Pedagogically-Informed Knowledge Mapping: Representing Contextualised Competences and Technology Implemented

Athitaya Nitchot[1], Lester Gilbert[2] and Wiphada Wettayaprasit[3]
[1]Prince of Songkla University International College Hatyai Campus, Prince of Songkla University, Hatyai Thailand
[2]University of Southampton, UK
[3]Faculty of Science, Prince of Songkla University, Hatyai, Thailand
athitaya.nitchot@gmail.com
lg11@soton.ac.uk
wiphada.w@psu.ac.th

Abstract: Knowledge can be represented as concept maps or directed graphs. Our research focuses on the use of knowledge mapping within the educational technology domain. The purposes of using knowledge mapping can be varied such as for self-learning, visualizing individual knowledge and sharing knowledge mapping. Knowledge mapping tools in the educational technology domain currently support learners and teachers in creating and visualizing a knowledge repository, usually of subject matter content or links to such content. However, when we consider the context of learning and teaching, none of the tools are based upon a pedagogically informed approach to knowledge in such a context. In our research, we identify contexts as, at the least, the situation, the resources, and the tools involved or required for the knowledge to be effectively demonstrated. We propose a pedagogically-informed knowledge mapping design, where knowledge is conceptualised as a contextualized learner competence or intended learning outcome, and proposes a tool called Mytelemap for creating and visualizing knowledge and recommending appropriate learning and teaching materials. The research question was set as "Does the use of knowledge mapping and Mytelemap correlate with performance on the final project?". Academic performance was operationalized as the final project mark, and the explanatory path for identifying its correlates was particularly interesting. The experiment suggested that satisfaction in using, and the motivation given by using the Mytelemap tool for knowledge mapping and visualization were significant predictors of engagement which was in turn the significant predictor of academic achievement. We hence conclude that the use of knowledge mapping and the tool significantly correlated with academic performance. However, the suggested results were limited to the knowledge domain of web technology, where the academic contexts referred to tools used in developing web site prototypes in an undergraduate curriculum. Future work will investigate contextualized competences in different domains and different contexts.

Keywords: Conceptual Model, Learner Competence, Knowledge Mapping, Learning Context, Computer Assisted Learning

1. Introduction

Knowledge can be represented in many forms (Sowa, 2000) and visualized, for example, as concept maps (Novak and Canas, 2006) or directed graphs (Hwang, 2003). Our research focuses on the use of knowledge mapping within the educational technology domain. Most technologies which claim to support the construction, visualization, and storage of "knowledge" simply deal with subject matter content or links to such content. For example, the Cmap tool (Shaw, 2017) allows users to construct concept maps and create subject matter nodes with relationships, and Openknowledgemaps.org (openknowledgemaps.org, 2020) provides an open source software for individual and community knowledge mapping, describing the relationships among the subject matter. However, such approaches fail to align with current considerations in teaching and learning which are concerned with contextualized competences and learning outcomes. In this paper we articulate a theory of pedagogically-informed knowledge comprising contextualized competences, demonstrate its instantiation in a prototype knowledge-mapping tool, and report an experiment which investigated the use of the tool by an undergraduate student cohort in a course on web site development. An earlier version of the tool showed user satisfaction (Nitchot, Wettayaprasit and Gilbert, 2019) and better support for learning compared with free browsing (Nitchot, Wettayaprasit and Gilbert, 2018). The structure of the paper is described as follows. Section 2 provides a literature review of knowledge mapping design, samples of knowledge mapping, and knowledge mapping technology support. Section 3 explains contextualization and its use in learning. Section 4 describes our prototype implementation and how it adopts contextualized competence. Section 5 explains the experimental study, and Section 6 provides conclusions and future studies.

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2. Knowledge Mapping and Reviews

2.1 Knowledge Mapping Design

There are several ways of representing knowledge. Novak and Canas (2006) used concept maps as the graphical tool for organizing and representing knowledge. Concepts are enclosed in circles or boxes and linked with relationships. A concept is defined as an object or event designated by a label with a meaningful statement. Novak and Canas (2006) outlined the steps of constructing a knowledge mapping (or concept map) as 1) identifying a domain of knowledge, 2) defining the question or problem in the selected domain, 3) identifying key concepts that apply to this domain, 4) ranking the concepts, 5) constructing a preliminary map for revision, and 6) finalizing the map. Figure 1 shows a sample concept map.

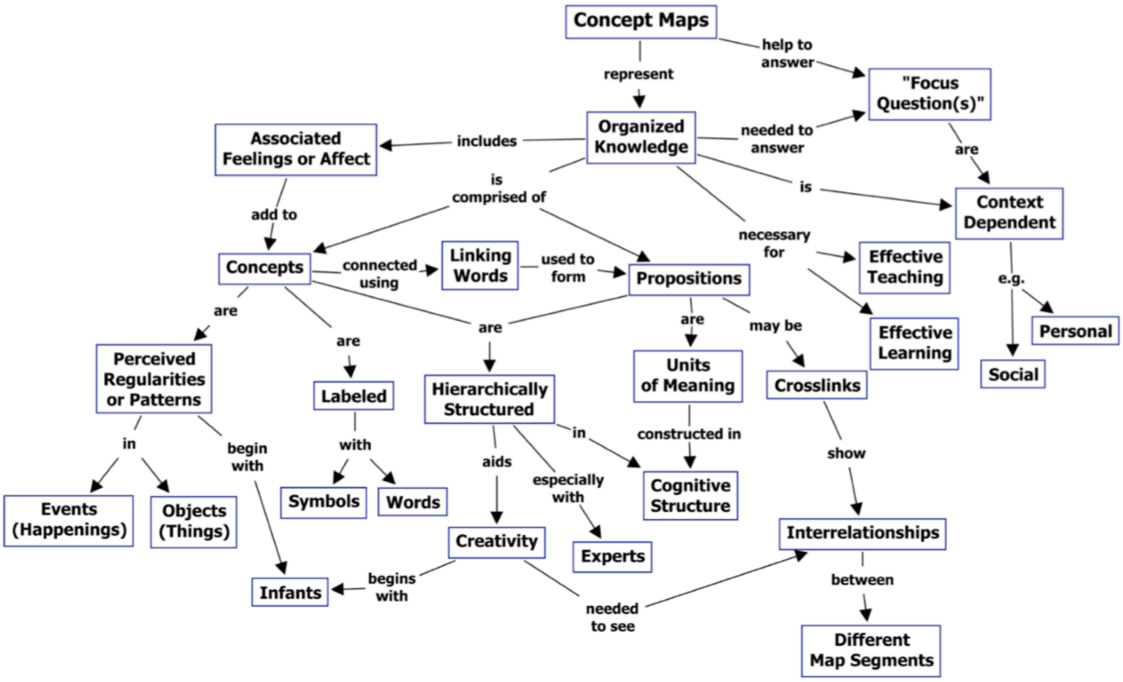

Figure 1: Sample Concept Map (Novak and Canas, 2006)

Lee, Lee, and Leu (2009) proposed a better way of defining concepts and their mapping to support a learning focus. Concepts in the structure are structured into learning sequences using epistemological ordering. A series or combination of such epistemologically ordered concepts is called a 'topological graph', considered to help teachers diagnose learning barriers and learner misconceptions.

Hwang (2003) presented a concept map called a 'concept effect graph'. The method, illustrated by an industrial case study, comprises six steps: 1) defining organizational knowledge, 2) process map analysis, 3) knowledge extraction, 4) knowledge profiling, 5) knowledge linking and 6) knowledge mapping validation. Relationships are modelled as prerequisites to be learned. The concept map from this research was used within an intelligent tutoring system to provide appropriate learner learning guidance and enhance learning performance. Figure 2 shows a sample concept map.

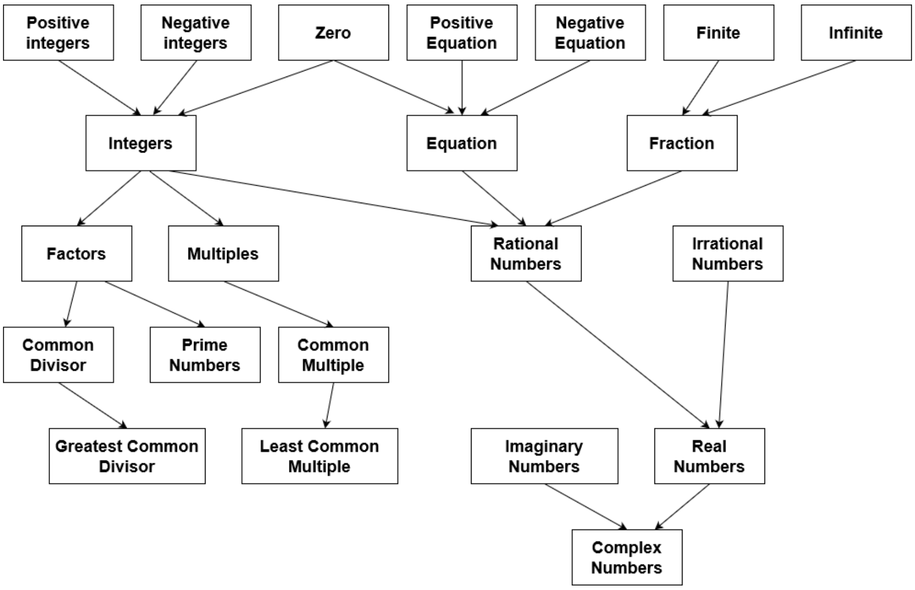

Figure 2: Sample Concept Effect Graph (Hwang, 2003)

Lee and Segev (2012) used data mining to automatically generate a knowledge mapping. This used the TF/IDF (Term Frequency-Inverse Document Frequency) algorithm that extracted keywords and then ranked pairs of keywords according to the number of appearances in the sentence and the document. The map was used to identify important ideas.

2.2 Knowledge Mapping Use

Knowledge mapping has been used for educational purposes. Zhu et al. (2018) proposed a learning path recommendation algorithm based on a knowledge mapping, where the paths helped learners to identify their learning needs and improve their learning efficiency. Li et al. (2020) constructed a knowledge mapping to help users navigate Q&A documents and reduce their information overload during the Q&A browsing process. Results showed that the approach was feasible and the knowledge mapping performed well in helping the users. Shaw (2017) studied the effectiveness of different knowledge mapping construction methods in the domain of programming language learning. The results suggested that different methods used with different learning styles significantly increased learning satisfaction (Shaw, 2017). Huang et al. (2018) proposed a knowledge mapping incorporating a learning log, exercise difficulty level, and learner ability. The map was used to personalize and recommend learning materials and guide teachers' observation of students' learning (Huang et al., 2018). El-bishouty, Ogata and Yano (2006) implemented a personalized knowledge awareness map (PerkamII) which allows the learners to share knowledge, interact, collaborate, and exchange individual experiences. The recommendations are given to learners via peer helpers according to learners' interests and current task.

Knowledge mapping has also been used in other domains. Woo et al. (2004) used experts' tacit knowledge in Architecture, Engineering and Construction (AEC) to develop a map which supported communication among experts. Kim, Suh and Hwang (2003) used a knowledge mapping to represent organizational knowledge and to transfer knowledge from experts to novices. Ong et al. (2005) presented the automatic generation of a hierarchical knowledge mapping based on online Chinese news in the domains of finance and health. Pyo (2005) developed a knowledge mapping in the domain of tourism, assisting users find destinations which matched their preferences and budgets.

2.3 Knowledge Mapping Based Learning Technology

Section 2.2 presented some uses of knowledge mapping within different research fields. Section 2.3 presented some research on the use of knowledge mapping for technology supported learning and teaching.

Shaw (Shaw, 2017) used the graphic tool IHMC Cmap (Cañas, Hill and Lott, 2003) for learners to design knowledge maps as an in-class activity. Cmap allows users to construct concept maps representing their understanding of a domain of knowledge, creating nodes and linking them to resources. Figure 3 shows a sample knowledge map.

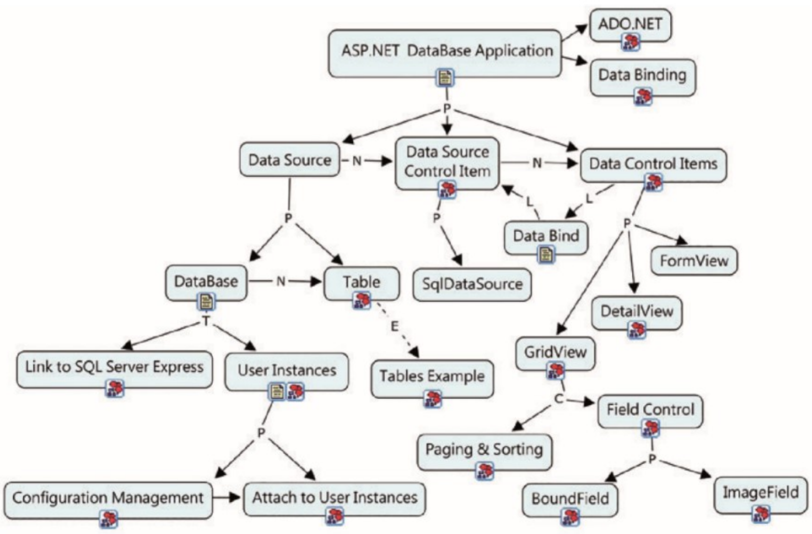

Figure 3: Sample Knowledge Mapping Created in CMap Tools (Shaw, 2017)

Lin et al. (2005) presented map-based knowledge management as a knowledge-sharing web-based platform for visualizing a project, helping users find needed knowledge more easily and effectively. This technology support helped users reuse knowledge maps from the knowledge bank repository database and present their knowledge maps more clearly, instead of relying on paper-based hand-drawn maps.

Kraker, Kittel and Enkhbayar (2016) introduced Open Knowledge mappings as a visual interface to scientific knowledge, providing an open-source software for individual and community knowledge mapping. Figure 4 shows sample of Open Knowledge maps interface when the search terms are "Web Technology". This interface consists of knowledge nodes and suggested links with metadata. However, there are no links connection between nodes provided or visualized.

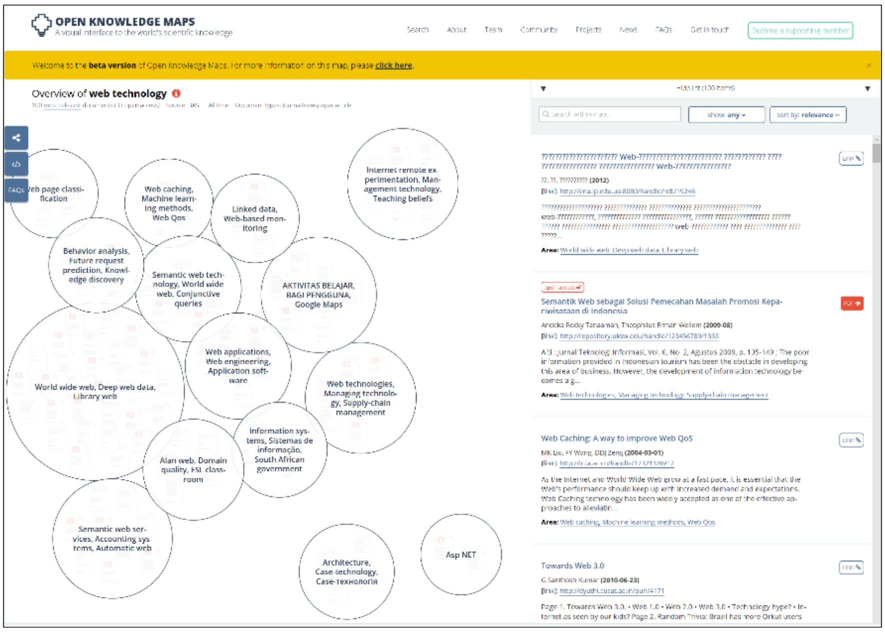

Figure 4: Interface of Open Knowledge mappings with Search Term "Web Technology"

(openknowledgemaps.org 2020)

Brewer (2009) described a knowledge map as a visual aid that showed where knowledge can be found, and developed a prototype called Mindmanager to manage and share knowledge maps among users. This software used drag-and-drop, making maps easy to edit, change, or correct. The relationships were expressed as arrows. This software is, however, more a drawing tool than a knowledge mapping tool.

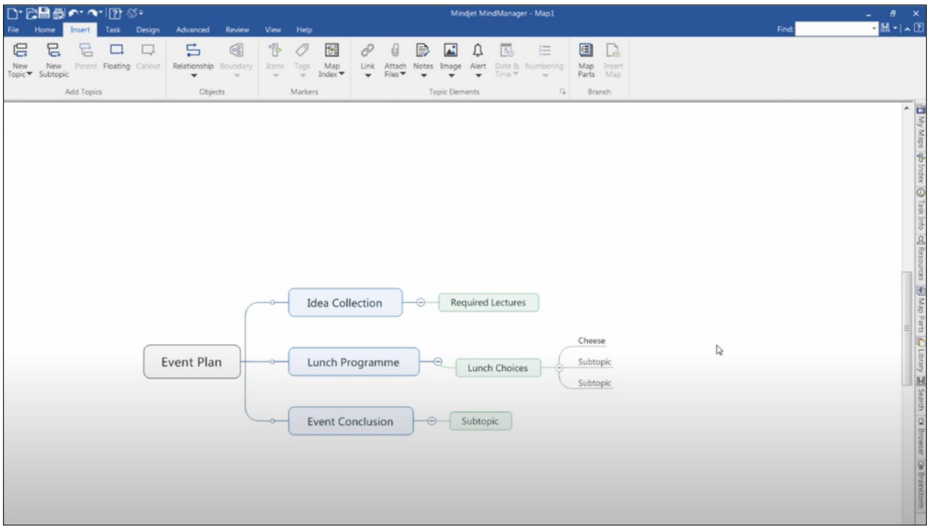

Figure 5: Interface of Mindmanager Showing a Knowledge Map of "Event Plan"

(Brewer, 2009)

Zheng et al. (2015) developed a computer-assisted knowledge mapping tool to analyze and measure knowledge elaboration. The tool automatically generated the relationships between new knowledge and prior knowledge and calculated the level of knowledge elaboration. Figure 6 shows a resulting knowledge mapping with generated relationships. Creating such knowledge mappings initially required the definition of all learning objectives and the coding of information flows.

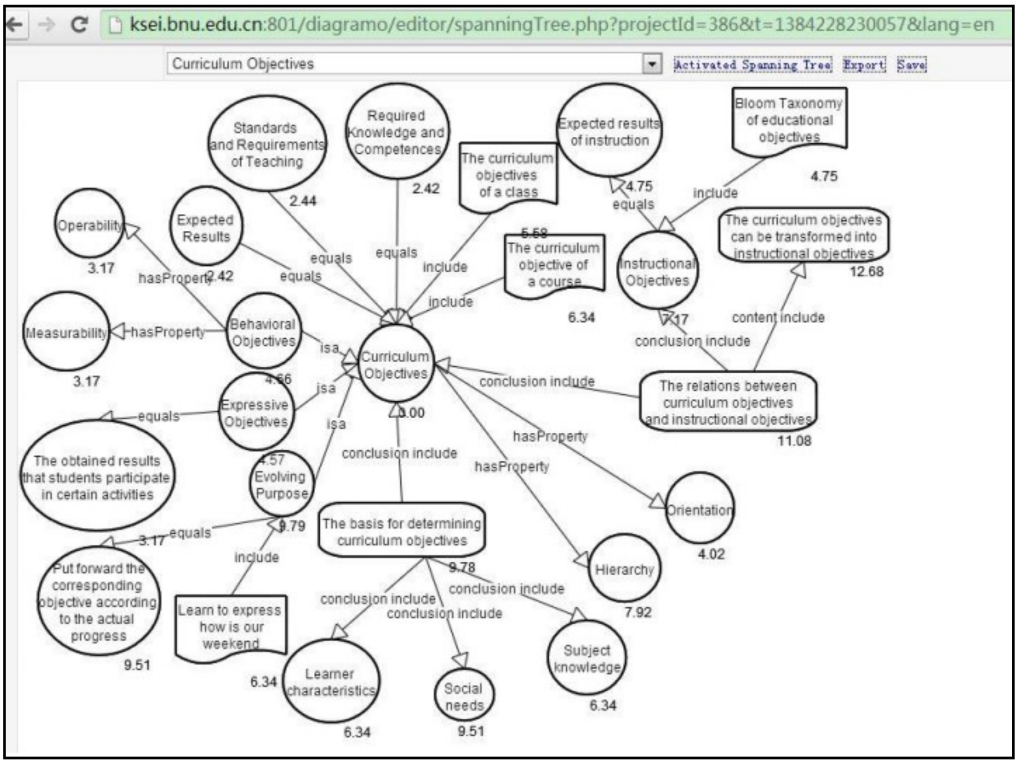

Figure 6: Interface of Computer-Assisted Knowledge mapping Tool (Zheng et al., 2015)

Other applications for creating and expressing knowledge mapping are Mindmeister (Anjomshoaa et al., 2010) and Knowledge mapper (Chung, Baker and Cheak, 2002), offering similar features to Mindmanager and Cmap tool. In our research, we propose Mytelemap tool which allows users to create their own knowledge mappings, link to learning materials, and review learning paths. Mytelemap prototype will be discussed in next section. This variety of applications is summarised in Table 1.

Table 1: Comparison Table of Knowledge mapping Application

Knowledge mapping Application	Software	Web-based	Knowledge mapping Creation	Free	Learning Path	Suggested Materials	Pedagogical Approach
CMap Tool	✓		✓	✓			
Open Knowledge Maps		✓		✓		✓	
Mindmanager	✓		✓				
Mindmeister	✓		✓	✓			
Knowledge Mapper	✓		✓	✓			
Mytelemap		✓	✓	✓	✓	✓	✓

From the lists of application in visualizing and managing knowledge map mentioned in this section, most help learners in visualizing and serving as the knowledge map repository. When we consider the context of learning and teaching, none of them are based upon a pedagogically informed approach to knowledge in such a context.

3. Learning Through Contextualization

3.1 Contextualization Definition

The literature discusses various aspects of context, though this concept is still not well defined. De Jong (2007) specifies the idea of context as identity, location, time, environment, and relation. Sampson and Fytros (2008) define context as job, occupations, function, life outcome, situation and task. Most classifications of context relate to context-aware computing and consider matters such as the location of users (Dey, 2001, Abowd et al., 1999) and the collection of nearby people, hosts, and accessible devices, as well as the changes to such matters over time (Schilit, Adams and Want, 1994). The three important aspects of context are where user is, who the user is, and what resources are nearby (Schilit, Adams and Want, 1994).

3.2 Contextualization Approach in Learning

Schmidt and Winterhalter (2004) defined context as the working environment, workflow system, human resources system, web browser, office application, and custom application. They also defined the context considered within the learning environment as the learning history, role of learners, and desired skills. This is similar to the definition given by Jovanović et al. (2007), who defined the context as the learning situation which includes the learner's experiences, skills, and competences. The learning context can also be learner preferences as learning styles, goals, motivation and learning time. Nabeth, Angehrn and Balkrishnan (2004) identified three contextual dimensions: educational, relating to situated learning (cognitive, social, and experiential); organizational, related to the particular characteristics and needs of an organization; and individual, connected to the specific characteristics of individual learners.

Learning systems able to provide adaptive support according to users' location are called context-aware ubiquitous (Hwang, Tsai, and Yang, 2008). Mobile learning and ubiquitous learning are related, where mobile learning concerns the general use of mobile devices in learning with little consideration of context, while ubiquitous learning concerns the use of context (such as time and location, which can be obtained from a mobile device) in the provision of adaptive support. Context-aware ubiquitous learning has been applied within different learning domain, for example Wu et al. (2012) developed a context-aware mobile learning system for nursing training course. This study used the sensing devices and mobile phones to detect locations in a dummy patient's body for assessing related specified diseases.

Muntean and Muntean (2009) propose Performance-based E-learning Adaptive Cost-efficient Open Corpus frameworK (PEACOCK), a ubiquitous e-learning environment that provides a meeting place for content providers and e-learners. PEACOCK considers the learners' e-learning experience and increases their learning satisfaction by selecting and providing e-learning content that best matches their expectations given existing cost, device, and network constraints.

In our research, we consider a conceptual model of "knowledge" as a contextualized competence as shown in Figure 7. In our previous research in proposing a tool for constructing a knowledge mapping (Nitchot, Wettayaprasit and Gilbert, 2019), only the subject matter of the map is concerned. This research adds contextualization data to the map representation, being the contextual factors, which are inherent in practical educational and training applications. For example, consider the competence of a computer science student to write HTML code using an online simulator (e.g. Codepen.io) or an offline text editor (e.g. Notepad); the output produced, and their associated ability, will be different and context-dependent.

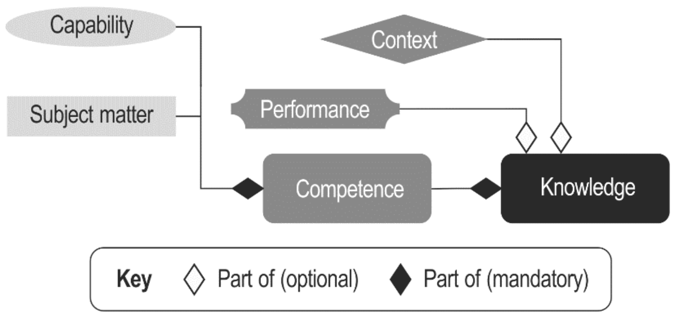

Figure 7: Conceptual Model of "Knowledge" as a Contextualized Competence

In our research, we identify contexts as, at the least, the situation, the resources, and the tools involved or required for the knowledge to be effectively demonstrated. We separate performance elements from contextual elements since they may vary within similar contexts, and note they are generally used when knowledge must be evidenced by way of certification or qualification, or recorded, perhaps in a personal portfolio or a personal resumé. These are illustrated in Figure 8.

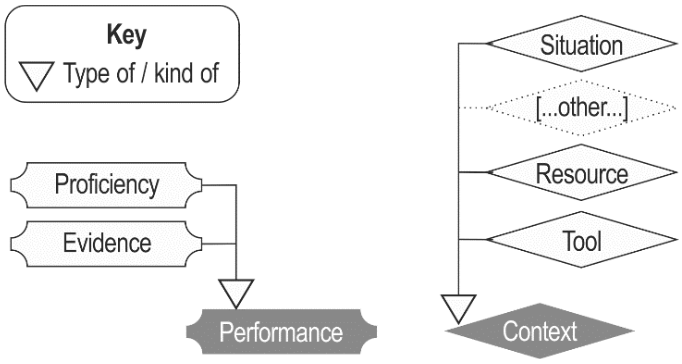

Figure 8: Some Context and Performance Elements of Knowledge

4. Mytelemap

4.1 Overview

Mytelemap is a web-based technology assisted learning and implemented to use the function of learning knowledge mapping for learners. This prototype was built to visualize the knowledge mapping from the graph visualization libraries (Ellson et al., 2004) and offering the study links based upon Google API service. In the first stage of implementation which described in Nitchot, Wettayaprasit and Gilbert (2019), there are features under consideration as link recommendations, learning paths, missing prerequisite service and learning resources management (as highlighted in red in figure 9). Linked learning recommendations were generated using Google API services given keywords from the knowledge map. There were two experiments conducted in the first stage. First experiment was conducted to test the overall satisfaction by the users and they felt satisfaction in using Mytelemap in general (Nitchot, Wettayaprasit and Gilbert, 2019). Second experiment compared the learning outcomes of learners using MyTeLeMap and using a free-browsing mode. The results showed that MyTeLeMap helped learners more than free browsing (Nitchot, Wettayaprasit and Gilbert, 2018).

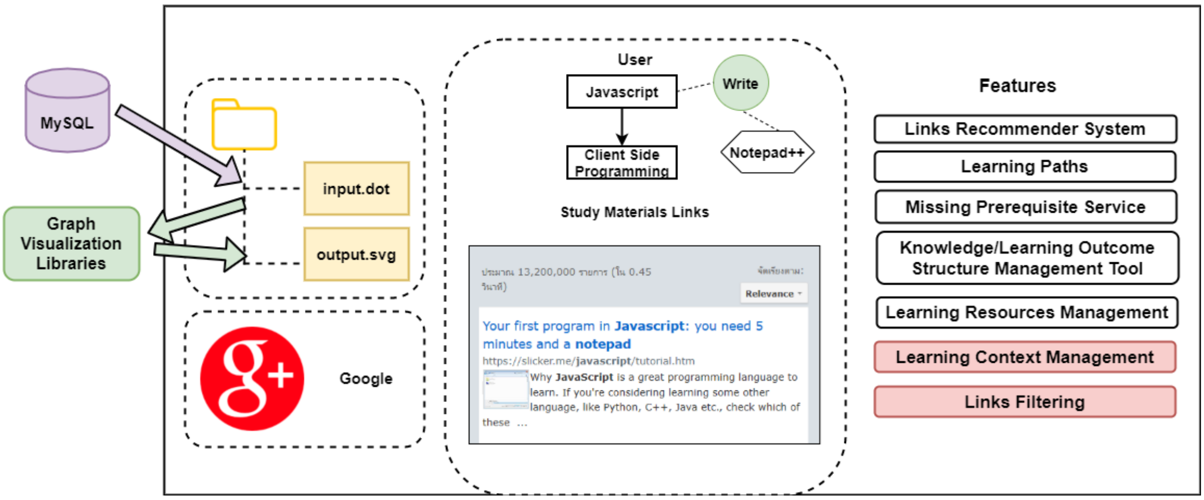

Figure 9: Architecture of Mytelemap System

4.2 Contextualization Feature

In second stage of Mytelemap implementation, the contextualization feature is concerned. As mentioned in section 3.2 about the importance of context considered within learner competence, our research adds contextualization data to the map representation, being the contextual factors, which are inherent in practical educational and training applications. For each node under one map, Mytelemap allow the map author create/mange learning outcome details (as shown in figure 10). In this sample, the map author has identified the learning outcome as 'Write JavaScript using notepad', where a capability is 'Write' and a context is 'Notepad' as shown in figure 11.

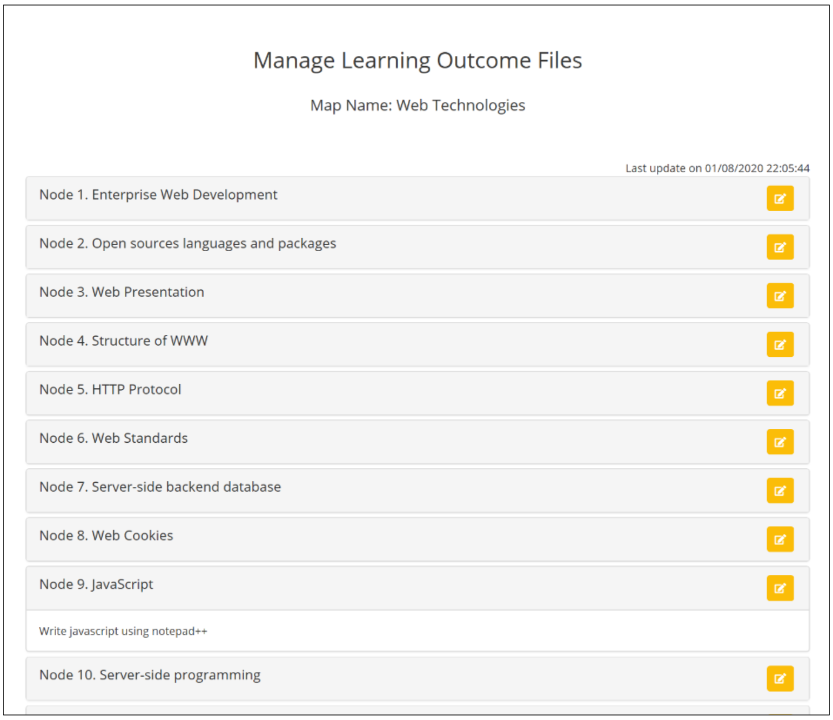

Figure 10: Mytelemap Page Showing a Page of Managing Learning Outcome Under One Map

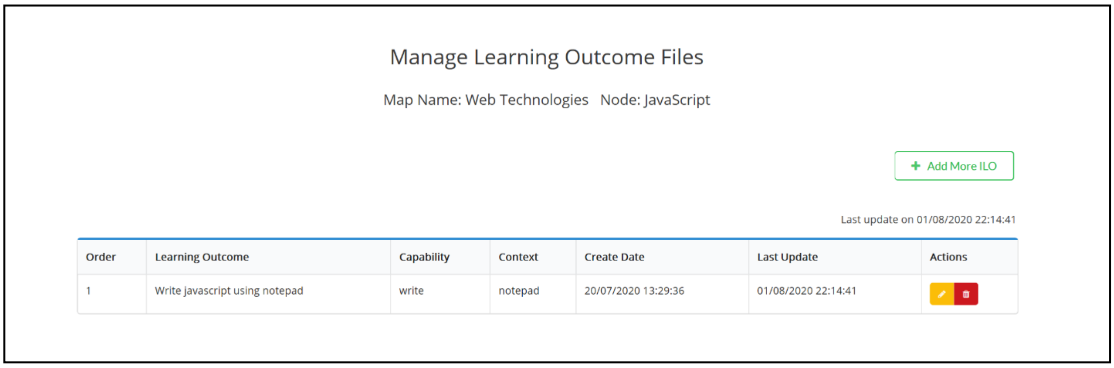

Figure 11: Mytelemap Page Showing a Page of Managing Learning Outcome Under Node 'JavaScript'

The context is used to filter the learning recommendation links resulting from the Google API call. For example, Figure 12 shows a knowledge map domain, 'Web Technologies', with link recommendations based on the keyword 'JavaScript' from the node name and filtered with the context keyword 'notepad'.

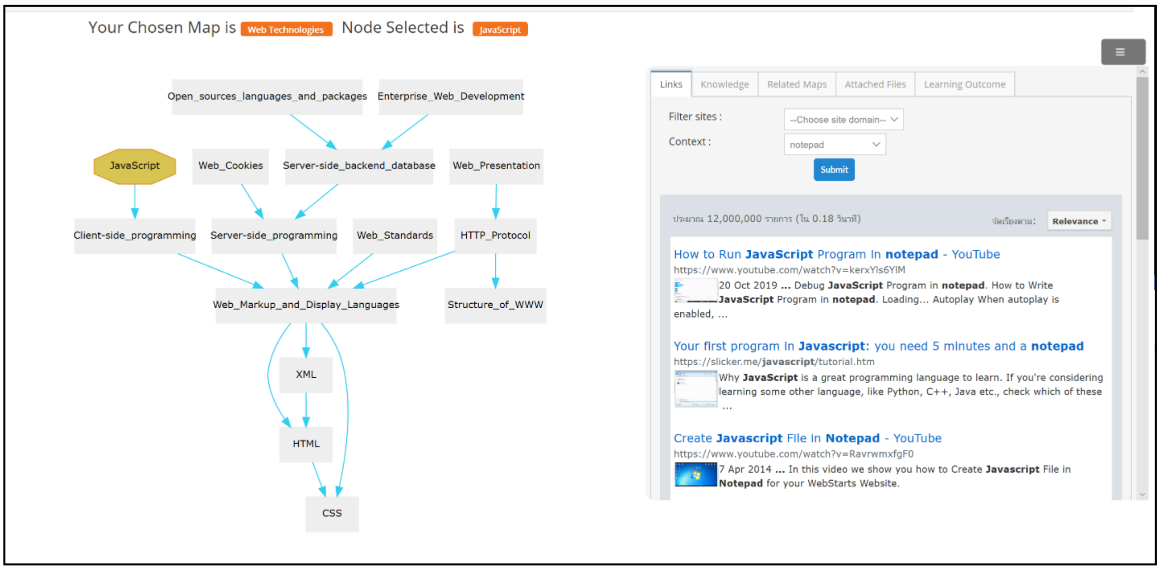

Figure 12: Mytelemap Page Showing the Web Technologies Map with Suggested Links for the JavaScript Node Filtered by the Context Term "Notepad"

5. Experimental Design and Results

5.1 Research Question and Experimental Design

The main research question in this study was "Does the use of knowledge mapping and Mytelemap correlate with performance on the final project?". The research was granted ethical approval by the University's Ethics Institutional Review Board under reference 2020-PSU-L-005. A sample size power analysis using GPower 3.1 (Faul et al., 2009) for a linear regression study with five predictors suggested that N = 20 would yield 90% power at the 5% level of significance in testing for R = 0.7 (R2 = 0.5). Accordingly, the 20 students enrolled in the Web Technology course (academic year 2020) at Prince of Songkla University International College were considered an adequate sample for detecting the relatively large effect size appropriate to this exploratory study, achieving adequate power at the conventional level of significance. A similar experiment (Rossi and Magni, 2017) explored the role of e-learning and of intellectual capital in value co-creation between the final user and the experimental team, mainly focusing on Italian participants in their investigation. At the start of the study, the participants provided their gender and GPA and their experiences of using ICT in learning in terms of the hours per week spent using different hardware (mobile, tablet/laptop, pc, etc) and their satisfaction ratings in using ICT compared with traditional tools (paper, pencil, pen). They were introduced to knowledge mapping and the use of Mytelemap as assisted learning tools.

During the study, participants used Mytelemap and knowledge mapping for four weeks in completing the course project, the development of a runnable website. Time stamps were recorded of logins and edits. At the end of the study, their knowledge maps were scored according to the number of subject matter nodes, capability verbs, and context tags, their projects were assessed and marked, and their opinions of knowledge mapping and Mytelemap tools were recorded in terms of intention to use, satisfaction, usefulness, and motivation.

Table 2: Descriptive Statistics Results (N=20)

Variable	Mean	Std. Deviation
Opinion against Mytelemap		
Intention to use Mytelemap	8.7	1.1
Satisfaction in using Mytelemap	8.3	1.3
Usefulness of Mytelemap	13.0	1.9
Motivation from using Mytelemap	8.2	1.1
Opinion against Knowledge mapping		
Intention to use Knowledge mapping	8.2	1.0
Satisfaction in using Knowledge mapping	8.6	1.1
Usefulness of Knowledge mapping	12.7	1.3
Motivation from using Knowledge mapping	8.2	1.4
Other variables		
On-line engagement	12.5	5.2
Knowledge mapping score	33.8	12.7
Project mark	139.4	18.3
GPA	3.3	.38
Number of hours in using ICT	81.3	15.3

Table 3: Questions for Opinion Ratings of Mytelemap and Knowledge mapping

Variable	Question
Intention to use	I intend to use [Mytelemap | knowledge mapping] to help me complete other assignments
	I intend to use [Mytelemap | knowledge mapping] to help my learning in other modules
Satisfaction	I feel satisfied with my overall experience of using [Mytelemap | knowledge mapping]
	My experience with using [Mytelemap | knowledge mapping] was better than I expected
Usefulness	Using [Mytelemap | knowledge mapping] improved the quality of my final projects
	Using [Mytelemap | knowledge mapping] enhanced my effectiveness in completing my final projects
	Using [Mytelemap | knowledge mapping] helped me visualize knowledge mappings better
Motivation	I felt motivated when using [Mytelemap | knowledge mapping]
	I enjoyed using [Mytelemap | knowledge mapping]

Table 2 shows the descriptive statistics of each variable. For the use of Mytelemap and knowledge mapping, ratings (intention to use, satisfaction, usefulness and motivation) were given on a Likert scale (Strongly agree – 5, Agree – 4, Neither agree nor disagree – 3, Disagree – 2, Strongly disagree – 1) as shown in Table 3. On-line engagement was derived from the time stamps (login count, map creation count, map modification count, node count, capability count, and context count). Knowledge mapping scores were from the number of ILOs identified, and their relevance, context, links, and labels.

The project involved the creation of a portfolio website and a WordPress website. Marks were given for proper installation, the use of themes, usability, accessibility, installed plugins, completion of the required site pages, extra features added. The number of hours per week in using ICT was the total from using ICT hardware (mobile tablet/laptop, pcm etc) in different study types (searching, reading/viewing, conversing/meeting, writing/recording notes, writing assignment, and sending/downloading files).

5.2 Results

The variables of Table 2 were entered as variables in a backwards regression (Field, 2000) where the dependent variable was Project mark and the remaining 12 variables (as described in Table 2) were predictors. As shown in Table 4, the only significant predictor was the Knowledge mapping score (adjusted R^2 = 0.38, beta = 0.64, p = .002).

Table 4: Coefficients Table When Dependent Variable is Project Mark

Variable	Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	p
Knowledge mapping Score	0.92	0.26	0.64	3.55	0.002

Adjusted $R^2 = 0.38$

Because the correlations matrix for the variables of Table 2 showed a range of variables with significant correlations which did not appear as significant predictors, a second backwards regression was undertaken where the dependent variable was Knowledge mapping score and the remaining 11 variables (excluding Project mark) were predictors. As shown in Table 5, the only significant predictor of Knowledge mapping score was Online engagement (adjusted $R^2 = 0.62$, beta = 0.80, $p < .001$).

Table 5: Coefficients Table When Dependent Variable is Knowledge mapping Score

Variables	Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	p
Online Engagement	1.95	0.35	0.80	5.64	<0.001

Adjusted $R^2 = 0.62$

Because both the correlations matrix for the variables of Table 2 showed a range of variables with significant correlations which did not appear as significant predictors, and the adjusted R^2 was higher in the second regression, a third backwards regression was undertaken where the dependent variable was Online engagement and the remaining 10 variables (excluding Project mark and Knowledge mapping score) were predictors. As shown in Table 6, there were five significant predictors of Online engagement (adjusted $R^2 = 0.59$).

Table 6: Coefficients Table When Dependent Variable is Online Engagement

Variables	Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	p
Intention to use Mytelemap	-6.64	1.30	-1.44	-5.12	<0.05
Satisfaction in using Mytelemap	6.48	1.42	1.63	4.57	<0.05
Motivation in using Mytelemap	3.23	1.08	0.71	2.98	=0.01
Usefulness of Knowledge mapping	-5.74	1.28	-1.48	-4.48	<0.05
Number of hours in using ICT	-0.27	0.07	-0.78	-3.66	<0.05

Adjusted $R^2 = 0.59$

The significant predictors were Intention to use Mytelemap ($p < 0.05$), Satisfaction in using Mytelemap ($p < 0.05$), Motivation in using Mytelemap ($p < 0.05$), Usefulness of Knowledge mapping ($p < 0.05$), and Number of hours in using ICT ($p < 0.05$). Satisfaction in using Mytelemap and Motivation in using Mytelemap were significant positive predictors of engagement, while Intention to use Mytelemap, Usefulness of Knowledge mapping, and Number of hours in using ICT were significant negative predictors. These three predictors were suppressor variables (Lancaster, 1999).

5.3 Discussion

Academic performance was operationalized as the Project mark, and the explanatory path for identifying its correlates was particularly interesting. The regression of all independent predictor variables against Project mark was expected to show a set of usefully significant predictors; instead, only Knowledge mapping score was shown as a significant predictor of Project mark. This was unsurprising, because Knowledge mapping score was the measure of performance closest in time to the participants' delivery of their project, but it was also puzzling given that the correlation matrix showed numerous significant relationships between the other predictors and with Project mark. A regression of the independent variables against Knowledge mapping score was undertaken, with renewed expectation of a set of useful predictors; instead, only Engagement was shown as a significant predictor of Knowledge mapping score. As before, this made sense, because Engagement may be considered an important prerequisite to academic performance, but again it was puzzling that no other predictors were significant in this regression. A final analysis was undertaken where the remaining independent variables, located earlier on the path leading to academic performance (as shown by Knowledge mapping score and Project mark), were regressed against Engagement. The results revealed the reasons for the initially puzzling lack of a predictive relationship, in the form of three highly significant suppressor variables (Intention to use, Usefulness, and Hours spent with ICT) coupled with two highly significant positive predictors (Satisfaction and Motivation). The path to academic performance suggested by these results is shown in Figure 13.

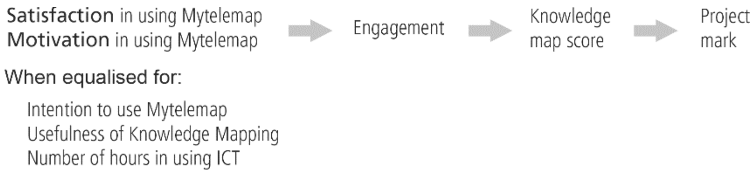

Figure 13: Explanatory Path for Academic Performance

6. Conclusion and Future Work

This research presents a conceptual model of pedagogically-informed knowledge as contextualized competences. This model adds contextualization data to the competence representation, allowing subject matter links to be more related to the learning context. The experiment suggested that satisfaction in using, and the motivation given by using the Mytelemap tool for knowledge mapping and visualization were significant predictors of engagement which was in turn the significant predictor of academic achievement. We hence conclude that the use of knowledge mapping and Mytelemap positively contributed to performance on the final project as mediated by learner engagement with the technology.

The experiment conducted was in the knowledge domain of web technology, where the academic contexts referred to tools used in developing web site prototypes in an undergraduate curriculum. However, there are some limitations of the knowledge domain explored and the number of participants considered within the experiment. Future work will investigate contextualized competences in different domains and different contexts, for example, training in the treatment of a poisoning incident.

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