristics into the curriculum.

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