J Sci Educ Technol (2013) 22:204–214
DOI 10.1007/s10956-012-9386-8

The Effectiveness of Concept Maps in Teaching Physics Concepts Applied to Engineering Education: Experimental Comparison of the Amount of Learning Achieved With and Without Concept Maps

Guadalupe Martínez · Ángel Luis Pérez ·
María Isabel Suero · Pedro J. Pardo

Abstract A study was conducted to quantify the effectiveness of concept maps in learning physics in engineering degrees. The following research question was posed: What was the difference in learning results from the use of concept maps to study a particular topic in an engineering course? The study design was quasi-experimental and used a post-test as a measuring instrument. The sample included 114 university students from the School of Industrial Engineering who were divided into two equivalent homogeneous groups of 57 students each. The amount of learning attained by the students in each group was compared, with the independent variable being the teaching method; the experimental group (E.G.) used concept maps, while the control group (C.G.) did not. We performed a crossover study with the two groups of students, with one group acting as the E.G. for the topic of optical fibers and as the C.G. for the topic of the fundamental particles of matter and vice versa for the other group. For each of the two topics studied, the evaluation instrument was a test of 100 dichotomous items. The resulting data were subjected to a comparative statistical analysis, which revealed a significant difference in the amount of learning attained by the E.G. students as compared with the C.G. students. The results allow us to state that for the use of concept maps, the average increment in the E.G. students' learning was greater than 19 percentage points.

Keywords Science education · Concept maps · Physics · Engineering

G. Martínez (✉) · Á. L. Pérez · M. I. Suero · P. J. Pardo
Orion Research Group, Department of Physics,
University of Extremadura, Avda. de Elvas s/n,
06071 Badajoz, Spain
e-mail: mmarbor@unex.es
URL: http://grupoorion.unex.es

Introduction

Concept maps are diagrams that represent organized knowledge (Novak and Gowin 1984). The theoretical basis for concept maps relies on Ausubel's Assimilation Theory (Ausubel 1968, 2000) and Novak's Theory of Learning (Novak and Gowin 1984), which state that people learn new things by using their existing knowledge and looking for ways to assimilate new knowledge. When learning meaningfully, the integration of new concepts into our cognitive knowledge structure occurs by linking this new knowledge to concepts we already understand.

A concept map is a graphical representation of these relationships between concepts in our cognitive structure. Because these knowledge representation tools must have a basic construction and specific characteristics (Cañas et al. 2003), not all graphs that contain text in their nodes are concept maps. Moreover, the literature is full of diagrams that are incorrectly portrayed as concept maps. Concept maps are two-dimensional, hierarchical, node-linked diagrams that represent conceptual knowledge in a concise visual form (Quinn et al. 2004; Horton et al. 1993).

Concept maps include not only concepts (often represented by a labeled box or circle) but also the relationships between the concepts (represented by a connecting line linking two concepts) (Novak and Cañas 2006). Words written on the line, called linking words, indicate the relationship between the two concepts. Any concept-link-concept triad is a meaningful statement termed a proposition or a unit of meaning. When creating a concept map, we must ensure that every two concepts and their corresponding linking phrases form a unit of meaning or a short sentence. A good concept map must emphasize the relationships between and among important concepts (Zeitz and Anderson-Inman 1992; Markow and Lonning 1998).

Thus, a concept map consists of a graphical representation of a set of propositions about a topic, and every concept map responds to a focus question that clearly identifies the issue the concept map should help to resolve.

When fostering creative thinking, there are two significant aspects of concept maps: a good hierarchical structure and the ability to find new cross-links (Novak and Cañas 2006). Concept maps tend to be represented in a graphically hierarchical fashion, with the most general concepts at the top of the hierarchy and the more specific, less general concepts arranged below. Cross-links are relationships between concepts in different segments of the concept map. They represent creative leaps because they help us see how a concept in one domain of knowledge represented on the map is related to a concept in another domain of the map.

Created with IHMC CmapTools, Fig. 1 presents a Concept Map of Concept Maps

Concept maps are widely used at different educational levels to help students better assimilate the concepts they are studying by developing new propositions that are naturally integrated into the student's cognitive structure, which leads to meaningful learning (Jonassen et al. 1997; Jonassen 2000; Novak and Gowin 1984; Okebukola and Jegede 1988; Pérez et al. 2001; Roth and Roychoudhury 1994). Indeed, the theory of meaningful learning states that the learning process is an interaction between pre-existing knowledge in the student's cognitive structure and new knowledge that is being assimilated (Ausubel 1968; Mintzes et al. 1998). As Ellis et al. (2004) noted, in science and engineering teaching, the learner's existing knowledge often contains deeply rooted misconceptions that make new learning difficult. The use of concept maps is promising, as it highlights issues of knowledge, knowledge structure, and the way ideas are related. For Pérez et al. (2010), there is clear evidence of the effectiveness of concept maps in assessing students' prior knowledge of scientific content and how it is organized (Anderson-Inman et al. 1998; Caswell and Wendel 1992) as well as the degree of understanding that students attain (Markham et al. 1994; Novak et al. 1983).

If used to their full potential, concept maps are an effective tool for stimulating meaningful learning, allowing students to construct knowledge through the organization and hierarchization of conceptual content (Novak et al. 1983; Novak and Gowin 1984; Novak and Musonda 1991; Chiu et al. 2000). Concept maps have a demonstrated effectiveness as cognitive tools (Cifuentes and Hsieh 2003; Kwon and Cifuentes 2007), regardless of whether students construct them individually or collaboratively in groups, although they are more effective in the latter case (Roth and Roychoudhury 1993; Kwon and Cifuentes 2007; Haugwitz et al. 2010). Studies have also demonstrated the usefulness of concept maps in synthesizing content studied during or at the end of a learning sequence (Horton et al. 1993; Pankratius 1990).

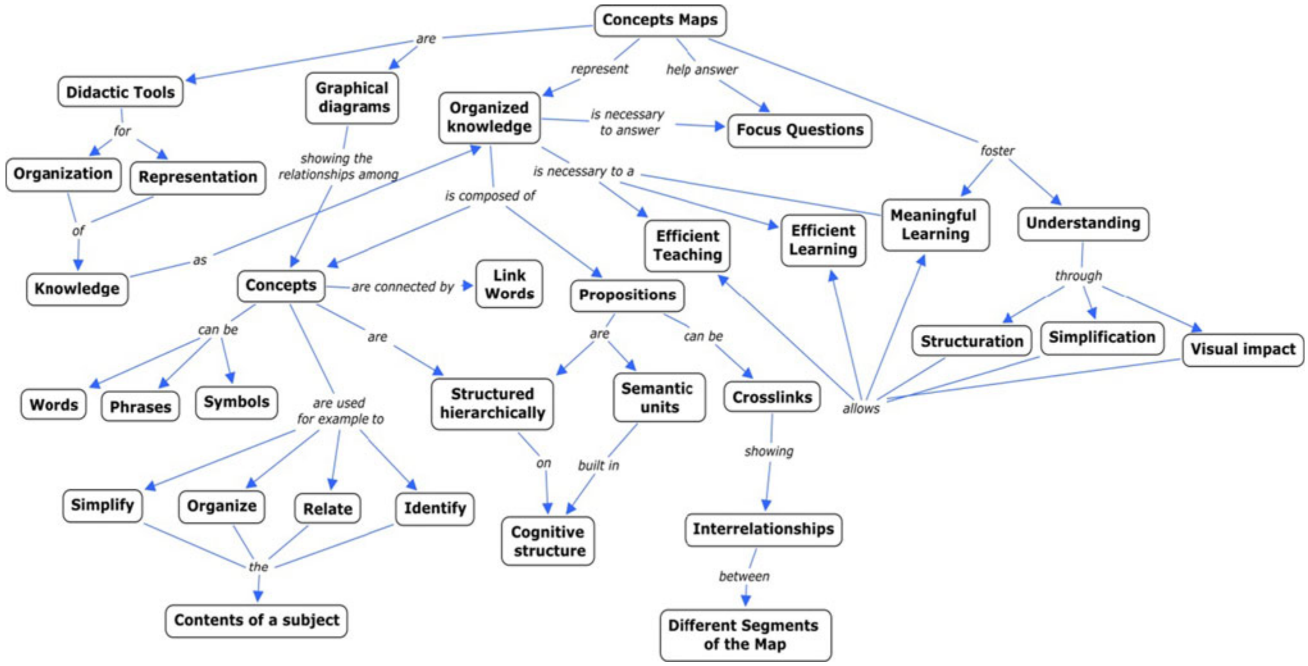

Fig. 1 Concept map about concept maps: Adaptation of the map created by J.D. Novak in his paper "The theory underlying concept maps and how to construct them", using the CmapTools software

As Cañas et al. (2003) state, the issue is not whether concept maps enhance learning; as with any other tool, their effectiveness depends on how are they used and the conditions in which they are used. Horton et al. (1993) reviewed the educational effectiveness of concept maps, finding that their educational benefits range from very positive to negative effects, with almost all studies showing various degrees of positive effects.

Focusing on the use of concept maps in science education, Okebukola and Jegede (1988, 1989) documented some of the primary advantages of concept maps, particularly a positive influence on students' academic performance. Montanero and Montanero (1995) studied their utility as pre-organizers, i.e., as a means of presenting an initial overview of the content and connecting it with students' prior knowledge. Walker and King (2003) named concept maps among several referenced forms of student assessment. Hernández and Serio (2004) compared several methods of teaching a scientific topic and showed that preparing a concept map is particularly useful as a method of pre-organization, regardless of whether the teacher presents it or the students themselves construct it, as long as the teacher explicitly helps students connect the map with what was just learned. Broggy and McClelland (2008) investigated the impact of concept maps on learning physics. The process of constructing a concept map is a powerful learning strategy that forces the learner to actively think about the relationship between the terms. For learners who perceive science as simply memorizing facts, concept maps are especially suited to studying science (Dorough and Rye 1997).

Austin and Shone (1995) used concept maps for assessment in physics and showed that they are useful in assessing the comprehension of relationships between the concepts required for multiple-step problem-solving in physics. For example, Zieneddine and Abd-El-Khalick (2001) studied the effectiveness of concept maps as learning tools in developing students' conceptual understanding in a freshmen college physics laboratory course and showed that those students who used concept maps scored substantially higher than those students who did not use maps. Moreover, the participants noted that concept maps helped them organize knowledge and promoted comprehension of physics concepts.

Other studies have pointed out the advantages of the collaborative use of concept maps in physics. Collaborative learning is based on the idea that students influence each other's learning when they exchange knowledge and negotiate its meaning (Baker et al. 1999; Barron 2003). There is evidence that this type of classroom activity changes misconceptions of physics. Roth and Roychoudhury (1992) found that when explanations and justifications were more extensive in discussions, there was a greater likelihood of conceptual change. Pérez et al. (2008) carried out a series of educational experiments wherein they tested the implementation of concept maps in support of processes of the collaborative reconstruction of knowledge and conceptual change in undergraduates. Their results demonstrated concept maps' potential to foster awareness and then to modify implicit theories about physical phenomena.

With the development of new technologies, many constructivist-based software programs have been developed for the individual or collaborative creation of concept maps, such as CmapTools, Inspiration, SmartIdeas, DEMCO, MACOSOFT and inter alia. The benefits provided by these computer tools have been widely recognized (Anderson-Inman and Zeitz 1993; Anderson-Inman and Ditson 1999; Royer and Royer 2004; Kwon and Cifuentes 2009; Nian-Shing Chen et al., 2008; Chiu et al. 2000; Alpert and Grueneberg 2001; Fisher et al. 1990; Reader and Hammond 1994; Liu et al. 2010; Cline et al. 2010). Concept maps are especially suitable in collaborative learning (Cañas et al. 2003; Stoyanova and Kommers 2002; Okebukola and Jegede 1988; Haugwitz et al. 2010; Pérez et al. 2006).

Although it is widely accepted that students learn more when they use concept maps (Novak 1998; Slotte and Lonka 1999; Patterson et al. 1992; Stoyanova and Kommers 2002; Pérez et al. 2006), the following question is frequently raised: "How much more do students learn as compared to when concept maps are not used?" We understand this question's motivation as assessing whether the improvement gained is worth the effort involved in learning how to use concept maps. The present study attempts to quantify this improvement with experimental data by comparing the effectiveness of two models of knowledge in teaching physics concepts in engineering disciplines as measured by the increase in the amount of learning that students attain when using them.

The research was conducted with university students from different disciplines first as a pilot trial during the academic year 2008–2009 (with none of these students participating in the definitive experiment) and then in 2009–2010 (the definitive collection of data). The experiment consisted of a comparison of the results of the academic performance of two student groups: one experimental group and one control group. The methodological approach for the experimental group was based on the use of concept maps, while the control group was based on traditional teaching without concept maps.

Figure 2 shows an example of a concept map of degradation of the signal in an optical fiber. This concept map was one of those used by students in the experimental group.

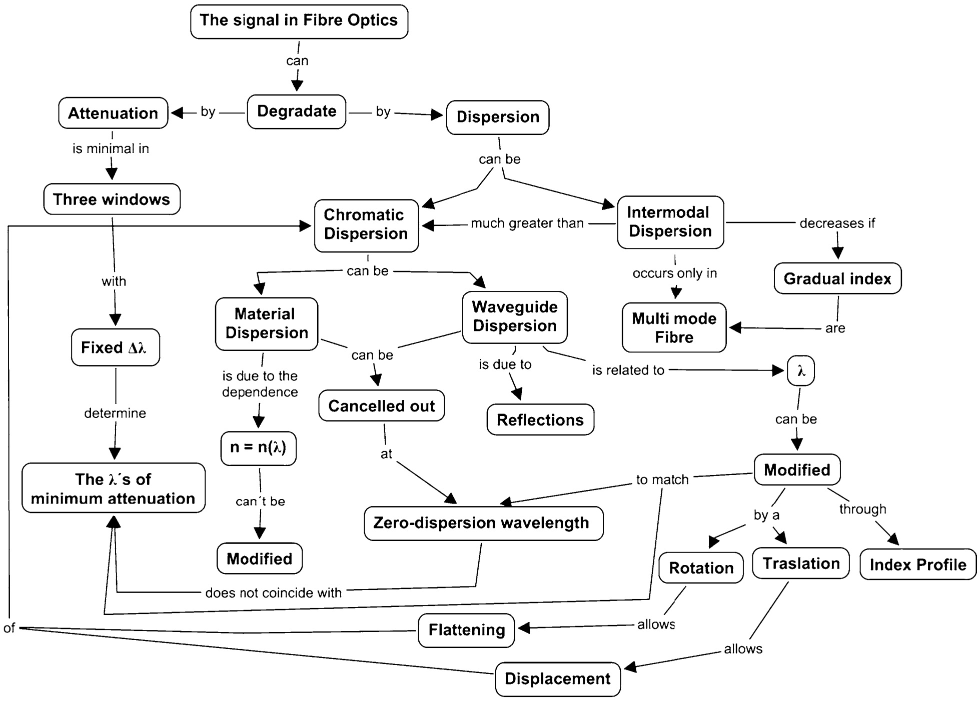

Fig. 2 Example of a conceptual map collaboratively developed by students in the pilot course, which would be later used with students in the experimental group

Objectives and Methods

Objectives

This study's main objective was to examine the effectiveness of concept maps in teaching physics concepts by experimentally determining the amount of learning that is attained by using concept maps, which was compared with that attained by students who did not use these maps, thus allowing us to quantify the effectiveness of using concept maps as a teaching strategy.

Hypotheses

The working hypotheses tested in the study were as follows:

Null Hypothesis (H0): There is no difference in the average learning attained by a group of students working with concept maps compared to an equivalent group studying the same topic but without using concept maps.

Alternative Hypothesis (H1): There is a difference in the average learning attained by a group of students working with concept maps compared to an equivalent group studying the same topic but without using concept maps.

Sample

The experimental study was conducted during the academic year 2009–2010 with 114 junior and senior students pursuing degrees in Electronic or Materials Engineering in the School of Industrial Engineering at the University of Extremadura. To guarantee the homogeneity between both groups, the students were evenly divided into two working groups according to capabilities, discipline, and academic record. Each group used two different teaching methods in their study of two physics topics, acting as the experimental group for one of the topics and as the control group for the other topic. Thus, one can quantify the learning achieved by the students in terms of the teaching methods used (as proposed in hypotheses H0 and H1). More specific guidelines are included below.

The first group of 57 students acted as the control group for the study of optical fibers (C.G.t1) and as the experimental group for the study of the fundamental particles of matter (E.G.t2).

The second group of 57 students acted as the experimental group for the study of Optical Fibers (E.G.t1) and as the control group for the study of the Fundamental Particles of Matter (C.G.t2).

Figure 3 shows a conceptual map of how students were distributed in the working groups.

The teaching method used for the experimental groups (E.G.t1 and E.G.t2) was based on the use of concept maps linked together, forming an advanced model of knowledge (Novak and Cañas 2006) of the subject studied as a learning strategy. The method used for the control groups (C.G.t1 and C.G.t2) was based on the use of a set of texts provided by the instructor, without the aid of concept maps. To ensure that the conceptual content of the topics under

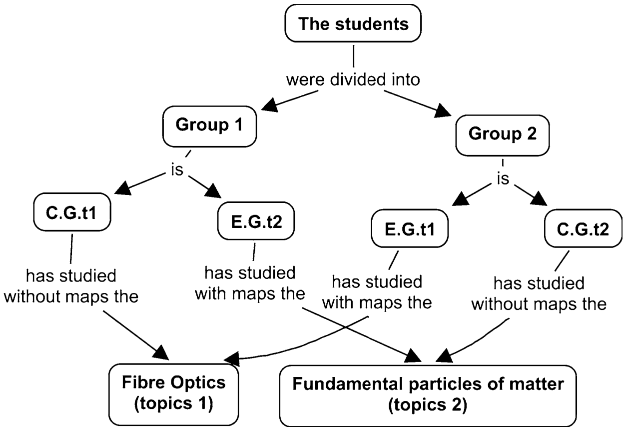

Fig. 3 A concept map showing the distribution, the teaching methodology used, and the topic studied by each group (control and experimental)

investigation were the same for the two groups, the concept maps used by the experimental groups were prepared from the texts provided to the corresponding control groups.

In most studies cited in the introduction, the concept maps employed were created by students. This is because the authors considered that the act of drawing a map can itself facilitate concept learning, as attempting to construct a concept map forces the individual to confront preconceptions and concept comprehension and to seek clarification when necessary (Anderson-Inman et al. 1998; Ellis et al. 2004). As an alternative, teachers can generate concept maps and use them as 'advance organizers' (Broggy and McClelland 2008). Here, the teacher constructs a concept map that focuses on the upcoming lessons' content. Smith (1987) finds concept maps a worthwhile heuristic in helping experts transmit their own knowledge more clearly to learners and in helping learners better understand the structure of knowledge. This allows students to identify connections between the conceptions they already possess and the new learning material. With concept maps, information can be presented in a condensed manner without sacrificing complexity and meaning. Gul and Boman (2006) declare that the visual presentation of concept maps allows students and teachers to identify the information without the dense presentation of words and verbal structures. Concept maps made by expert teachers in the field are an effective tool for teaching and learning physics and have a positive impact on both short-term and long-term learning.

In addition to the above-mentioned studies, the benefits of learning after collaboratively constructing concept maps have also been corroborated (Cañas et al. 2003; Stoyanova and Kommers 2002; Okebukola and Jegede 1988; Haugwitz et al. 2010; Pérez et al. 2006). These studies led to our decision that the concept maps used by students of the experimental groups would be constructed by the expert teacher and then reconstructed collaboratively with a pilot group of students in the School of Industrial Engineering during the 2008–2009 academic year. This guaranteed that the revised version's propositions were units of meaning negotiated between the teacher and students.

We developed two models of knowledge for specific topics constructed collaboratively with a group of students in the School of Industrial Engineering: (1) Optical Fibers comprised 13 interlinked maps supplemented with a multitude of resources and (2) the Fundamental Particles of Matter comprised 6 interlinked concept maps with supplementary resources. The two models are available on our Cmap Website "Universidad de Extremadura (España)" in the directory "Modelos de Conocimiento," where they can be used interactively through the CmapTools application. (See http://grupoorion.unex.es:8001/servlet/SBReadResourceServlet?fid=1HWBMHTH4-DQ0BWM-1Z7K for the knowledge model of Optical Fibers, and http://grupoorion.unex.es:8001/servlet/SBReadResourceServlet?fid=1HWBMTSTH-14RY2TP-1ZQD for the knowledge model of Fundamental Particles of Matter).

Research Design

The study was conducted following a quasi-experimental crossover design with a post-test and control group. The teaching method used was taken to be the independent variable, i.e., whether concept maps were used in teaching physics. The dependent variable was the amount of learning attained by the students. To ensure the validity of our study, we controlled for possible interfering variables that may influence the final result, i.e., the topics chosen for study and the instructor's teaching skill.

In the first case, the topic chosen for study could influence the results because the existence of prior knowledge of the subject matter would likely affect the final level attained by a particular student. To make the starting point as uniform as possible and to better delimit the real differences in the amount of learning attained by the experimental groups compared with the control groups, we chose topics with high-level content that would not have been covered previously in any lecture courses taken by the students. These topics were "optical fibers" and "fundamental particles of matter". This choice ensured that the students would have minimal initial knowledge of the topic, which also minimized the influence of the interfering variable "prior knowledge" on the final results.

In the second case, to minimize the effect of the instructor's teaching skills as a variable, the same instructor taught both groups of students; that is, the instructor taught ten 2 hours sessions with each group of students: five sessions on topic 1 and five on topic 2. In the sessions with a control group, the instructor used a classical teaching methodology and relied on traditional resources and texts to explain content. In the sessions with an experimental group, this same content was explained using interlinked concept maps with the software program CmapTools (Cañas et al. 2001, 2003; Novak and Cañas 2006). This software package provides a virtual learning space in which concept maps can be constructed collaboratively as complete models of knowledge of a topic under investigation and can be used as a tool with which to navigate through its complex domains of knowledge. It allows users to add resources to the maps they construct (e.g., images, videos, tables, text), thereby promoting meaningful, active, and participatory learning.

The teaching method used by the teacher of the experimental groups was based on the explanation and development of concepts and relationships between them, which is the basis of proposals for making concept maps (Moon et al. 2011). This teaching methodology was intended to focus students' attention on the most significant relationships between the fundamental concepts of the subject matter and was used because the concept map is an ideal tool to negotiate the meanings of concepts and their corresponding relationships. The CmapTools software was used to support the first construction of concept maps by the expert teacher, collaborative reconstruction of concept maps with the pilot group, and the subsequent presentation and use of concept maps in classes with students of the experimental groups.

During the sessions when the teacher worked with students of both control and experimental groups, all students had at their disposal the material their instructor used in the respective theoretical classes, i.e., texts, notes, and presentations on the content (control group students), and models of knowledge with concept maps (experimental group students). On completion of the theoretical classes, both working groups were assigned the same amount of time (about 8 hours) for individual study using the material that they had been given.

Evaluation Instruments

The instrument used to quantify the students' conceptual learning consisted of two post-tests (one for each study topic). An initial design of 120 questions in each test was given to twenty students in the pilot trial. The results were subjected to analysis using the LXR-TEST software program (Logic eXtension Resources 2011) to eliminate questions that were insufficiently discriminatory. To this end, the items were first analyzed qualitatively to verify their consistency with the content to be evaluated and then quantitatively to calculate each item's discrimination index. From this analysis, we reconstructed two final tests of 100 dichotomous items, each of an equivalent standard of demand of conceptual understanding. These final tests served as post-tests to evaluate each working group when they had finished studying the corresponding topic. The tests are available at the following web address where our students worked interactively with concept maps: http://grupoorion.unex.es:8001/servlet/SBReadResourceServlet?fid=1HWBMHJHW-1PFXF03-1Z6Y.

To qualitatively assess the validity of the experience, we conducted a series of informal interviews upon completion of the classes to keep a record of student satisfaction, where they could show their opinion on the methodology used. The qualitative information collected in these interviews can be summarized like this: the use of models of knowledge with concept maps provided not only a more dynamic and entertaining environment in the classroom, but it also secured a more efficient learning. The acquired knowledge about the more relevant concepts to the subject matter was built in a more robust way by students.

Statistical Analysis

To test the research hypotheses, the post-test scores were subjected to a descriptive statistical analysis, which included verifying the normality of their distribution. The resulting statistics allowed us to determine the amount of learning attained by the students of each group and to quantify the increment in learning achieved by the experimental groups compared to the control groups. These analyses were carried out using the IBM SPSS program package (Argyrous 2005; Levesque 2007).

Results and Discussion

Table 1 (left) presents the statistics for the scores the students obtained in their study of Optical Fibers, including the sample size, mean, standard deviation, standard error of the mean, first and third quartiles, and the difference in scores between the experimental groups compared to control groups (Δ learning (ΔL)). The columns correspond to the mean results obtained by the E.G.t1 and the C.G.t1 groups. Table 1 (right) presents the equivalent statistical results for the post-test evaluating the Fundamental Particles of Matter topic.

Table 2 shows the Shapiro–Wilk test to verify the normal distribution of the sample population of all working groups.

The results of the Shapiro–Wilk Test (Table 2) allowed us to accept the normality of the C.G. distributions because the p-values corresponding to the two control groups were considerably greater than 0.05 (significance between 0.606 and 0.200). However, in the

Table 1 Descriptive statistics of the responses of the C.G. and E.G. students in the study of optical fibers (left-hand side) and in the study of the fundamental particles of matter (right-hand side)

	Topic 1: optical fibers		Topic 2: fundamental particles of matter	
	E.G.t1	C.G.t1	E.G.t2	G.C.t2
N student	57	57	57	57
Mean	83.51	61.74	82.42	62.88
Standard error of the mean	0.92	0.93	1,02	1.07
Standard deviation	6.92	7.05	7,72	8.07
Percentile				
25	77.00	56.00	75.00	57.00
75	88.00	67.00	86.20	68.8
Δ learning (ΔL)	83.51–61.74 = 21.77 percentage points		82.42–62.88 = 19.54 percentage points	

Table 2 Shapiro–Wilk Test

	Shapiro–Wilk		
	Statistical	d.f (degrees of freedom)	Significance
C.G.t2	0.983	57	0.606
E.G.t2	0.950	57	0.021
G.C.t1	0.972	57	0.200
E.G.t1	0.930	57	0.003

experimental groups, the variable of correct answers was not distributed as a normal distribution, as the values of significance obtained in both groups E.G.t1 and E.G.t2 were below the predetermined alpha level of significance (0.05). This led us to choose the parametric Student's *t* test for comparison between test results obtained in the control group (C.G.t1 and C.G.t2) and to choose the nonparametric Mann–Whitney test (Mann and Whitney 1947) to analyze the difference in scores between the experimental groups (E.G.t1 and E.G.t2) and their respective control groups.

Table 1 shows differences in the mean scores obtained by the various working groups: E.G.t1 (83.51 ± 0.92) points over 100, C.G.t1 (61.74 ± 0.93) points over 100, E.G.t2 (82.42 ± 1.02) points over 100 and C.G.t2 (62.88 ± 1.07) points over 100. In the following section, we will examine these differences in detail.

For example, there was a difference in the mean scores of the two control groups. To verify if this difference was significant at a 5 % significance level, we applied the Levene test and Student's *t* test for the equality of means of independent samples due to the normal distribution of the correct answers in the control groups (Table 2). The purpose of comparing the two control groups was to verify (1) if the mean scores obtained by the two groups were similar and (2) if the two topics selected were similar in difficulty (in terms of the students' capabilities). The results of these tests are presented Table 3.

Table 3 Levene test and Student's *t* test for independent samples for a 5 % significance level (a = 0.05): control groups

Differences between control groups	Homoskedasticity assumption
Levene homoskedasticity test	
F	1.195
Significance (*p*-value)	0.277
t test for equal means	
t	0.803
d.f. (degrees of freedom)	112
Significance (*p*-value)	0.423
Difference of means	1.140
Standard error of the difference	1.419
95 % confidence interval for the difference	
Lower	−3.952
Upper	1.672

The Levene test (Table 3) showed that the homoskedasticity of the two groups could not be rejected because the *p*-value was 0.277 ($p > 0.05$). Indeed, the table shows that the difference in the means was 1.140 with a standard error of 1.419. The two-tailed p-value resulting from the *t* test was 0.423 ($p > 0.05$), and the difference between the two groups was not significant at a 5 % significance level. In particular, this indicates that the mean scores obtained in the two control groups were similar and that the two topics were therefore similar in difficulty.

Given this equivalence in the difficulty of the topics as established for the control groups, the question to consider was whether the use of a concept map-based teaching strategy would lead to similar learning increments for the two topics or whether these increments would be influenced by the choice of topic. To control for this variable, the study design crossed the student groups so as to isolate

Table 4 Results of the Mann–Whitney test

Groups	N	Mean rank	Sum of rank
C.G.t1	57	29.75	1,695.50
E.G.t1	57	85.25	4,859.50
C.G.t2	57	31.65	1,804.00
E.G.t2	57	83.35	4,751.00

Ranks

the independent variable "teaching method" from possible interfering variables regarding the homogeneity of the groups. Thus, the students of C.G.t1 acted as E.G.t2, while those of C.G.t2 acted as E.G.t1.

Table 1 demonstrates that the mean scores of the two experimental groups were similar and different from those obtained for the control groups. To verify if these differences with the respective control group scores were significant at a 5 % significance level (a = 0.05), the data were subjected to a Mann–Whitney test to test the following null hypothesis: "There is no increase in the average learning attained by a group of students working with concept maps compared to an equivalent group studying the same topic but without using concept maps.". The results of the Mann–Whitney test are presented in Tables 4 and 5.

Table 4 shows that the C.G.t1 group had an average rank of 29.75, while the E.G.t1 had an average rank of 85.25. It could also be seen that C.G.t2 had an average rank of 31.65, while E.G.t2 had an average rank of 83.35. The results of the Mann–Whitney test (Table 5) were in the expected direction and were significant, $z = -8.972$ (topic 1), $z = 8.356$ (topic 2), and $p < 0.05$, showing that the differences in mean scores of the experimental groups with respect to their respective control groups were significant (i.e., not due to chance but to the teaching strategy used).

Based on the results obtained from the Mann–Whitney test, we can say with a significance level of 5 % that there was an increase in the experimental group's scores. In terms of averages, the increase of learning achieved by students using concept maps is estimated at 21.77 percentage points for the topic of Optical Fibers and at 19.84 percentage points for the topic of the fundamental particles of matter, a result consistent with that obtained for topic 1. The value of the mean learning increment differed between the two topics. When directly comparing the mean test scores, there were no apparent significant differences in the learning increments between the two topics studied. With a more exhaustive study comparing a greater number of topics, we would be able to say whether the learning gain obtained by using concept maps is independent of the topic chosen, provided that those topics have an equivalent level of conceptual content and are studied at the same level of demand. This comparison would allow us to apply the present findings to many other topics.

Table 5 Mann–Whitney test for a 5 % significance level (a = 0.05) for topic 1 (left) and topic 2 (right)

	Topic 1	Topic 2
Mann-Whitney U	42.500	151.000
Wilcoxon W	1,695.500	1,804.000
Z	−8.972	−8.356
Significance	0.000	0.000

The results were both statistically and educationally significant, given the large effect size coefficients obtained: $r = 0.842$ for the topic of optical fibers and $r = 0.778$ for the topic of the fundamental particles of matter.

Taking into account the existence of an increase in the percentage of correct answers on tests of students in the experimental group versus the control group, these results allow us to answer the following research questions:

A. Results relative to research question 1: What percentage of items on a test have a ΔL higher than a given level? Figs. 4 and 5 present the answer to this question.

In Fig. 4, one can read the percentage of items that have a learning increment greater than a certain value represented on the *X*-axis. For example, when the test is taken by the experimental group students, 60 % of the items have a learning increment greater than 18 percentage points.

B. Results relative to research question 2: Given a specific item on a test, what is the probability that ΔL is greater than a certain level? Table 6 presents the results corresponding to the two topics studied.

For example, for topic 1, there is a 74 % probability that the learning increment of a particular item will be greater than 20 percentage points.

Conclusions

The results confirm our initial hypothesis that there is a difference in learning for students who use concept maps and the CmapTools software package as compared to those who do not. This increment, ΔL, was determined for the study of both optical fibers and the fundamental particles of matter. The results are consistent with those of other studies showing that concept maps are a useful cognitive strategy for the structured acquisition of information and for discovering the meaning of the concepts being learned. The results also suggest that the learning gains achieved by using concept maps are similar to the study of topics that were clearly distinct but with an

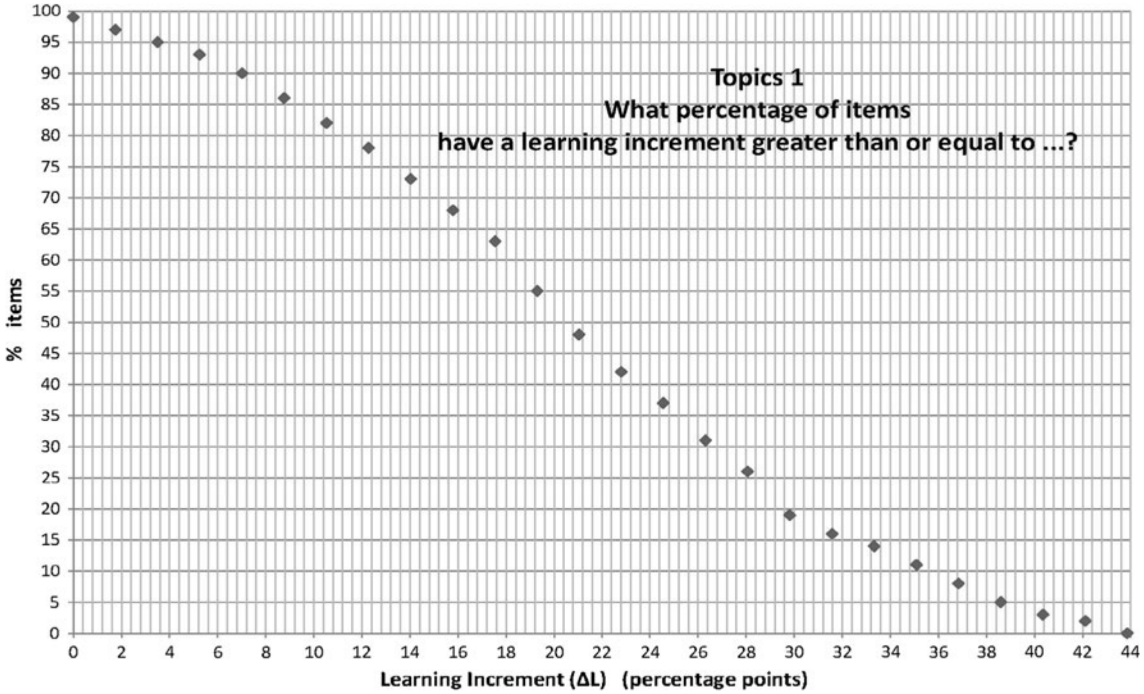

Fig. 4 Percentage of items whose ΔL exceeds a certain level (represented on the *horizontal axis*): Topic 1

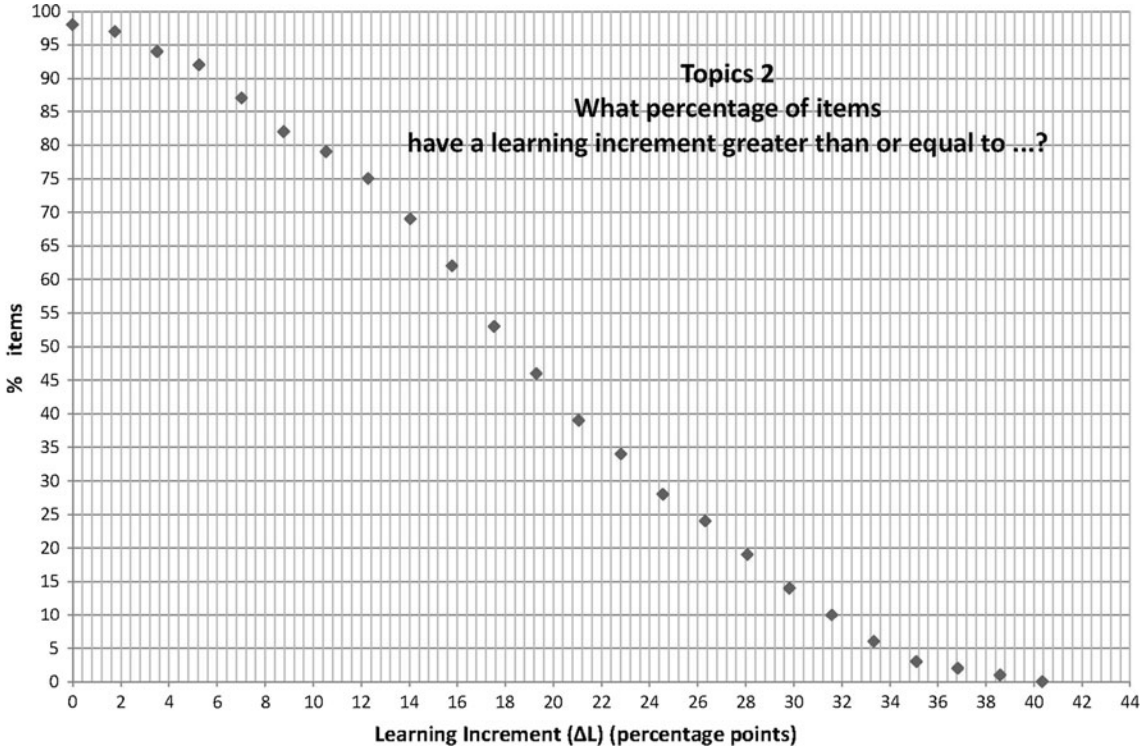

Fig. 5 Percentage of items whose ΔL exceeds a certain level (represented on the *horizontal axis*): Topic 2

equivalent level of conceptual content; however, further research on additional topics should be carried out to confirm the latter conclusion. In sum, our results confirm that concept maps are an effective tool for general physics teaching because they help students learn the concepts meaningfully, regardless of the topic under investigation.

Table 6 The calculated probability of finding a particular item whose ΔL exceeds a certain level for topic 1 (left-hand columns) and for topic 2 (right-hand columns)

Optical fibers		Fundamental particles of matter	
ΔL > … (percentage points, pp)	Probability %	ΔL > … (percentage points, pp)	Probability %
5	98	5	94
10	95	10	84
15	87	15	68
20	74	20	48
25	57	25	28
30	38	30	13
35	22	35	5
40	10	40	2
45	4	45	0
50	1	50	0

In particular, we found that the implementation of concept map-based teaching methods increased learning by 21.77 percentage points on average.

References

Alpert SR, Grueneberg K (2001) Concept mapping with multimedia on the Web. J Educ Multime Hyperme 9(4):313

Anderson-Inman L, Ditson L (1999) Computer-based concept mapping: a tool for negotiating meaning. Learn Lead Technol 26(8):6–13

Anderson-Inman L, Zeitz L (1993) Computer-based concept mapping: active studying for active learners. Comput Teach 21(1): 6–11

Anderson-Inman L, Ditson LA, Ditson MT (1998) Computer-based concept mapping: promoting meaningful learning in science for students with disabilities. Inf Technol Disabil 5:1–2

Argyrous, George Statistics for research: with a guide to SPSS (2005). 2nd (ed). London: Sage. ISBN: 1412919487

Austin LB, Shone BM (1995) Using concept mapping for assessment in physics. Phys Educ 30(1):4145

Ausubel DP (1968) Educational psychology: A cognitive viewpoint. Rinehart and Winston, New York

Ausubel DP (2000) The Acquisition and Retention of Knowledge: a Cognitive View. Kluwer Academic Publishers, Dordrect; Boston

Baker M, Hansen T, Joiner R, Traum D (1999) The role of grounding in collaborative learning tasks. In: Dillenbourg P (ed) Collaborative learning: cognitive and computational approaches. Elsevier Science Ltd, Oxford, pp 31–63

Barron B (2003) When smart groups fail. J Learn Sci 12:307–359

Broggy J, McClelland G (2008) An investigation to determine the impact of concept mapping on learning in an undergraduate physics course. New Direct Teach Phys Sci 4:34–38

Cañas AJ, Ford KM, Novak JD, Hayes P, Reichherzer T, Suri N (2001) Online concept maps: enhancing collaborative learning by using technology with concept maps. Sci Teach 68(4):49–51

Cañas AJ, Coffey JW, Carnot MJ, Feltovich P, Hoffman RR, Feltovich J et al. (2003). A summary of literature pertaining to the use of concept mapping techniques and technologies for education and performance support. Report from the Institute for Human and Machine Cognition

Caswell RM, Wendel CT (1992) Conceptual changes occurring in elementary teachers' knowledge of science concepts throughout long-term instruction. Paper presented at the American Educational Research Association Annual Meeting, San Fransisco, CA

Chen NS, Kinshuk, Wei CW, Chen HJ (2008) Mining e-Learning domain concept map from academic articles. Comput Educ 50:1009–1021

Chiu CH, Huang CC, Chang WT (2000) The evaluation and influence of interaction in network supported collaborative concept mapping. Comput Educ 34(1):17–25

Cifuentes L, Hsieh YJ (2003) Visualization for construction of meaning during study time: a quantitative analysis. Int J Instruct Med 30(3):263–273

Cline BE, Brewster CC, Fell RD (2010) A rule-based system for automatically evaluating student concept maps. Expert Syst Appl 37(3):2282–2291

Dorough DK, Rye JA (1997) Mapping for understandingusing concept maps as windows to students' minds. Sci Teach 64(1): 36–41

Ellis GW, Rudnitsky A, Silverstein B (2004) Using concept maps to enhance understanding in engineering education. Int J Eng Educ 20(6):1012–1021

Fisher KM, Faletti J, Patternson H, Thornton R, Lipson J, Spring C (1990) Computer-based concept mapping. J Coll Sci Teach 19: 347–352

Gul RB, Boman JA (2006) Concept mapping: a strategy for teaching and evaluation in nursing education. Nurse Educ Pract 6(4):199–206

Haugwitz M, Nesbit JC, Sandmann A (2010) Cognitive ability and the instructional efficacy of collaborative concept mapping. Learn Individ Diff 20(5):536–543

Hernández P, Serio A (2004) ¿Cómo hacer eficaces los mapas conceptuales en la instrucción? Infancia y Aprendizaje 27:247–265

Horton PB, McConney AA, Gallo M, Woods AL, Senn GJ, Hamelin D (1993) An investigation of the effectiveness of concept mapping as an instructional tool. Sci Educ 77:95–111

Jonassen DH (2000) Computer as mindtools for schools: Engaging critical thinking. Prentice Hall, Upper Saddle River

Jonassen DH, Reeves TC, Hong N, Harvey D, Karen P (1997) Concept mapping as cognitive learning and assessment tools. J Interact Learn Res 8(3/4):289–308

Kwon SY, Cifuentes L (2007) Using computers to individually-generate versus collaboratively-generate concept maps. J Educ Technol Soc 10(4):269–280

Kwon SY, Cifuentes L (2009) The comparative effect of individually-constructed versus collaboratively-constructed computer-based concept maps. Comput Educ 52:365–375

Levesque R (2007) SPSS programming and data management: a guide for SPSS and SAS users fourth edition, SPSS Inc., Chicago. ISBN 1568273908

Liu PL, Chen CJ, Chang Y (2010) Effects of a computer-assisted concept mapping learning strategy on EFL college students' english reading comprehension. Comput Educ 54:436–445

Logic eXtension Resources (2011) LXR-Test software. http://www.lxrtest.com

Mann HB, Whitney DR (1947) On a test of whether one of two random variables is stochastically larger than the other. Ann Mathemat Stat 18(1):50–60

Markham KM, Mintzes JJ, Jones M (1994) The concept map as a research and evaluation tool: further evidence of validity. J Res Sci Teach 31(1):91–101

Markow PG, Lonning RA (1998) Usefulness of concept maps in college chemistry laboratories: students' perceptions and effects on achievement. J Res Sci Teach 35(9):1015–1029

Mintzes JJ, Wandersee JH, Novak JD (1998) Teaching science for understanding. Academic Press, London

Montanero M, Montanero M (1995) Didáctica del momento angular de una partícula. ICE, Badajoz

Moon B, Hoffman RR, Novak J, Cañas A (2011) Applied Concept Mapping: Capturing, Analyzing, and Organizing Knowledge. CRC PRESS, USA

Novak JD (1998) Learning, creating and using knowledge: Concept maps as facilitative tools in schools and corporations. Lawrence Erlbaum Associates, Mahwah

Novak JD, Cañas AJ (2006) The theory underlying concept maps and how to construct them. Technical report IHMC CmapTools

Novak JD, Gowin DB (1984) Learning how to learn. Cambridge University Press, Cambridge

Novak JD, Musonda D (1991) A twelve-year longitudinal study of science concept learning. Am Educ Res J 28(1):117–153

Novak JD, Gowin DB, Johansen GT (1983) The use of concept mapping and knowledge mapping with junior high school science students. Sci Educ 67(5):625–645

Okebukola PA, Jegede OJ (1988) Cognitive preference and learning mode as determinants of meaningful learning through concept mapping. Sci Educ 72:489–500

Okebukola PA, Jegede OJ (1989) Students' anxiety towards and perception of difficulty of some biological concepts under the concept mapping heuristic. Res Sci Technol Educ 7:85–92

Pankratius WJ (1990) Building an organized knowledge base: concept mapping and achievement in secondary school physics. J Res Sci Teach 27:315–333

Patterson ME, Dansereau DF, Newbern D (1992) Effects of communication aids and strategies on cooperative teaching. J Educ Psychol 84:453–461

Pérez AL, Suero MI, Montanero M, Pardo PJ (2001) Three-dimensional conceptual maps: an illustration for the logical structure of the content of optics. International conference physics teacher education Beyond 2000. Selected contributions. ISBN 2-84299-312-8, pp 603–604. Editorial Elsevier Francia

Pérez AL, Suero MI, Pardo PJ, Montanero M (2006) Utilización de Cmaps para mejorar los conocimientos relativos a la luz mediante su reconstrucción colaborativa. Concept maps: theory, methodology, technology In: Proceedings of the second international conference on concept mapping San José, Costa Rica

Pérez AL, Suero MI, Pardo PJ (2008) Utilización de Cmaps para mejorar los conocimientos relativos a la refracción de la Luz mediante su "Reconstrucción Colaborativa". Óptica pura y aplicada 41:17–23

Pérez AL, Suero MI, Montanero M, Pardo PJ, Montanero M (2010) Chapter 17 Concept maps and conceptual change in physics on Handbook of research on collaborative learning using concept mapping. ISBN 15-990-4992-2, pp. 325–345, 2009 Idea Group Publishing, USA

Quinn HJ, Mintzes JJ, Laws RA (2004) Successive concept mapping: assessing understanding in college science classes. J Coll Sci Teach 33(3):12–16

Reader W, Hammond N (1994) Computer-based tools to support learning from hypertext: concept mapping tools and beyond. Comput Educ 12:99–106

Roth W-M, Roychoudhury A (1992) The social construction of scientific concepts or the concept map as device and tool thinking in high conscription for social school science. Sci Educ 76:531–557

Roth W-M, Roychoudhury A (1993) The concept map as a tool for the collaborative construction of knowledge: a microanalysis of high school physics students. J Res Sci Teach 30:503–534

Roth WM, Roychoudhury A (1994) Science discourse through collaborative concept mapping: new perspectives for the teacher. Int J Sci Educ 16:437–455

Royer R, Royer J (2004) Comparing hand drawn and computer generated concept mapping. J Comp Mathemat Sci Teach 23(1):67–81

Slotte V, Lonka K (1999) Spontaneous concept maps aiding the understanding of scientific concepts. Int J Sci Educ 21:515–531

Smith KA (1987) Educational engineering: heuristics for improving learning effectiveness and efficiency. Eng Educ 77(5):274–279

Stoyanova N, Kommers P (2002) Concept mapping as a medium of shared cognition in computer-supported collaborative problem solving. J Interact Learn Res 13:111–133

Walker JMT, King PH (2003) Concept mapping as a form of student assessment and instruction in the domain of bioengineering. J Eng Educ 92(2):167–179

Zeitz L, Anderson-Inman L (1992) The effects of computer-based formative concept mapping on learning high school science. American Educational Research Association, San Francisco

Zieneddine A, Abd-El-Khalick F (2001) Doing the right thing versus doing the right thing right: concept mapping in a freshmen physics laboratory. Eur J Phys 22:501–511