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RESEARCH ARTICLE

Pre-school teachers' digital concept maps and instructional design practices

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Abstract: Concept mapping has been a useful and effective technique for representing and assessing science content knowledge. Technological advances have also allowed the creation of user-friendly digital concept map applications. However, there appears a need to examine pre-service teachers' digital concept mapping practices in relation to their instructional design practices *i.e.* lesson planning. Hence, this study investigated the quality of pre-service pre-school teachers' (n = 26) digital concept maps in reference to the quality of their lesson plans. The quality of the digital concept maps was assessed based on an examination of the quality of a) structure, b) content, and c) their overall quality. Furthermore, it examined teachers' preferences and reflections on digital concept maps in relation to physical (*i.e.* paper-and-pencil) concept maps. Mixed methods were used including qualitative analysis and statistical correlations of the quality scores of the lesson plans and concept maps. Findings revealed no significant correlation between the quality of digital concept maps and the quality of lesson plans, while the consistency of the focus between the two correlated significantly with the quality of the digital concept maps. The number of concepts, propositions and cross-links as well as conceptual hierarchy were found as indicators of the overall quality of the digital concept maps. A comparison between digital and physical concept maps revealed that teachers' views and arguments varied between the two. The findings of the study speak to the relevance and applicability of digital concept maps for teacher training programmes.

Keywords: pre-school teachers, technology integration, lesson plans, pre-service teacher training, teachers' views

1 Introduction

Scientific knowledge and skills are needed in order to understand and deal with real-world problems, which are characterised by complexity and tentativeness (Levrini et al., 2019). Central to this endeavour is the development of an understanding of scientific concepts, as well as the connections between these concepts. Particularly, deep science learning occurs when making connections among ideas/concepts of science (Krajcik & Shin, 2023). However, grasping a high degree of understanding of science concepts and phenomena has traditionally been challenging for pre-school teachers (Kallery & Psillos, 2001). Pre-school teachers often feel the need for additional knowledge and support in science, while research also shows that pre-school teachers do not dedicate enough instructional time to science (Early et al., 2010; Raviv & Galili, 2023). Hence, it becomes of high importance to examine and implement methods, tools, and techniques that could further assist pre-school teachers in advancing their competencies in science and science teaching.

As concerns instructional tools, research shows that implementing technological tools has the potential to facilitate science learning at the pre-school level, therefore it becomes essential for pre-service teachers to be trained on how to use technology for science instruction (Kalogiannakis & Zaranis, 2011). As concerns techniques, one technique that can effectively impact science understanding is concept mapping. Concept mapping has been extensively used by science education researchers and educators in order to visualise the science concepts along with the relationships between the concepts. A concept map is actually "a schematic device for representing a set of concept meanings embedded in a framework of propositions" (Novak & Gowin, 1984). Concept maps is a tool where concepts and the connections between them are visualised, and that can promote conceptual understanding (Farrokhnia et al., 2019). Particularly, it can facilitate the understanding of the phenomenon by stressing the small number of key ideas represented by concepts, where concepts can be defined as "the perceived regularities in events of objects, or records of events or objects, designated by a label" (Novak & Cañas, 2008). The concepts are connected with links *i.e.* arrows or lines, also labelled with an action verb/part of a phrase. A full phrase including two concepts and a link is called a proposition, which is "a statement about some object or event in the universe, either naturally occurring or constructed", sometimes also called semantic unit or unit of meaning (Novak & Cañas, 2008). The overall network structure of a concept map relates to the ways the human mind assimilates information, based on cybernetic models of human learning and problem-solving (Novak et al., 1983).

The applicability of concept maps can be very wide. Concept maps have been utilised and explored for several purposes in the past decades since the 80s when they were introduced by Novak and Gowin (1984). In the context of science education, they have been commonly used as a schematic way to represent the natural phenomena under study, by also revealing the organisation of knowledge and the connections between the concepts. This can be used by teachers as a teaching tool to demonstrate the phenomena to teach (Reiska & Soiska, 2015). However, concept maps can also be developed by students themselves in order to develop an increased understanding of the phenomena under study, often through a collaborative task with peers (Alansari, 2010; Farrokhnia et al., 2019).

One of the most common applications of concept maps has been to use them as an assessment tool for understanding science (Alansari, 2010; Friege & Lind, 2006; Xia et al., 2023). Particularly, it can assess not only the acquisition of knowledge, but also the organisation and representation of knowledge through several metrics and evaluation criteria (Cañas et al., 2015). Similarly, concept maps can be used to investigate students' prior knowledge and misconceptions about the phenomena (Alansari, 2010; Hartmeyer et al., 2018). Concept maps can also act as a means of scaffolding or as a means to trigger reflection with the learners (Villalon & Calvo, 2011).

Although a lot of studies have utilised concept maps as a teaching or assessment tool, there are limited studies that have used concept maps in the context of instructional design. Coffey et al. (2007) have used concept maps in a digital learning environment as a tool for course designers to create a course. Ummels et al. (2015) have created a 'reference concept map' *i.e.* a map depicting all concepts and propositions that students are expected to learn based on a textbook analysis, as a facilitating means to guide the design of the course. However, both studies utilised concept maps developed by course designers, while, to our knowledge, there seems to be a shortage of studies on how pre-service teachers' concept maps relate to their instructional design practices, *i.e.* their ability and/or difficulty to design science teaching. Artiles' et al. (1994) study was one of the few that have used teachers' concept maps for planning lessons, but the focus was rather on examining their consistency with their teaching practices in the classroom.

Therefore, in this study, we aim to analyse preservice teachers' digital concept maps of the scientific phenomena they design to teach. Specifically, we analyse the quality of the concept maps and the difficulties that they address while using digital/physical concept maps in reference to the quality and difficulties in their developed worksheets and lesson plans. As a result, we can examine if and how concept maps can retrieve valuable information regarding the instructional design process that pre-service teachers carry out and the particular difficulties that they encounter. Hence, this study extends the applicability of concept maps in terms of investigating their ability to depict teachers' lesson-planning practices.

Furthermore, technological advances in the science classroom have allowed the use of concept maps in digital form, *e.g.* by using digital apps and computers where the user can either touch, or click, drag, and draw arrows among concepts, *etc.*, an approach which we shall call 'digital concept maps' henceforth. This feature (digital *vs* physical/paper-and-pencil ones) is often categorised under the term 'type of response' (Hartmeyer et al., 2018). Brandstädter et al. (2012) and Uygur (2019) have examined the efficacy of the digital type of response in relation to students' performance. In both studies, their statistical analysis between pre- and post-tests showed improved students' performance when using the digital concept maps in comparison with the paper-and-pencil ones. Similarly, Royer and Royer (2004) found that the student group that used digital concept maps ended up creating more complex concept maps. Regarding attitudinal gains, Hwang et al. (2013) examined the efficacy of digital concept maps while using teacher-centred interactive whiteboards and student-centred use of computers with touchscreens. In both modalities, students exhibited significantly high acceptance of the two digital forms of concept maps compared with the paper-and-pencil ones, although significant gains in positive learning attitudes were found only in the interactive whiteboard case. In the context of higher education, a study by Islim (2018) with college students revealed no difference in the quality of digital and physical concept maps (*i.e.* their correctness and elaborateness), and similarly no difference in students' academic performance in a developmental psychology course.

Although most of the above studies advocate for rather positive effects of using digital concept maps for student performance and attitudes, it appears a specific need to examine the advantages and disadvantages of digital concept maps compared with physical concept maps from a pre-service teacher point of view. Specifically in the context of pre-school education, research shows that technology integration remains sporadic due to factors that relate not only to the availability of resources but also due to teachers' skills, beliefs, and behaviours (Hoareau et al., 2021). In other words, there exists a need to inspect not only the differences with conventional paper-and-pencil concept maps, but also the arguments, according to pre-service teachers, that digital concept maps become appropriate for teacher education. In this light, Waight and Abd-El-Khalick (2012) caution against horizontal and one-size-fits-all uses of technology without considering the role of knowledge, expertise and culture of the agents, which can detrimentally affect the instructional design process (Nipyrakis & Stavrou, 2022). Hence, the usability, affordances and disadvantages of digital concept maps should be examined for instructional design purposes. Teachers' views along with their arguments and justifications for using digital forms of concept maps are examined, which can further inform the effective implementation of technological tools such as digital concept maps for instructional purposes.

Therefore, the research questions of the study are:
RQ1: how do pre-service teachers' concept maps relate to pre-service teachers' instructional design practices *i.e.* the development of lesson plans and worksheets for science teaching?
RQ2: what affordances and difficulties do pre-service teachers identify in developing digital concept maps in relation to physical concept maps?

The outputs of the study aim to inform the literature regarding the use of digital concept maps for assessing teachers' instructional design practices, which could appear useful in the context of developing and implementing teacher education programmes. Moreover, the end-users' perspectives of the digital advances made in the context of concept maps can provide insights that could drive further modifications in the digital technologies used for concept mapping.

2 Literature review

2.1 Concept maps

One of the main characteristics of concept maps is that they use a graph representation of knowledge, consisting of concepts (in the shape of ovals/boxes) and links (in the form of directed arrows or lines). Typically, concept maps represent concepts in a hierarchical order, where the central concepts are positioned at the top middle of the map (Novak & Cañas, 2008). However, that is not always the case, since some researchers have also used non-hierarchical forms due to the nature of the phenomena examined (Hartmeyer et al., 2018), or even cyclic forms *e.g.* to represent dynamic relationships (Safayeni et al., 2005). Another common feature of concept maps is that they are built upon responding to a focus question, which guides the development of a concept map. This feature is important, since otherwise the concept map can extend to several related phenomena and lose focus. Cross-links is another important feature, which means having links between different segments or domains of the concept map. Some concept maps also represent events or objects for clarification of the concepts, usually not represented in boxes/ovals like the concepts (Novak & Cañas, 2008).

The meta-analysis of Shi's et al. (2023) study revealed that mind/concept mapping can significantly affect learning outcomes. In order to assess the efficacy of concept maps, several methods and scoring scales have been developed. One common practice is to use concept maps in combination with achievement tests. For example, İngeç (2009) has used concept maps in combination with achievement tests, and has found a divergence between the scores of the two, indicating that finding relationships between concepts is a far more difficult endeavour than acquiring knowledge on a topic.

Another common practice is to compare the students' concept maps with a concept map of an expert, *i.e.* a reference map, and analyse the number of common concepts or edges (Friege & Lind, 2006). Xia et al., (2023) have also evaluated the latent constructs *i.e.* the knowledge, skills and cognitive processes that undergraduate students make in their concept maps in relation to the expert-drawn concept map, in order to provide targeted feedback to students.

Utilising network metrics and treating concepts as nodes in a network is another method to analyse concept maps (Ruiz-Primo & Shavelson, 1996). Counting the number of concepts, relations between concepts, number of components that the graph resolves, or number of concepts that are connected with only one concept, are some metrics to analyse interconnectedness based on graph theory (Friege & Lind, 2006). On the other side, some studies have also proposed a qualitative evaluation of concepts and the relations between concepts in order to evaluate their correctness and the general cognitive structure of the individuals (Ekinci & Şen, 2020; Friege & Lind, 2006).

Assessing the quality of a concept map seems to be a complex endeavour, and it also relates to the purpose, the audience to which it corresponds, and where and when it is undertaken (Reiska & Soiska, 2015). Particularly, Cañas et al. (2015) stress that assessing the quality of a concept map should take into consideration both the quality of content, the quality of structure, and the overall quality. In this sense, several factors should be examined, such as a) the extent to which it answers a focus question in an explanatory and not solely descriptive way, b) its conciseness, *i.e.* the extent to which it includes an optimal number of necessary concepts, and its c) high clarity and communicative character, as well as its overall quality based on the context of its use.

2.2 Digital concept maps

Digital features that have been integrated into concept mapping include but are not limited to computers, mobile and smart devices, touchscreens, interactive whiteboards, as well as web-based software and tools where peers can share and collaborate on the same concept map (Alansari, 2010; Farroknia et al., 2019; Hartmeyer et al., 2018; Hwang et al., 2013; Islim, 2018). Apart from the different 'type of response' compared with paper-and-pencil ones, digital technologies affect the classroom ecosystem more holistically. Digital concept maps not only offer a visual representation, but the users are given the ability to maintain, reuse, and modify them accordingly with ease (Alansari, 2010; Coffey et al., 2007; Royer & Royer, 2004). Given the fact that the usefulness of digital technologies is one of the most prominent features for preservice teachers (Kalogiannakis & Papadakis, 2019), digital concept maps could be considered quite appropriate in this sense.

Another affordance of digital concept maps is an easy-to-make representation in more than 2D layers, *e.g.* through hyperlinks that connect several sub-maps. In this light, Huang et al., (2012) used digital concept maps by organising concepts in several different layers, what they named 'multidimensional' concept maps. Specifically, contrasting a common 2D concept map, they used hyperlinks among different -and smaller- concept maps. Their findings support better academic performance and higher learning satisfaction for students, since the knowledge structure could be even more simplified for them. Digital concept mapping can also be enhanced by the metaverse environment's features in terms of keeping a history of the user's interaction, and implementing eye movement and voice recognition technology (Huang & Chien, 2022).

Digital concept maps have also been used as an integral part of a serious game, *i.e.* as part of the gaming scenarios while playing the game (Hwang et al., 2013b). Similarly, increased learning achievement was observed by the researchers as well as a decrease in the cognitive load. Furthermore, digital technologies have also been used in analysing digital concept maps. Bleckmann and Friege (2023), for example, have made use of a supervised machine learning algorithm to automatically evaluate students' concept maps for formative assessment purposes, and exhibited a satisfactory agreement between human raters and the machine learning one. Finally, digital concept maps can provide a space for feedback and collaboration among peers, where users can easily interact and discuss their concept maps with peers (Hartmeyer et al., 2018). Considering the above, this study aims to contribute by exploring what pre-service teachers think about digital and physical concept maps in the context of instructional design of science lessons.

3 Methods

3.1 Outline of the study

The study was conducted in the context of an undergraduate science education course for first-grade pre-service preschool teachers. Participants were pre-service teachers who voluntarily enrolled in delivering additional creative essays as part of their deliverables for the course and agreed to participate in the study. As shown in Table 1, after a series of introductory lessons, in the 7th meeting, the pre-service teachers were assigned to develop a worksheet and a lesson plan on a scientific topic of their choice. Subsequently, in the 8th meeting, they were assigned to develop two concept maps regarding this scientific topic they chose, one in physical form *i.e.* a paper and pencil one, and one in digital form with the use of a digital app, which in this case was CMapTools (https://cmap.ihmc.us/). The two concept maps did not have to be identical, hence the teachers were allowed to modify each concept map if and as they wanted. A preliminary activity (15') of developing their physical concept maps took place during the 8^{th} meeting where they were given the opportunity to ask for assistance. In order to facilitate teachers' use of the digital app, a guide document was developed and shared with pre-service teachers regarding the installation and use of CMapTools, while a demonstration of how to develop a digital concept map was carried out during the 7^{th} and 8^{th} meetings. The pre-service teachers co-created an example of a digital concept map with the assistance of the instructor on a given scientific topic during the 7^{th} meeting.

Table 1 Implementation of the study

(Weekly) session number	Content	Deliverables Assigned
1-5	Theoretical principles of science education	
6	Introduction on worksheets and lesson plans (I). Worksheet and lesson plan examples.	Worksheet and lesson plan on a science topic
7	Introduction on worksheets and lesson plans (II). Science content examples. Introduction on concept maps. Concept map example.	
8	Concept maps (II). Concept map examples (II).	Physical/digital concept map
9	Concept maps (III). Reflection.	
10-13	Alternative teaching methodologies	

3.2 Development of Concept maps

A set of principles/prompts was shared with the pre-service teachers regarding the development of the concept maps. These principles derive from the literature (Novak & Canas, 2008), and were contextualised for the needs of our study. First, the pre-service teachers were prompted to formulate a focus question regarding the phenomenon that they want to represent in order to assist them remain focused on the main phenomenon to teach as well as the teaching goal. This would prevent confusing them with similar teaching goals/phenomena or making the concept map chaotic. Second, they were suggested to create a small list of concepts before drawing the concept map, so that pre-service teachers could be oriented on using some main core ideas of the phenomenon. Third, they were recommended to use cross-links, since it is considered to reveal a deep and holistic understanding of the phenomenon. Fourth, they were recommended to position the main concepts in a hierarchical order and in the middle, something that could facilitate subsequent connections with other concepts. However, that direction was provided rather as a recommendation and not in a mandatory sense, since the content/topic (*e.g.* chemistry or biology) may or may not be indicative for a hierarchical representation (Hartmeyer et al., 2018). The use of events as a non-box representation was also presented as an option, however, without necessitating its use by the pre-service teachers. The choice of using directed or non-directed ties between concepts was left to the students according to their own preferences and meaning-making perceptions. Some additional practical recommendations included not repeating the same concept in different boxes, and not worrying whether the phrase was grammatically totally correct (*e.g.* by missing articles or different declensions of the nouns, *etc.*).

3.3 Data collection

Data collection for this study includes:
(1) the delivered concept maps, both in physical and digital form;
(2) the delivered worksheets and lesson plans;
(3) a pre-questionnaire regarding pre-service teachers' prior experiences and views on with concept maps (if any);
(4) a post-questionnaire regarding i) pre-service teachers' views on the usability of concept maps, ii) the challenges that they faced, iii) the features of the digital concept maps that they found useful, and iv) their preferences between a physical concept map and a digital one, along with their justifications.

The analysis of the delivered concept maps was made in parallel with the analysis of the teachers' delivered worksheets and lesson plans. Therefore, the analysis included solely the number (n = 26) of participants who had delivered a digital concept map, a physical concept map, a worksheet, and a lesson plan. To avoid redundancy, I refer to instructional design practices as ‘lesson planning’, even though it includes the examination of both worksheets and lesson plans.

3.4 Ethics statement

The present study met the ethics/human subject requirements of our institution at the time the data were collected.

3.5 Data analysis

3.5.1 Quality of instructional design

In order to analyse the quality of teachers’ instructional design practices, an initial examination of their worksheets and lesson plans was made, and a matrix was created including brief qualitative descriptions of the inaccuracies and shortcomings in each case. General patterns were qualitatively inferred based on the teachers’ difficulties depicted in the matrix. Subsequently, the quality of teachers’ lesson planning was assessed, following a similar categorisation to the quality of concept maps. Particularly, the analysis included:

I1) their structure; *i.e.* the extent to which the lesson plans followed the five main phases of constructivism: orientation, elicitation, restructuring, application, and review (Driver & Oldham, 1986).

I2) their content; *i.e.* the extent to which there were scientific inaccuracies/shortages of not.

I3) their quality, consisting of the focus *i.e.* to what extent the lesson plans were focused on the main goal and theme; conciseness *i.e.* the extent to which the activities adequately elaborated the teaching goal; and clarity *i.e.* the extent to which the language used was appropriate and clear for the students.

In each item, a ranking score from 0 to 2 was used, and an aggregated ranking score named IOv (with a maximum score of 6). Inductively-made criteria were kept for the analysis in order to establish reliability in the coding process.

3.5.2 Quality of digital concept maps

The quality of the digital concept maps was inferred based on the following three dimensions suggested by Cañas et al. (2015): 1) the quality of the structure of the concept map, 2) the quality of the content of the concept map, and 3) the overall quality of the concept map. In each dimension, items derived from Cañas’ et al. (2015) study that were deemed appropriate were implemented according to the scope of this study, *i.e.* for instructional design purposes. Specifically, for the assessment of the quality of the structure, the items used included:

1a) the number of concepts

1b) the number of propositions,

1c) the number of cross-links,

1d) the conceptual hierarchy *i.e.* the extent to which it appears a hierarchy of the core concepts based on a qualitative evaluation of the relative position of the core concepts on the map and their degree of connectivity -and not necessarily a conventional top-bottom classification.

All items were ranked on a scale from 0 to 2. The 1a, and 1b items were ranked based on set threshold values, *e.g.* for $6 \leq n < 12$ they were ranked as 1, and for $n \geq 12$ they were ranked as 2. Similarly, 1c was ranked as 1 for n = 1 or 2 cross-links, while it was ranked as 2 for $n > 2$. A set of criteria was inductively formulated and kept in order to establish the reliability of the coding process. An overall ranking score (CSOv) in this dimension was formed by aggregating the ranking in these 4 items (*i.e.* with a maximum of 8). Notably, no reference map was used since the pre-service teachers were given the opportunity to develop concept maps concerning a topic of their choice.

The assessment of the quality of the content included:

2a) the quality of concepts; *i.e.* the extent to which the concepts used were scientifically accurate and relevant and their labels were expressed comprehensively

2b) the quality of propositions, similarly as in 2a for the propositions

2c) the quality of cross-links, similarly for the cross-links

2d) the quality of hierarchy, similarly to the conceptual hierarchy expressed.

As previously, all items were qualitatively ranked on a scale from 0 to 2, while an overall ranking score (CCOv) emerged through the aggregation of the ranking scores in the four items (*i.e.* with a maximum of 8).

The assessment of the overall quality related to the whole structure of the digital concept map, and included the following items:

3a) the extent to which it relates and responds to the focus question. In this case, the focus question was deemed to relate to the scope that the pre-service teachers had written in their lesson plans

3b) the conciseness, *i.e.* the extent to which it was deemed to include an optimal number of concepts; in other words not missing concepts or including unnecessary concepts

3c) the extent to which the concept map communicates messages/meanings clearly and with clarity.

A ranking scale of 0 to 2 was used, as well as an aggregated ranking score (CQOv) (with a maximum of 6) of the aforementioned items. Additionally, an overall aggregated score (COv) regarding the three quality dimensions of the concept maps was used (with a maximum score of 22).

3.5.3 Accordance between lesson planning and concept maps

Subsequently, the concepts, propositions, cross-links, and conceptual hierarchy in each digital concept map were examined in relation to the teachers' developed lesson plan. A ranking score from 0 to 2 was used in each item, as well as an aggregated score (CAccOv) (with a maximum of 8). A qualitative inspection of the general topic was made regarding whether the teacher chose to partly/fully change the topic of their concept map.

3.5.4 Accordance between digital and paper-and-pencil concept map

The structure, content, and quality of the paper-and-pencil concept map were qualitatively compared to the digital concept map, and any differences between the two were noted down through a brief description matrix.

In order to examine correlations between the above dimensions, correlation tests were carried out by using the PSPP software (https://www.gnu.org/software/pspp). A preliminary examination of the aggregated ranking scores IOv, CSOv, CCOv, CQOv, COv revealed information regarding the results from Shapiro-Wilk normality tests, as well as the kyrtosis and skewness, as shown below in Table 2.

Table 2 Preliminary Examination of the Variables (Ranking Scores)

Variable	N	Shapiro-Wilk normality test		Kurtosis		Skewness	
		statistic	Sig.	Kurtosis	S.E.Kurt.	Skewness	S.E.Skew.
IOv	26	0.95	0.25	0.37	0.46	-0.38	0.89
CSOv	26	0.93	0.08	-0.77	0.46	0.28	0.89
CCOv	26	0.95	0.28	-0.13	0.46	-0.59	0.89
CQOv	26	0.92	0.05	-0.09	0.46	-0.94	0.89
COv	26	0.94	0.12	-0.69	0.46	-0.11	0.89
CAccOv	26	0.9	0.02	0.52	0.46	-0.67	0.89

As we can see, CAccOv does not pass the normality test at the 0,05 significance level, while CQOv and CSOv barely pass the normality test. Additionally, we can see that there are variables with a high skewness and kurtosis, as can also demonstrated through histograms. Therefore, non-parametric Spearman correlation tests were chosen for these items and sub-items.

3.5.5 Teachers' views on digital and physical concept maps

Teachers' responses in the pre- and post-questionnaire were qualitatively analysed with content analysis (Mayring, 2015). Specifically, inductively coded themes were noted, and general patterns were identified in each questionnaire question concerning the scope of the study. Teachers' responses were also analysed in reference to the findings of the analysis of the delivered concept maps in order to increase validity.

4 Findings

4.1 RQ1: how do pre-service teachers' concept maps relate to pre-service teachers' instructional design practices?

4.1.1 Quality of lesson planning

Table 3 showcases the quality scores of teachers' worksheets and lesson plans, as well as the quality scores of their digital concept maps. A general inspection of the quality of lesson plans in Table 3 in tandem with the matrix of qualitative descriptions of inaccuracies reveals that preservice teachers addressed several difficulties at the structural level (Average = 0.73, STD = 0.76). Specifically, it appeared that teachers's worksheets were often lacking the phases of review and application. Another common pattern was that making predictions was missing or students were prompted to write their predictions after the prompts to execute the experiment/activity. Challenges also appeared considering the quality of the lesson plans (Average = 0.73, STD = 0.59), especially in terms of the focus. Pre-service teachers tended to include activities that had similar but diverse teaching goals in relevant phenomena/concepts.

Table 3 Quality scores for teachers' lesson planning and concept mapping

	Lesson Planning				Concept maps: Structure					Concept maps: Content					Concept maps: Overall Quality					
Participant	Structure	Content	Quality	IOv	Concepts	Propositions	Cross-links	Con. Hierarchy	CSOv	Concepts	Propositions	Cross-links	Con. Hierarchy	CCOv	Focus Q.	Conciseness	Clarity	CQOV	COV	CAccOv
1	0	1	1	2	8	13	1	1	5	2	1	2	2	7	2	2	1	5	17	8
2	1	1	0	2	7	6	0	0	2	2	0	-	0	2	2	1	1	4	8	1
3	0	0	0	0	9	8	0	1	3	2	2	-	2	6	1	2	2	5	14	1
4	0	0	0	0	12	12	0	1	5	1	1	-	1	3	1	2	1	4	12	5
5	2	2	2	6	13	13	0	2	6	2	1	-	2	5	2	2	2	6	17	4
6	0	1	0	1	13	9	0	1	4	1	0	-	1	2	1	2	0	3	9	0
7	0	1	1	2	18	18	0	2	6	1	1	-	1	3	2	2	1	5	14	4
8	1	1	1	3	10	13	2	1	5	1	1	1	1	4	1	0	1	2	11	0
9	1	1	1	3	8	8	1	2	5	1	1	1	2	5	2	1	1	4	14	7
10	1	1	1	3	11	12	0	1	4	0	1	-	1	2	1	1	1	3	9	4
11	0	1	1	2	6	5	0	1	2	1	1	-	1	3	0	0	1	1	6	0
12	0	1	0	1	5	0	0	1	1	0	0	-	1	1	1	0	0	1	3	3
13	0	1	0	1	22	1	6	2	6	2	0	0	2	4	2	2	0	4	14	1
14	2	1	1	4	15	19	0	1	5	2	2	-	1	5	1	1	1	3	13	1
15	1	0	0	1	10	10	0	1	3	1	0	-	1	2	1	1	1	3	8	3
16	0	1	0	1	20	10	0	1	4	1	0	-	1	2	1	0	0	1	7	0
17	1	1	1	3	5	4	0	0	0	0	0	-	0	0	1	0	0	1	1	1
18	1	2	1	4	8	7	0	1	3	1	0	-	1	2	0	0	1	1	6	1
19	2	2	1	5	14	13	1	1	6	1	1	1	1	4	0	1	1	2	12	1
20	2	0	0	2	8	10	1	1	4	0	1	2	0	3	1	1	1	3	10	6
21	0	1	1	2	13	9	0	2	5	2	1	-	2	5	1	1	1	3	13	2
22	0	2	1	3	7	6	0	2	4	2	1	-	2	5	2	2	1	5	14	4
23	0	1	1	2	14	13	0	2	6	2	1	-	2	5	2	2	2	6	17	4
24	1	2	1	4	15	16	3	1	7	2	1	2	1	6	2	1	0	3	16	4
25	1	1	2	4	7	7	0	2	4	2	2	-	1	5	2	1	1	4	13	4
26	2	2	1	5	10	14	2	2	6	1	1	1	1	4	2	2	1	5	15	7
Avg.	0.73	1.08	0.73	2.54	11.08	9.85	0.65	1.27	4.27	1.27	0.81	1.25	1.19	3.65	1.31	1.15	0.88	3.35	11.27	2.92
STD	0.76	0.62	0.59	1.52	4.39	4.61	1.33	0.59	1.68	0.71	0.62	0.66	0.62	1.69	0.67	0.77	0.58	1.54	4.22	2.34

4.1.2 Quality of digital concept mapping

Pre-service teachers' digital concept maps included a ranging amount of concepts (Average 11.08, STD = 4.39), as also demonstrated in the histogram depicted in Figure 1a. However, the number of concepts used was not significantly correlated with the quality of the concepts (Spearman corr. = 0.26, Sig. = 0.196). Therefore, we cannot infer that the pre-service teachers who included more concepts necessarily had an accurate scientific representation of these concepts. However, the number of concepts was significantly correlated with the overall quality of concept maps (COv) (Spearman corr. = 0.42, Sig. = 0.031).

Similarly, the propositions (Average 9,85, STD = 4.61) are depicted in the histogram in Figure 1b. Misuse of propositions include cases where pre-service teachers did not add labels on the links, represented propositions in boxes too, or used the opposite direction of the linking arrows. The correlation between the number of propositions and their quality was found strong and significant in this case (Spearman corr. = 0.46, Sig. = 0.02), as well as the overall quality of concept maps (Spearman corr. = 0.57, Sig. = 0.002). It seems that developing a dense network of links among concepts was an indicator of having a scientifically correct representation of the propositions.

On the other hand, the appearance of cross-links was scarce, as shown in Figure 1c, confirming that it is a demanding skill for concept mapping. Notably, no correlation was found between the number of cross-links and their quality (Spearman corr. = 0.02, Sig. = 0.907), although a marginally significant correlation was found between the number of cross-links and the overall quality of concept maps (Spearman corr. = 0.39, Sig. = 0.048). Even in cases where pre-service teachers created many cross-links, their scientific validity was not necessarily good, which strengthens the argument that making accurate cross-links being a quality factor for expert concept mappers.

Also, the conceptual hierarchy was another indicator that significantly correlated with the quality of the hierarchy (Spearman corr. = 0.67, Sig. < 0.001), and the overall quality of the concept map (Spearman corr. = 0.66, Sig. < 0.001), indicating that it is a good predictor of quality.

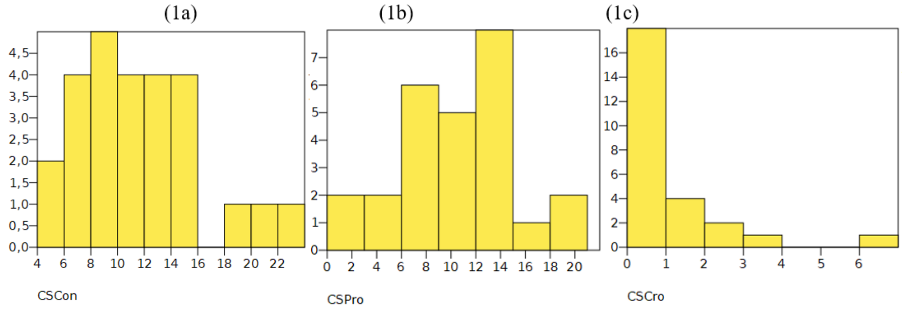

Figure 1 Histograms of Concepts (1a), Propositions (1b) and Cross-links (1c)

Regarding the overall quality of the digital concept maps, a noteworthy result concerns the relatively low average of clarity (Average = 0.88, STD = 0.55). There were cases where links were not expressed with clarity *e.g.* there were big sentences or there was no action verb explicitly mentioned, or similarly, concepts were not expressed clearly as nouns, or a repetition of the same concept in another place in the map. Cases like these were deemed to have limited the overall clarity of the concept map.

4.1.3 Lesson planning and concept mapping quality correlations

A general inspection regarding the aggregated score of the quality of the instructional design (IOv) and the aggregated score of the concept map (COv) revealed a medium correlation (Spearman corr. = 0.25, Sig. = 0.21) which was not statistically significant, as shown in Table 4. Therefore, we cannot safely infer that good concept mappers are necessarily good lesson planners, and vice versa. Table 4 showcases correlation coefficients between individual scores in each of the three quality dimensions of concept mapping.

Table 4 Correlation between quality of instructional design and concept mapping dimensions

	Spearman corr.	Std.Error	T	Sig.
IOv-CSOv	0.35	0.17	1.84	0.08
IOv-CCOv	0.27	0.19	1.39	0.18
IOv-CQOv	0.03	0.20	0.16	0.87
IOv-COv	0.25	0.18	1.29	0.21

We can see that no significant correlation can be inferred, although it appears an average and marginally significant correlation between the quality of the structure of the concept map and the instructional design quality. Hence, based on the results of this case study, we can infer that we cannot assume that a good concept mapper is necessarily a good lesson planner (and vice versa), even though there seems to be an affinity with the structure of the concept map *i.e.* the number of concepts, propositions, cross-links and conceptual hierarchy used.

4.1.4 Consistency between lesson planning and concept mapping

Inspecting the extent to which the theme of the lesson plan differed from the developed digital concept maps, we created the CAccOv aggregated score, as described in the methods section. Table 5 shows correlations of CAccOv with the quality of instructional design (IOv), the quality dimensions of structure, content and overall quality of concept mapping, as well as the aggregated quality score of concept mapping (COv).

Table 5 Correlations between the consistency of lesson planning to concept mapping and quality variables

	Spearman corr.	Std.Error	T	Sig.
CAccOv-IOv	0.20	0.18	0.99	0.33
CAccOv-CSOv	0.38	0.13	2.01	0.06
CAccOv-CCOv	0.38	0.14	2.04	0.05
CAccOv-CQOv	0.60	0.10	3.69	< 0.01
CAccOv-COv	0.58	0.11	3.45	< 0.01

We can see in Table 5 that the quality of lesson planning did not correlate significantly to the extent to which the concept maps were thematically in accordance with the lesson plans. However, the consistency between concept maps and lesson plans seemed to be indicative of the quality of the concept maps, as well as for the individual quality dimensions of concept maps (*i.e.* CSOv, CCOv, CQOv). These results were statistically significant or marginally significant. Therefore, we could infer that the pre-service teachers who stayed focused on their lesson plan goals and themes were also the ones who developed good concept maps.

4.1.5 Digital *vs* physical concept maps

The comparison between the delivered digital concept maps and physical concept maps showed that a great amount of concept maps were identical (n = 12) or almost identical (n = 5) in the two forms. That means that the pre-service teachers replicated the pencil-and-paper concept map in digital form or vice versa. In 6 cases the maps had a common theme but with some differences, while in 3 cases the two forms of concept maps had many differences.

Particularly, in 5 cases, the digital form of the concept map was deemed to be more elaborated or complete, while in 4 cases the physical form was deemed to outclass the digital form. The differences that were deemed to be advantages for the digital maps include i) having additional branches and concepts, ii) being structurally bigger and better elaborated than the physical, iii) having more concrete and scientifically accurate concepts/terms, and iv) being more focused on the phenomenon.

On the other side, the advantageous differences regarding the physical concept maps were the following: i) some propositions were more clearly depicted and distinguished compared with the digital representation, *e.g.* labels on the links were added or the links' labels diversified from the boxes of the concepts, ii) additional concepts or links were added, iii) the arrows of the links had a more accurate and meaningful direction, iv) were more organised and clear conceptually-wise, and v) some physical concept maps also included sketches (n = 1) or drawings (n = 2) that were explaining more some concepts.

Consequently, in this case study, we cannot infer that the quality of the digital or the physical concept maps was substantially better. Some differences were noted in a few cases, without identifying a common pattern.

4.2 RQ2: what affordances and difficulties do pre-service teachers identify in developing digital concept maps in relation to physical concept maps?

4.2.1 Physical concept mapping

Most pre-service teachers mentioned that they had no prior experience or knowledge about concept maps. As concerns the development of physical concept maps, six pre-service teachers mentioned no difficulty with them. Seven participants mentioned conceptual difficulties, like finding the linking words (n = 3) or concepts/terms so that all would be connected (n = 2), or comprehension issues (n = 2). However, practical issues were also mentioned, such as the ones below.

#9: To fit in the paper and be uniform.

#2: Connection between concepts, since I was starting from a small place and I kept putting concepts so at the end the arrows got messy a bit.

Readability (n = 1), making information compact (n = 3), or fear of being torn out or lost were also mentioned as challenges.

4.2.2 Digital concept mapping

The most referred difficulties in digital concept maps related to technicalities. Particularly, challenges related to the concept mapping app and the time needed to familiarise with the app (n = 3), difficulty in handling the arrows and their direction (n = 4), downloading the app (n = 2), or potential problems with internet connectivity and addressing bugs (n = 2). One participant mentioned conceptual difficulties, *i.e.* how to connect the place the arrows correctly for meaning-making, while one participant mentioned that digital concept maps would negatively affect creativity or studying. Six teachers mentioned no difficulties with digital concept maps.

On the other hand, teachers were asked to specify what features they found useful in digital concept maps. One participant mentioned their synoptic character, as described below.
#11: interconnections that are short and compact

Two participants highvalued the fact that you don't have space restrictions, so you can extend it anyhow. Pre-service teachers also reflected on arrows features, *e.g.* that they could be bidirectional (n = 1), or that you could write labels on them (n = 1), while others mentioned the boxes feature of the concepts (n = 2). Three participants mentioned customisation features, such as that you could change the colour, font or bold the labels. Additional arguments include the easiness of converting to pdf (n = 1), safety in keeping from getting lost (n = 1), and the fact that it is a quicker way compared with the physical one (n = 1). Finally, one participant mentioned no useful features.

4.2.3 Digital *vs* physical concept map comparisons

Pre-service teachers were called upon to explicitly compare the digital with the physical form of concept maps. Their views varied. Six participants preferred the digital ones, four participants preferred the physical ones, and two participants stated no preference/were neutral. The stated advances of the digital ones include having a lot of space (n = 1), the ability to erase (n = 1), user-friendliness (n = 3), being easily readable (n = 2), automation and time-saving features (n = 2), and the fact that it is not destroyed (n = 1).

On the other hand, the participants who preferred the physical ones mentioned that it is easier (n = 1), problems with technology (n = 1), the ability to see what you write and being able to correct it (n = 1), and that it can be decorated and look nicer for kids (n = 1).

5 Discussion

This case study examined the quality of teachers' digital concept maps in relation to the quality of their lesson planning, as well as the differences between digital and physical concept maps. The findings of the study provide insights into teachers' instructional design practices and concept mapping practices.

Specifically, as regards pre-service pre-school teachers' instructional designing, this study corroborates the existing problems concerning their shortages of science content knowledge and knowledge in science teaching (Kallery & Psillos, 2001), as well as feelings of insecurity in them (Raviv & Galili, 2023). Not only science is a demanding discipline for pre-school teachers, but also constructivistic lesson planning seems a challenging endeavour, especially for first-graders.

These issues were also depicted in several cases concerning the structure, content and overall quality of the concept maps that the pre-service teachers developed. However, even though there seemed to exist an affinity between the quality of lesson planning and the quality of the structure of concept mapping, this case study found no significant correlation between them. Hence, we could infer that a good and clear representation in a concept map is not a sufficient indicator of a good lesson plan and vice versa. We could interpret this finding in terms of science teaching requiring a diverse skillset from science knowledge. Even when pre-service teachers could create a decent content representation in terms of a concept map, shortcomings in constructivistic lesson planning could still arise. On the other hand, digital concept mapping requires graphic representation skills as well as basic technological skills; therefore pre-service teachers who could deliver a decent lesson plan might find it difficult to deliver a good digital concept map. Hence, the findings of this case study do not reveal an alignment between pre-service teachers' concept mapping and instructional design, while on the contrary, Artiles' et al. (1994) study revealed consistency between pre-service teachers' concept mapping and instructional practice. We can hypothesise that differences between instructional design and practice, as well as the fact that this case study focused solely on science instruction might have caused differentiated results from the study of Artiles et al. (1994), which is something that remains to be further explored.

Regarding the quality of concept maps, some more specific findings revealed that conceptual hierarchy, the number of concepts, propositions and cross-links were significantly correlated with the overall quality of the concept map, as also stated in the literature about concept maps (Cañas et al., 2015). However, in the case of concepts and cross-links, the quantity of them was not correlated with the quality of the content of the concepts or cross-links, respectively. In other words, more concepts or cross-links do not necessarily mean that these would appear scientifically correct. This finding showcases, first, that both the structure and the content quality should be examined, as stated in the literature, and second, that there is an optimal number of concepts in each case that could deliver the message of the concept map clearly and with scientific validity (Cañas et al., 2015). Nevertheless, conceptual hierarchy as well as the number of propositions were still correlated with their quality, indicating that hierarchy and the density of links are good predictors of the overall quality of the concept map.

Another notable finding concerns the importance of focus and consistency to the lesson plan theme in the quality of the concept map. Findings support that good concept maps were significantly correlated with the extent to which they stayed in accordance with the lesson plan theme. We could infer that pre-service teachers who moved away from the lesson plan theme and goals were more prone to inaccuracies in all three quality dimensions of concept maps examined. This finding supports the facilitating effect of having a focus question that guides the development of a concept map (Novak & Cañas, 2008).

5.1 The advantages of digital concept maps

This case study further examined the digital affordances of digital concept maps. Research shows that teacher training programmes in technology integration that are disconnected from the teaching practice or taken a long time ago do not impact teachers' attitudes towards technology (Zaranis et al., 2017). Therefore, the findings of this study speak to the need to use digital technologies in tandem with their applicability to teaching practice, in our case their lesson planning practices.

As concerns the design practices of the pre-service teachers, most teachers designed their digital concept map similarly to the physical one, while no general pattern appeared regarding which version of the concept map was of better quality. Similarly, pre-service teachers' reflections on the comparison between the digital and physical forms varied. Several advantages of the digital form were stated by teachers, such as having unlimited space to work, customisation, and readability. Many students mentioned no difficulty in developing digital concept maps, which corroborates the facilitating role of computers in concept mapping (Reiska & Soiska, 2015). However, some teachers addressed technical difficulties in developing the map or downloading/installing the app. On the other hand, concerning the physical map, difficulties mentioned related to conceptual difficulties in meaning-making, making it compact, and being fragile/temporary. Another notable feature mentioned of the physical concept map was that it can be more easy and creative, one can add sketches and decorate it.

The aforementioned reflections revealed that even though the new generation of pre-school teachers is considerably familiar with digital technologies, there still are perceived advantages of the paper-and-pencil form of the concept maps. Their views concerning customisation, drawings and appearance could be interpreted in reference to their agency as pre-school teachers, where activities that integrate art and physical materials are common. Hence, no general pattern towards the digital or physical concept maps appeared.

Limitations of the study relate to the small sample size of participants and the short-term character of the intervention. The quality scoring method implemented in the study also requires further examination and validation. Additionally, the fact that participants were called upon to deliver both the digital and the physical concept map in the same time frame might have influenced the similarity among the two. Finally, the correlations found among variables in the tests cannot safely advocate causal relationships between them (Makrakis, 2005); however, they signify operational connections that could support and frame the qualitative inspection between these variables.

Overall, the findings of the study speak to the importance of examining teachers' digital concept mapping in relation to their instructional practices through the examination of several quality dimensions: structure, content and overall quality. This can further inform the implementation and use of techniques such as concept mapping for teacher education programmes.

Conflicts of interest

The author states that there is no conflict of interest.

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