USING GRAPH-BASED HEURISTICS TO ANALYZE A SYSTEMATIC LITERATURE REVIEW AND VALIDATE AN EXPERT-BASED TAXONOMY

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ABSTRACT

The study presented in this paper uses heuristics from computer linguistics and graph theory to analyze a systematic literature review on educational technology. A literature review was conducted to validate an expert-based taxonomy which was developed to ontologize delivered teaching and learning for easy reuse. The sample includes N = 121 publications. The findings indicate that the yielded key words that were generated through T-MITOCAR Artemis contained key features that were rated as being relevant to the experts and caused the expert-based taxonomy to be changed and restructured. The results of this study provide directions on how time-consuming elements of systematic literature reviews could partially be automated.

KEYWORDS

Systematic Literature Review, Taxonomy, Validation, Technology-Enhanced Learning and Instruction, Mental Models

1. INTRODUCTION

Designing technology-enhanced learning and instruction in such a way that it promotes students' learning is of special interest in higher education. Therefore, it is important to align the intended learning outcomes with the choice of teaching and assessment methods (Biggs and Tang, 2007). Consequently, it is of interest to identify the impact of lesson designs and describe them for reuse in teaching (Vercoustre & McLean, 2005; Agostinho et al., 2009). For a reusable description of teaching, design patterns can offer a promising way to describe effective teaching patterns. The pattern approach, which originated in architecture (Alexander et al., 1977), was later applied in object-oriented software design (Gamma et al., 1993) and has already been established in education (Bergin et al., 2012; Derntl, 2005; Standl, 2014). To be able to identify patterns, the collected teaching data needs to be described in a suitable database-structure to be able to mine patterns. The backbone of this appropriate structure is, first, the development of a basic hierarchical structure as a taxonomy (Gamma, 1993).

Considering this, the aims of this study are: (1) to validate a taxonomy developed to ontologize digital instructional design, (2) to use innovative technologies to identify key concepts obtained through a systematic literature review. The present paper is structured in two main parts: First, we discuss the theoretical background and the selection of T-MITOCAR Artemis as an appropriate instrument to analyzing text material. Second, we explain how we conducted the study and discuss the results and innovational aspects of this study.

2. THEORETICAL BACKGROUND

The use of digital technologies in learning and instructional environments has been investigated in various context, like for instance, improving self-regulated learning (Freihofner, 2018; Pirnay-Dummer & Ifenthaler, 2018) and collaboration (Pifarré, M. and Martí, 2018; Swanson et al, 2021; Besser et al. 2022). Bellou et al. 2018 found that most empirical studies in Chemnistry Education focus first on the learning outcomes, then on student's motivation when investigating digital technologies in teaching practices and a few studies focus on teachers attitudes on digital technologies.

A number of features of instructional quality have been identified and categorized as distinctive predictors for the impact on student learning (Helmke, 2009; Seidel & Shavelson, 2007). For the identification of effective technology-enhanced instructional designs, it is furthermore required to consider domain-specific features that meet the need of the particular context. When investigating domain-specific terms, concepts, or entities of teaching learning settings, a taxonomy can provide a way to put this data into an ordered, hierarchical structure with categories and sub-categories (Rich, 1992). Furthermore, a taxonomy provides an adequate conceptual framework to structure features of teaching-learning settings in a way that they can be classified and retrieved (Vercoustre and McLean, 2005). Based on the structure of the taxonomy, a database structure facilities storing, updating and manipulating the information of teaching-learning settings (Vysniauskas & Nemuraite, 2016).

When conceptualizing key features of learning and instructional design and of instructional technologies that have been used in order to prompt learning, a taxonomy provides a way to put them into an ordered, hierarchical structure (Rich, 1992). While a taxonomy represents a domain in categories and sub-categories, an ontology adds to the taxonomy further semantics with relationships between the (sub)-categories and also defines further details. Therefore, a taxonomy can be considered as the backbone of an ontology (Giunchiglia and Zaihrayeu, 2007). Ontologies provide a promising way of storing distinctive features of learning and instructional design. An ontology is defined as an explicit specification of a conceptualization (Gruber, 1995). Bimba et al. (2016) distinguish between different forms of ontologizing: (1) application ontologies, (2) domain ontologies, (3) generic ontologies, and (4) representation ontologies. The application ontology captures all the relevant key features that are required to model knowledge in a specific domain. The domain ontology illustrates the domain specific conceptualizations. The generic ontology aims to generalize and be valid in different domains. The representation ontology is limited to a specific domain. In terms of capturing learning and instructional design in different domains, an ontology is needed that is able to store the key features of learning and instruction through a taxonomy in a generic way so that they can be transferred into other domains. Consequently, the features that are stored in the database which cover best-practice-examples must be stored on an abstract level. The application of web ontologies is a suitable way to store and represent an objective knowledge directory (Kampmann et al., 2020). However, teaching and learning designs are dynamic and, therefore, need to be ontologized dynamically.

2.1 Emerging Technology

2.1.1 Aim of Literature Review

The purpose of this systematic literature review was: (1) to validate a taxonomy developed to ontologize digital instructional design, (2) to use innovative technologies to identify key concepts obtained through a systematic literature review.

2.2.2 Identifying Key Concepts of a Literature Review with T-MITOCAR Artemis

T-MITOCAR Artemis (Text-Model Inspection Trace of Concepts and Relations Artemis) is a further development of T-MITOCAR. T-MITOCAR is a computer-based software application (Pirnay-Dummer & Ifenthaler, 2010; Pirnay-Dummer, Ifenthaler & Spector, 2010; Pirnay-Dummer, 2015a) which is strictly based on the theory of mental models (Seel, 1991). It is automated in its procedure and analysis and has proven to deliver homogeneous, reliable, and valid results in multiple studies. The software measures a specific set of properties of language re-representations and generates associative graphs from texts using heuristics from computer linguistics (Pirnay-Dummer, 2015b) and graph theory (Tittmann, 2010) combining theoretical foundations of mapping knowledge in a way and onto a format that is close to how humans internally represent knowledge for learning (Jonassen & Cho, 2008; Pirnay-Dummer & Seel, 2018; Spector, 2008; Strasser, 2010).

T-MITOCAR Artemis can be used to examine and aggregate knowledge-domains in learning and instruction. It uses multi-cluster text corpora as input and visualizes continents on a knowledge map out of several texts of a particular domain (Pirnay-Dummer & Ifenthaler, 2010; Lachner & Pirnay-Dummer, 2008, Pirnay-Dummer, 2015a).

3. RESEARCH QUESTION

The following research questions are of interest:

1. To what extent can T-MITOCAR Artemis be used to validate an expert-based taxonomy?
2. To what extent can heuristics be used to systematically analyze a literature-reviews?

4. METHOD

The systematic review was aligned to the proposed eight steps of Okoli and Schabram (2010). In accordance with Ifenthaler, et al. (2020) and Okoli (2015) all eight steps are essential: (1) identify the purpose, (2) draft a protocol and train the team, (3) practical screen, (4) search for literature, (5) extract data, (6) appraise quality, (7) synthesize studies, and (8) write the review.

The purpose was to find further potential key features that could be of relevance for the taxonomy. Several relevant databases were included (ERIC, PsycInfo and dissertation-databases). The keywords used were ('educational technology' or 'technology enhanced learning' in combination with 'teacher education' or 'higher education' and 'self-efficacy' and 'technology integration') as well as ('digital teaching' or 'digital learning' in combination with 'teacher education' or 'higher education' in combination with 'TPACK' or 'pre-service-teachers' in combination with 'innovation', and not including 'school'). In addition, we consulted dissertation -databases (dart-europe, obvsg, oatd, ucl). We used the following keywords for dart-europe ('mobile technology in the classroom'); ('pre-service teachers' in combination with 'self-efficacy' in combination with 'technology integration') as well as ('higher education' in combination with 'technology integration'). For obvsg we used the following keywords ('educational technology' in combination with 'educational technology'). We used the following keywords for ucl ('mobile technology in the classroom' in combination with 'higher education). To be included, publications had to meet the criteria: (1) published between 2015 and 2020, (2) peer reviewed. Duplicate publications were removed. Only those publications were included that were completely available.

The studies found were analyzed through T-MITOCAR Artemis. All retrieved studies were sorted into several domain-based clusters of up to ten studies, in order to generate knowledge maps through T-MITOCAR Artemis. The titles and abstract of the studies were reviewed and content-clusters created by an expert in the field of technology-enhanced learning. This intermediate step was implemented to generate knowledge-maps of domain-specific subjects through T-MITOCAR Artemis.

Finally, one expert in the field of digital teaching and learning independently and one trained person reviewed and rated the automatically reported concepts produced through T-MITOCAR Artemis in regard to: (1) the relevance of depicting educational technology; (2) if the concepts were already part of the taxonomy, and (3) if not, whether they should be included. The ratings of the concepts are illustrated in Table 1. All concepts are independently rated on a 5-point Likert scale (1 = not relevant, … 5 = relevant).

Table 1. Rating of the produced concepts through T-MITOCAR Artemis

Please rate the following taxonomy.		
1. The concept is relevant in order to depict digital teaching-learning-scenarios		
Not relevant	O O O O O	Relevant
2. The concept is already part of the taxonomy.		
No	O O O	Yes
3. The concept should be included in the taxonomy.		
No	O O O	Yes

The two experts who developed the initial taxonomy and the trained person met again and went through the concepts that were rated at least, as rather relevant. If those concepts were regarded by at least one person as relevant and were not yet part of the taxonomy, they went through a consensus-validation and were either added to the taxonomy or not.

5. RESULTS

Our literature search resulted in 312 publications. 223 publications were found in educational and psychological databases - 101 were available and included in the analysis. 89 publications were found in dissertation-databases - 21 were available and included in the analysis. Table 2 and Table 3 show the key word combinations and the numbers of publications that were found in the different databases.

Table 2. Results of the databases

Database	Keyword combination	Results
ERIC	(“digital teaching” OR “digital learning”) AND (“Teacher Education” OR “Higher Education”) AND (“TPACK” OR "pre-service teacher") AND ("innovation") NOT "school"	93
ERIC (2015-2020)	("educational technology" OR "technology enhanced learning") AND ("Teacher education" OR "Higher education") AND ("self-efficacy") AND ("technology integration")	36
PsycInfo(2010-2020)	(“digital teaching” OR “digital learning”) AND (“Teacher Education” OR “Higher Education”) AND (“TPACK” OR "pre-service teacher") AND ("innovation") NOT "school"	89
PsycInfo (2015-2020)	"educational technology" AND "pre-service teachers" AND "technology integration"	5
Total		223 Available Publications : 101

Table 3. Results of the dissertation-databases

Database	Keyword combination	Results
Dart.europe	"mobile technology in the classroom"	1
Dart.europe	“pre-service teachers” and “self-efficacy” and “technology integration”	8
Dart.europe	Higher Education AND technology integration	3
search.obvsg.at	"educational technology" AND "pre-service teachers" AND "technology integration"	1
search.obvsg.at	"educational technology"	2
oatd.org	("pre-service teacher") AND ("educational technology")	11
ucl-new-primo.hosted. Exlibrisgroup.com	"mobile technology in the classroom" AND "higher education"	63
Total		99 Available publications : 21

Publications that were dublicated were deleted. Altogether, 121 available publications were included in the T-MITOCAR Artemis analysis (one study was deleted due to major Turkish elements which could not be analyzed by the instrument). The following clusters were created in order to analyze the publications through T-MITOCAR Artemis (see Table 4).

Table 4. Clusters of studies found in ERIC & PsychInfo and dissertation-databases

Database	Clusters	Number of texts
ERIC & PsychInfo	Acceptance / Readiness	6
	Assessment	4
	Attitude	5
	Authenticity	5
	Beliefs	8
	Computer	7
	Environment	6
	Game / Gamification	5
	Innovation	12
	Perception	10
	Reflection	5
	Strategies studies	6
	Teaching practice	8
	Technologies’ development	3
	Innovation in Educational Technology	10
PhD-databases	Digital Technology	8
	Higher Education	4
	Reflection	3
	Lesson-specific aspects	6
		121

Figure 1 shows a knowledge map that was generated through T-MITOCAR Artemis out of ten studies that were grouped into the cluster of “Innovation in Educational Technology”. It contains 149 concepts that were generated out of ten texts through T-MITOCAR Artemis.

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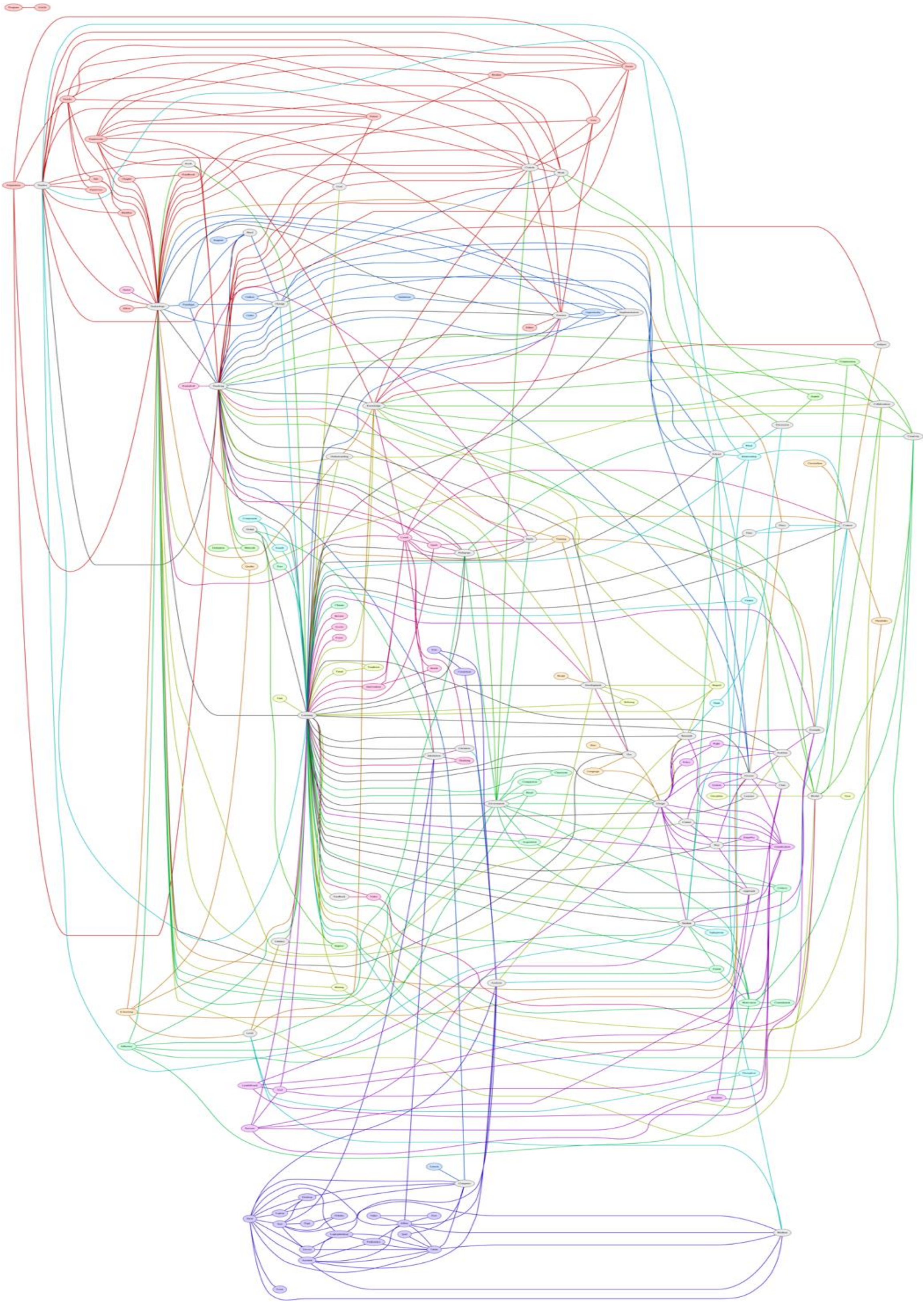

Figure 1. Knowledge map of the cluster Innovation in Educational Technology

The 19 knowledge maps yielded 403 concepts – 71 concepts were excluded as it turned out that in some studies there were still Turkish elements included in the references when referring to Turkish language. Therefore, 298 potentially relevant concepts were included into the rating. In a next step, these concepts were independently rated by two raters (one expert in the field of learning-enhanced technology and one trained rater). In a post-hoc analysis, another expert rated the 298 concepts as well. This was done in order to guarantee that different experts rated the same concepts as either relevant or not. The following Table 5 to Table 7 show the results of the ratings. Table 5 indicates that, on average, most of the concepts were rated as irrelevant, whereas 35 were regarded as maybe relevant, 34 as rather relevant and 44 as relevant.

Table 5. Descriptive results of the raters regarding the relevance of the concepts

Rating of the concepts	Expert 1	Trained Rater	Expert 2	AM
Not relevant	137	160	212	170
Less relevant	22	15	9	15
Maybe relevant	44	27	33	35
Rather relevant	50	27	24	34
Relevant	43	70	20	44
Sum	299	299	298	

Table 6 shows that most concepts were rated as not yet part of the taxonomy.

Table 6. Descriptive results of the raters regarding not yet part

Rating of the concepts	Expert 1	Trained Rater	Expert 2
Not yet part of the taxonomy	231	194	256
Already part of the taxonomy	28	78	20
Partly part of the taxonomy	29	26	23

Table 7 reveals that most concepts were rated as to be included into the taxonomy. Expert 1 rated that 20 concepts should be included and 1 concept may be included. Finally, 21 concepts were in particular discussed in the consensus-validation when restructuring changing the taxonomy.

Table 7. Descriptive results of the raters regarding including the concepts

Rating of the concepts	Expert 1	Trained Rater	Expert 2
Not including into the taxonomy	278	277	283
Should be included into the taxonomy	20	16	15
Should maybe be included into the taxonomy	1	4	0

Table 8 shows the correlation coefficient (Spearman) between the ratings of the 299 concepts. All correlations with an asterisk (*) are statistically significant ($p > 0.05$). It reveals that the raters differed in their estimations of the concepts that were generated through T-MITOCAR Artemis. Even the experts did not agree in their ratings.

Table 8. Intercoder reliability between the raters regarding the relevance of the concepts

Rater	r
Expert 1 vs. expert 2	0.52 (*)
Expert 1 vs. trained rater	0.50 (*)
Expert 2 vs. trained rater	0.46 (*)

Table 9 reveal the development of the number of concepts in the taxonomy before and after the literature review and after N = 3 additional experts discussed that taxonomy and restructured it and added or deleted concepts together.

Table 9. Development of the number of concepts in the taxonomy

	Before Literature Review	**after Literature Review**	**After Experts**
Taxonomy	88 concepts (76 concepts without duplicates)	69 concepts (65 concepts without duplicates)	111 concepts (74 concepts without duplicates)
part of T-MITOCAR Artemis	15 concepts	11 concepts	16 concepts
Partly part of T-MITOCAR Artemis	26 concepts	23 concepts	26 concepts
Not part of T-MITOCAR Artemis	35 concepts	38 concepts	33 concepts

Some concepts were included in the taxonomy about the name of the knowledge map (like for instance: acceptance, attitudes). Table 11 shows the concepts that were inserted into the taxonomy after the literature review and after the experts-round, which were also part of the concepts generated through T-MITOCAR Artemis. Moreover, the experts deleted concepts from the taxonomy that had not been proposed by T-MITOCAR Artemis, like for instance, automation, digital didactics and digital knowledge.

Table 10. Concepts inserted into the taxonomy

	Inserted into the Taxonomy after the Literature Review	**Inserted into the Taxonomy after the Expert discussion**
Proposed by T-MITOCAR Artemis	Culture Feedback Focus Tasks	role
Partly proposed by T-MITOCAR Artemis	(digital) tool Learning (&) goal	Augmentation (pre-recorded) video
Cluster Name	Acceptance Attitudes	
Not proposed by T-MITOCAR Artemis	Stability TPACK Transparency of the chosen methods types	

6. DISCUSSION AND CONCLUSION

This paper describes an aspect of the procedure for creating a structure for obtaining good teaching practices as patterns. To identify good teaching practice for designing digital teaching settings, a taxonomy provides a suitable domain-specific structure as a conceptual model for a database for pattern mining in lesson design data. The presented study provides an approach on validating a taxonomy of digital instructional designs drafted by experts in the field for a systematical validation in literature. Results show two main findings: first, the provision of a semi-automated analysis of systematic literature reviews. When it comes to time-consuming phases of systematic literature reviews, such as identifying key features that are significant in the text corpora. Although the context in which the concepts were used was not considered, the results show that T-MITOCAR Artemis provided relevant and significant concepts that prompted the expert modification of an expert-based taxonomy. In addition, experts who were completely unaware of the concepts generated by the tool added concepts to the taxonomy that had already been proposed by T-MITOCAR Artemis but had not previously been part of the taxonomy. The same experts even deleted concepts from the taxonomy that the software had not proposed. This gives first directions on semi-automatizing this step of literature review in different domains. Second, although experts in the same domain were asked to evaluate the same concepts - they seem to have different models of which concepts were already part of the taxonomy or not.

Limitations and Future Work

The present literature review is limited in various points which must be addressed in future work. First, the intercoder reliability between the experts were insufficient, which needs to be addressed in future work. Further work needs to explore the understanding of the concepts used in the taxonomy in more detail. A limitation of this study is that it only involved a few experts in technology-enhanced learning. Different groups of experts in the field of technology-enhanced learning need to be regarded, like for instance not only researchers but also teachers and practitioners as well in order to further validate the taxonomy.

Another limitation was that the instrument used in this study provided several concepts which were of no interest and were not implemented into the taxonomy. However, as a tool to give a first orientation to provide a cluster of ontologies, T-MITOCAR Artemis gives a first direction of automatizing some steps of literature reviews. However, experts still need to go through the findings in the end to decide whether the concepts generated are of relevance or not.

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