Concept Mapping Strategy to Improve Non-computer Science Students' Learning Achievements in Logical Database Design

Lynda Farza, Military Academy, Tunisia

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Abstract
This study aims to investigate the effects of using concept mapping on student's performance on logical database modeling. One hundred and two undergraduate students participated in the study. These students were assigned into three groups with three different learning approaches: two experimental groups and one control group. The three learning approaches were compared to find out what effects they have on learning database modeling. The concept map was used as a first step of data modeling by the two experimental groups, while the control group was taught using the conventional approach without using the concept mapping strategy. We have studied the logical database schema made by all students during the achievement test to see if there was a significant difference between the student's scores of the three groups. The findings revealed that for novice students, using the concept map strategy in the database design may be more efficient than the conventional approach. It can help to enhance the academic performance of students in logical database modeling. Based on our observations and the students' statements, we can also consider that the concept map had a positive effect on the students' attitudes towards the content, increased the students' motivation, helped to induce a positive dynamic among them, a greater engagement and interest in the subject matter.

Keywords: Computer Science, Database, Database Design, Logical Database Design, Concept Map, Entity/Relationship Diagram, Relational Schema

Introduction

Concept maps developed by Novak in 1972 are based on Ausubel's Assimilation theory (Ausubel, 1968) and Novak's Theory of Learning (Novak and Gowin 1984) which state that meaningful learning takes place when learners relate new knowledge to knowledge already acquired.

They are graphical tools used for organizing and representing knowledge. Concept maps include not only concepts but also relationships between them indicated by connecting arrow lines linking between two or more concepts and linking phrases that describe the relationship between concepts (Novak and *Cañas*, 2006).

Concept mapping can be a valuable learning tool used as an adjunct to other study methods, helping students organize and integrate information, gain new insights, relate new information to what they already know and detect areas where there are misunderstandings (Pintoi and Zeitz, 1997).

Concept maps have been used in a variety of teaching contexts and disciplines, including medicine (Daley et al., 2016), biology (Cathcart et al., 2010; Sakiyo and Waziri, 2015; Bergan-Roller et al., 2018), physics (Alias et al., 2006; Broggy and McClelland, 2009), chemistry (BouJaoude and Attieh, 2008; Mun et al., 2014; Ghani et al., 2017), mathematics (Oneca et al., 2006; Hafiz et al., 2017) and computer science (Gurupur et al., 2015; Santos et al., 2017; Omer et al., 2020).

In the context of computer science, concept mapping has been used in introducing computer course (Tokdemir and Cagiltay, 2010), in learning computer programming (Matthews, 2010; Jain et al., 2014; Dogan and Dikbiyik, 2016), in learning database concepts (Moen, 2009; Arruarte et al., 2014; Czenky and Kormos, 2014), in object-oriented modeling (Sien, & Carrington, 2007; Sien, 2011) and in conceptual database modeling (Gómez-Gauchía and McFadyen, 2011; Farza, 2018a; Farza, 2018b).

Nevertheless, students' performance in using concept map in the context of database design has rarely been assessed. Thus, this study aims to investigate the effects of using concept mapping on student's performance on logical data modeling.

The research question investigated in this study was as follow: what is the effect of using concept mapping on students' learning achievement in logical design of relational database schema?

Teaching Approach Adopted

The relational database design is an important topic in an introductory database course, and therefore it is most important that novices students understand it. Educators have a twofold challenge in teaching relational database design concepts: they need to deliver the theory of relational databases and also provide students with practical skills to perform effectively in real life (Al-Dmour, 2010).

Database design includes three design phases: conceptual design, logical design, and physical design. The result of the conceptual design is a conceptual schema (Entity-Relationship (ER) diagram or UML class diagram). The result of the logical design phase is a logical database

schema (relational database schema) which represents all information described by a conceptual schema produced during the conceptual design phase. The goal of the physical design is to implement the database.

In order to lead non-computer science students to develop the expected knowledge, it seemed relevant to us to propose the conceptual map as a tool that could deepen the understanding of the problem to be modeled and reduce the difficulties of transposing the description of the domain in natural language to the logical relational database schema.

Thus, to help novices' students to design a relational database schema, we envisaged only a two-step approach: a step of elaboration of the conceptual map and a step of transposition of this one towards a relational schema.

Principles of the Concept Map

The first step in designing a database is to create a concept map. Then the concept map is converted into a relational schema.

We extend previous work (Sien and Carrington 2007, McFadyen 2008, Farza 2018a, Farza 2018b) by adding mainly to the concept map the representation of the cardinality concept. This concept describes how the relation occurs between the main concepts. It is established by business rules.

The figure below represents the key-concepts of a conceptual map (Farza,2018a, 2018b):

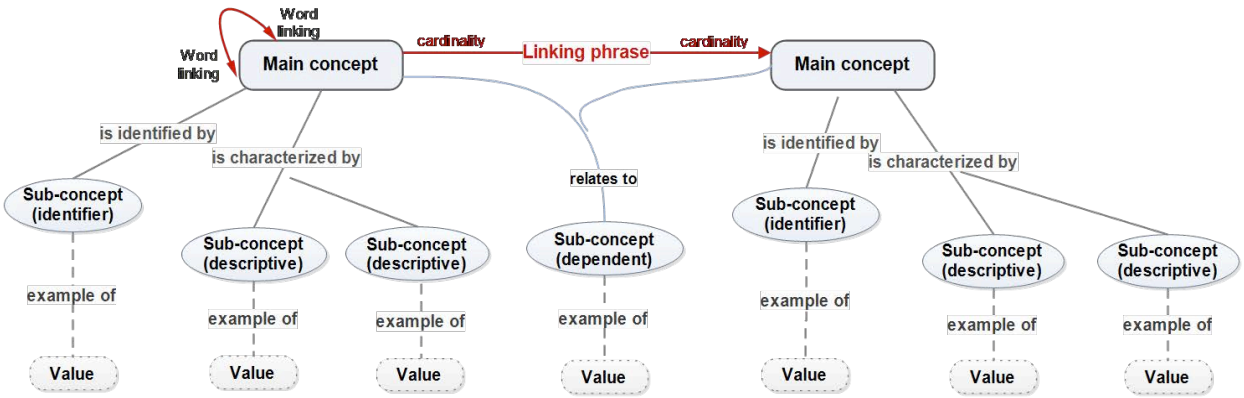

Figure 1: The Key-concepts of the Conceptual Map

- Several types of sub-concepts occur in the conceptual map: identifier sub-concept, descriptive sub-concept and dependent sub-concept.
- The main concept is described by descriptive sub-concepts and identifier sub-concept.
- The main concepts can be classified into a strong main concept and a weak main concept.

Concept	Description
Main concept	Represents a set of objects of the real world that have the same characteristics.
Instance	Specific example of the main concept.
Identifier sub-concept	Uniquely identifies each instance of the main concept.
Dependent sub-concept	Characteristic related to two main concepts.
Weak main concept	Main concept that depends on the existence of one or more other main concepts. This kind of concept can be identified uniquely only by considering the sub-concept identifier of another strong main concept.
Linking phrase	Represents the meaning of the link between - two main concepts (arrow line), - a main concept and itself (bidirectional arrow arc to and from the same main concept), - a main concept and a sub-concept (line), - a sub-concept and an instance (or value) of this sub-concept (dashed line).
Cardinality for a link	Specifies the number of instances of a main concept (minimum and maximum) associated with one instance of the related main concept. The minimum cardinality will be zero or one and the maximum cardinality will be one or many
Types of link	Links between main concepts can be - one-to-many (maximum cardinality one on one side and many on the other side), - one-to-one (both maximum cardinalities are one), - many-to-many (maximum cardinalities are many on both sides).

Table 1: Representation on Concept Map

Example of a Concept Map

The figure 2 shows an example of a conceptual map designed for a simple *personnel management* database for a company with several departments. Each department has at least one employee. An employee is assigned to only one department, but can work on one or more projects at different times. At least one employee is assigned to a project, but an employee may be not assigned to any projects. We keep track of the start date and the end date that an employee works on each project.

Each employee manages at most one department and each department is managed by only one employee.

Employees are supervised by a direct supervisor, who is himself an employee (an employee has at most one direct supervisor). Conversely, employees may or may not have subordinates. We want to keep track of the dependents of each employee. Each dependent (son and daughter) is dependent of only one employee. Dependents are identified by both employee number and the name of the dependent.

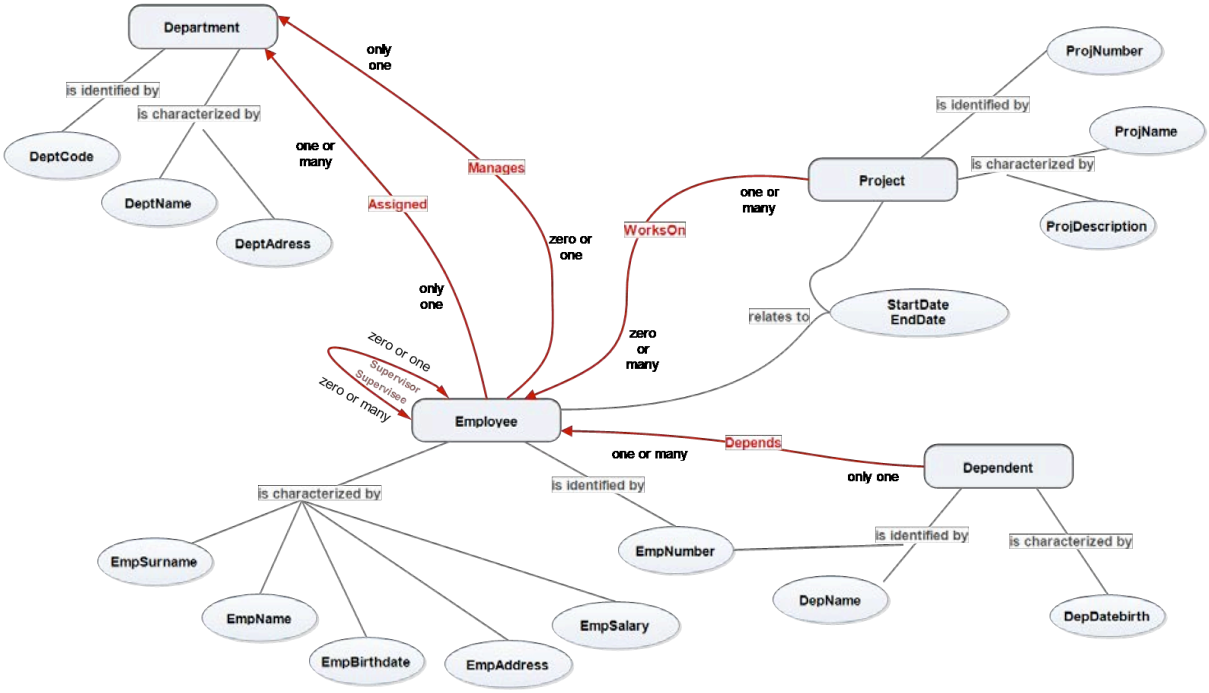

Figure 2: A Concept Map for a Personnel Management Scenario

Transformation of the Concept Map to a Relational Schema

The next step in the design process is to transform the concept map obtained to a relational database schema according to a set of translation rules. The aim is to construct a relational schema that represents all of the information described by the concept map.

The relational model is based on four main concepts: the relation, the attribute, the primary key and the foreign key.

Below the different steps required to transform the concept map to a relational schema.

- **Step 1: Mapping of Strong Main Concepts**

The concept map contains three strong main concepts: *Department*, *Employee* and *Project*.
Each strong main concept is transformed into a relation; its sub-concepts (identifier and descriptive) become attributes of the relation. The identifier sub-concept becomes the primary key of the relation and had to be underlined.

In our example, we generate three relations: *Department*, *Employee* and *Project*.

- **Step 2: Mapping of Weak Main Concepts**

The concept map contains one weak main concept: *Dependent*.
A weak main concept is also represented as relation. All the sub-concepts of the weak main concept form the attributes of the relation. The primary key of the relation is the combination of the primary key of the relation - which corresponds to the strong main concept – included as a foreign key and the partial identifier sub-concept of the weak main concept.

In our example, we include the primary key *EmpNumber* of the *Employee* relation as a foreign key attribute of the *Dependent* relation. The primary key of this relation is the combination (*EmpNumber, DepName*).

- **Step 3: Mapping Links Between Main Concepts**

One-to-many link:
A link one-to-many between main concepts is converted by including the primary key from the relation - which corresponds to the many-side main concept – as foreign key in the relation that represents the other one-side main concept.

In our example, we include the primary key *DeptCode* of the *Department* relation as foreign key in the *Employee* relation. We also include the primary key of the *Employee* relation as foreign key in the same relation because the link is recursive (link between a main concept and itself: from Employee to Employee) and calls it *EmpSupervisor*.

One-to-one link:
A link one-to-one between main concepts, with optional participation for one side main concept (cardinality: zero or one) and mandatory participation on the other one side (cardinality: only one), is converted by including the primary key from the relation - which corresponds to the main concept with optional participation – as foreign key in the relation that represents the main concept with mandatory participation.

In our example, we include the primary key of the *Employee* relation as foreign key in the *Department* relation and call it *EmpManager*.

Many-to-many link:
A link many-to-many between main concepts is converted by creating a new relation. The primary key of the two relations – that represents the two participating main concepts – are included as foreign key attributes in the new relation. Their combination will form the primary key. All sub-concepts related to the two main concepts become attributes of the new relation.

In our example, we create a relation *EmployeeWorks* in the relational database schema. The primary keys of the *Employee* and *Project* relations are included as foreign keys in *EmployeeWorks* relation. The primary key of this relation is the combination (*EmpNumber, ProjNumber*). Attributes *StartDate* and *EndDate* represent the other attributes of EmployeeWorks relation.

The figure below shows the relational schema which has been derived from the concept map (figure 2) by application of transformation rules.

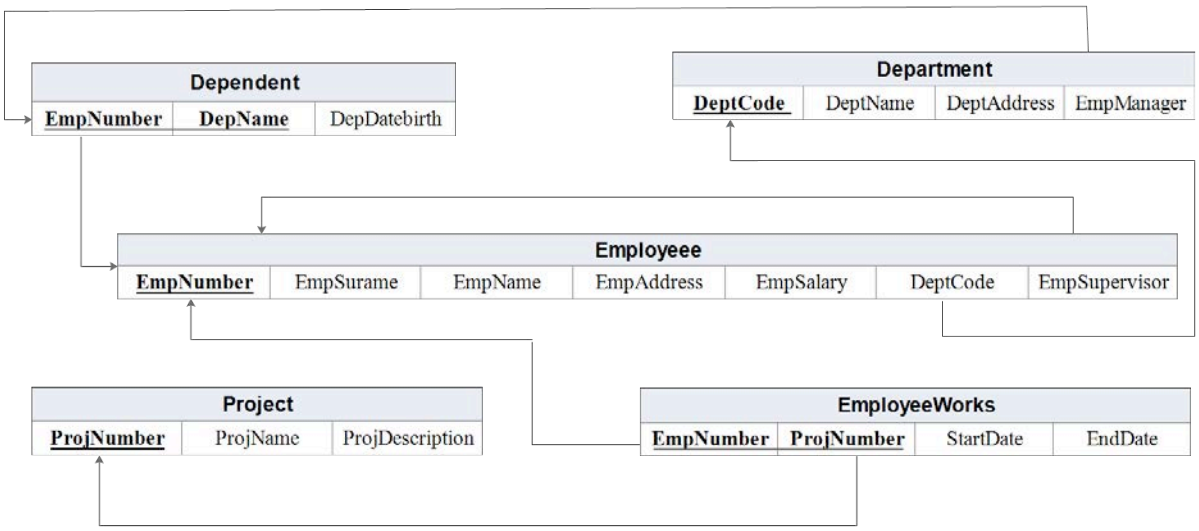

Figure 3: A Relational Database Schema for a Personnel Management Scenario

Below the textual representation of the relational schema:
Department(<u>DeptCode</u>, DeptName, DeptAddress, *EmpManager*)
Employee(<u>EmpNumber</u>, EmpSurame, EmpName, EmpAddress, EmpSalary, *DeptCode*, *EmpSupervisor*)
Project(<u>ProjNumber</u>, ProjName, ProjDescription)
EmployeeWorks(*<u>EmpNumber, ProjNumber</u>*, StartDate, EndDate)
Dependent(*<u>EmpNumber, DepName</u>*, DepDatebirth)

Material and Methods

Participants

The study was carried out over two academic years during which the students were taught a database design course.

The first study was conducted during the 2015/2016 academic year, to investigate the effect of utilizing concept mapping strategy as a first step in conceptual database design on the novice learner's performance in conceptual data modeling. This study (study 1) included two groups of non-computer science university undergraduate students: group 1 (experimental group with 22 students) was working with concept maps, while group 2 was not using the concept map (control group with 28 students). The results of this study suggest that, for novice learners, the concept map strategy in conceptual data modeling is more efficient than the traditional approach because it simplifies modeling tasks (Farza, 2018a, 2018b).

The present study was conducted during the 2017/2018 academic year, to compare the effect of using concept mapping strategy on the novice learner's performance in logical data modeling. The sample of the study consisted of one hundred and two non-computer science university undergraduate students randomly assigned into three groups: experimental group 1 (33 students), experimental group 2 (35 students) and a control group (34 students). All students were not familiar with database design and never heard about concept map.

While study 1 has investigated the effect of using concept map on student's performance in conceptual data modeling, the current study focuses on the effect of students' performance in logical data modeling.

Experimental Procedure

Students from three groups followed the same database design course with the same teacher and using the same teaching pedagogical approach combining learning from examples in problem-solving situations, collaborative learning and continuous formative assessment (Farza, 2015).

The main learning objectives of this course are to make students be able to understand fundamental relational database concepts and to be able to develop a database relational schema for specific database requirements.

Each group received 21 hours of instruction, 3 hours per week for 7 weeks. The only difference between groups was the used teaching approach in database design.

Three approaches (figure 3) were used, in this experiment, to teach data modeling: the conventional approach for the control group, the conceptual oriented approach for the first experimental group and the logical oriented approach for the second experimental group.

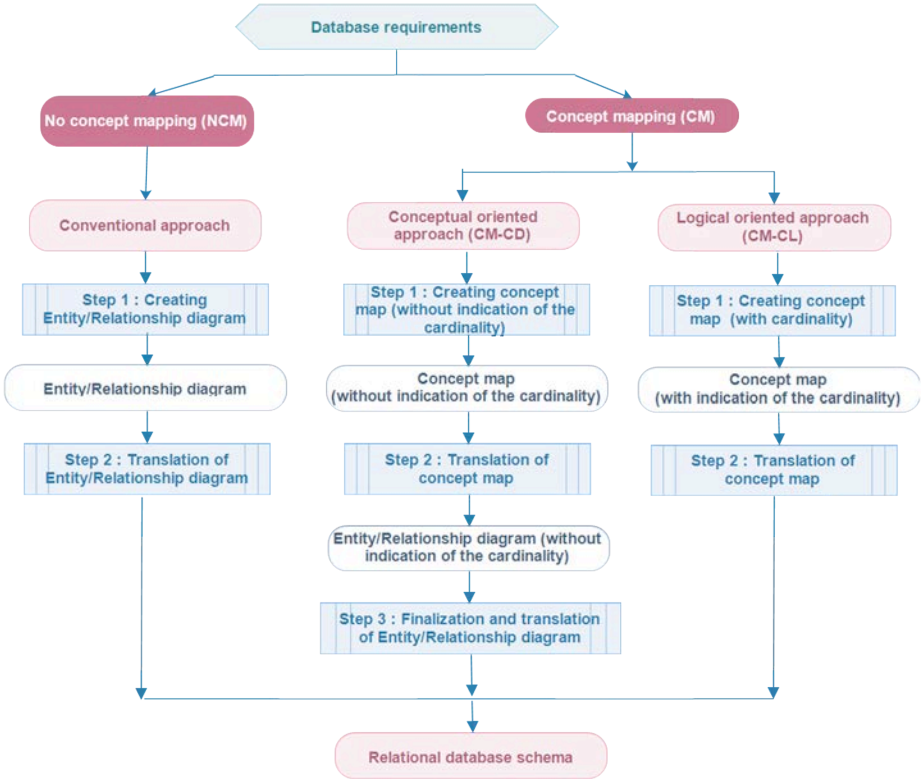

Figure 4: Teaching Approaches

The concept map was used as a first step of data modeling by the two experimental groups, while the control group was taught using the conventional method without using the concept mapping strategy.

- The conventional approach design, used with the control group (NCM), consisted of two steps: create an Entity-Relationship (ER) diagram (conceptual schema) responding to the database requirements and translate it to a relational schema (logical schema) by mapping the ER diagram to a relational schema using mapping rules.

- The conceptual oriented approach, used with the first experimental group (CM-CD), consisted of three steps: create the concept map responding to the database requirements, translate it to an ER diagram and create a relational schema by mapping ER diagram to relational schema using mapping rules.
- In the logical oriented approach, used with the second experimental group (CM-LD), only two steps were required to create a relational database schema: create the concept map responding to the database requirements and convert it to a relational schema by mapping the concept map obtained to the relational schema using mapping rules.

Many examples of solved database design problems using concept maps were given to the students of the two experimental groups.

The first example contains database requirements and a concept map responding to these requirements. After discussion with students of the example given, a second partially solved problem example containing the requirements of the database and a partially concept map was presented to students. They were asked to complete the concept map and translate it into a relational schema. In the last example, students were asked to construct a common concept map collaboratively (by groups of two or three students) and to give the relational database schema. A discussion was then conducted to allow students to show and discuss the concept map and the relational schema made.

Other exercises of increasing complexity, to be solved individually, were offered to the students to complete their learning. These required the construction of a concept map to produce a relational database schema.

Only the first experimental group had to elaborate the ER diagram before given the relational schema.

Instruments of Research

In this research a pre-test was conducted at the beginning of the course to evaluate students' computer science prior knowledge. At the end of the treatment, an identical post-test, of two hour periods, was administrated to the students in three groups, to determine the effectiveness of the concept mapping strategy on students' academic achievement in logical database design. They were asked to give a relational database schema that satisfies the given requirements. Only experimental groups had to produce before a concept map. The first experimental group had to translate the concept map into an ER diagram before giving the relational database schema.

The relational schemas made by students were scored out of seven.

Data Analysis Method

Data analysis was based on one independent variable: teaching modality (conventional approach, conceptual oriented approach, logical oriented approach). The dependent variable analyzed was the score in the problem solving post-test.

Descriptive statistics was used to analyze and determine the mean achievement scores for each group in logical database design. One-factor analysis of variance (ANOVA) was used to determine if there was a significant difference between groups.

Results and Discussion

We will present and analyze the results that we obtained following the statistical treatment.

A one way ANOVA showed that there was no significant difference between the pre-test scores of experimental groups and control group.

The research question was to investigate the effectiveness of the concept mapping versus the conventional approach on the logical data modeling teaching.

The following table shows the participants' mean scores and standard deviations on the post achievement tests:

Group	N	Mean	Standard deviation	Standard Error mean	95% Confidence Interval of the Difference	
					Lower	Upper
Control group (NCM)	34	4	1,174	0,201	3,795	4,615
Experimental group 1 (CM-CD)	33	5,121	1,494	0,262	4,591	5,651
Experimental group 2 (CM-LD)	35	5,028	1,543	0,260	4,498	5,558

Table 2: Descriptive Statistics for the Post-test

The results in Table 2 indicate that the mean scores on the post-test in the experimental group 1 (5.121) for the conceptual oriented approach and the experimental group 2 (5.028) for the logical oriented approach were higher than those of the control group (4). The experimental group 1 (M = 5.121, SD = 1.494) and the experimental group 2 (M = 5.028, SD = 1.543) performed almost the same on the post-test. The achievement of these two groups suggests that when students used the concept map as a first step either in the conceptual database modeling or in the logical database modeling, the results are better than teaching with the conventional design approach. However, the standard deviation is higher for the conceptual mapping approaches (conceptual oriented approach and logical oriented approach) than for the conventional approach.

To see if these differences are significant, a one-way ANOVA analysis of variance was used to observe whether there are differences attributed to the teaching approaches. The results of which are presented in Table 3.

Source of variation	Sum of Squares	df	Mean square	F	Level of Significance
Between groups	17,209	2	8,605	4,301	0,016
Within groups	198,045	99	2,000		
Total	215, 255	101			

Table 3: Results of ANOVA Analysis

As shown in Table 3, the ANOVA analysis revealed statistically significant difference between the post-test scores of the experimental and the control groups ($p = 0.016 < 0.05$). This means that the teaching approach has a major effect on students' learning performance.

In order to determine which of the three teaching approaches has a significant impact on learner performance, we applied a Tukey's HSD post-hoc test. Table 4 below shows the results obtained:

Group		Mean difference	95% Confidence Interval		p
I	**J**	**(I-J)**	**Lower Bound**	**Upper Bound**	
NCM	**CM-CD**	-0, 91533	-1, 7377	-0, 0929	**0, 025**
	CM-LD	-0, 82269	-1, 6331	-0, 0123	**0, 046**
CM-CD	**NCM**	0, 91533	0, 0929	1, 7377	**0, 025**
	CM-LD	0, 09264	-0, 7240	1, 9092	0, 961
CM-LD	**NCM**	0, 82269	0, 0123	1, 6331	**0, 046**
	CM-CD	-0, 09264	-0, 9092	0, 7240	0, 961

Table 4: Results of Tukey's HSD Post-hoc Test

This result allows us to refine the conclusion derived from the ANOVA test and to specify for which teaching approach significant differences in students' average scores are observed. Tukey post-hoc test (Table 4) revealed that the mean difference in scores between conventional approach (NCM) and conceptual oriented approach (CM-CD) was statistically significant ($p = 0.025 < 0.05$). The difference in mean scores between conventional approach (NCM) and conceptual logical approach (CM-LD) was statistically significant ($p = 0.046 < 0.05$). The Tukey test showed, therefore, a significant difference between groups in favor of the two experimental groups regarding the control group. In other words, the two groups who used the concept map in the database design process performed significantly better than the control group who used the conventional approach. However, the means scores between the two experimental groups (CM-CD and CM-LD) were not significantly different ($p = 0.961 > 0.05$).

This suggests that the use of concept mapping strategy as a first step of database design can improve the students' performance in the logical design of relational database schema, compared to the conventional approach without using concept mapping.

In conclusion, the results of study 1 (Farza, 2018a, 2018b) and the present study (study 2) reveal that the use of the concept map as the first step in database design can improve both novice students' performance in constructing the conceptual schema of a database (study 1) and in constructing the logical schema of a database (study 2).

Thus, the results of this study and the first one suggest that, for novice learners, the concept map strategy in data modeling is more effective than the conventional approach because it simplifies the modeling tasks, enables students to better understand the database requirements and to facilitate the learning process of database design.

Conclusion

In an introductory database course, database design is a fundamental topic that it is important to novice students will understand it correctly.

The present study investigates the impact on students' performance of using concept mapping strategy to support database design learning process. Three learning approaches were compared to find out what effects they have on learning: the conventional approach, the conceptual oriented approach and the logical oriented approach. The last two approaches use the concept map as a first step of database design.

The findings revealed that for novice non-computer science students, using the concept map strategy in the database design may be more efficient than the conventional approach. It can help to enhance the academic performance of students in logical database modeling. The concept map could be also helpful in the improvement of the understanding of a problem domain.

For future research, it will be important to detect and analyze logical modeling errors. The question to be formulated for this further research is how the use of a concept map could reduce errors produced by students when making relational database schema.

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