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The effects of web-supported and classical concept maps on students' cognitive development and misconception change: a case study on photosynthesis

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Abstract

New networking technologies increase the effectiveness and the adoption of interactive tools in all education levels. Concept maps are one of the most important of these interactive tools. They have been widely used as learning and teaching tools in science education. The purpose of this study is to investigate the effectiveness of web-supported concept maps (WSCMs) and classical concept maps (CCMs) on students' cognitive development and misconception changes about photosynthesis subject. The sample of this study consists of total 74 students and 2 experienced teachers in Trabzon. CCMs were transferred to the virtual environments in the form of WSCMs by authors. At the beginning, Photosynthesis achievement tests (PAT) and photosynthesis concept test (PCT) were administered as pre-tests and post-tests both to experimental group and control group. After the educational program, general science achievement on PAT increased by 10 % in favor of experimental group (EG) at significant level ($p<0.05$). Although the increased at knowledge level in cognitive development was 16.00 % in the EG and 16.80 % in control group (CG). These changes were 26.60 % and 18.90 % at comprehension and application levels in the EG and 10.54 %15.50 % in the CG for cognitive development, respectively. The results revealed that using WSCMs in teaching photosynthesis is very effective for students to reach comprehension level of cognitive domain. In addition, misconceptions about food, nutrition and energy sources for plants were decreased in the EG more than in the CG.

Keywords:Web supported science education; Cognitive development; Misconceptions; Photosynthesis

1. Introduction

One of the main objects of science education is to help students learn concepts meaningfully. Learning basic concepts during the primary and secondary education is very

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crucial for the learning of advanced concepts [1]. It was argued that if new concepts were compatible with previous concepts, meaningful learning would occur [2]. Therefore, it is important to know what prior knowledge students bring to a learning environment in order to help them construct new knowledge [3]. For better learning and understanding of scientific concepts, it has been advised by several researchers that the students' earlier conceptions should be taken into account at all stages of instruction [4, 5]. In this respect, concept teaching has a great importance in science education.

The students' conceptions in the literature have been identified with different terms, such as misconceptions, preconceptions, alternative frameworks, children's science, naive conceptions and so forth. [6, 7, 8]. Concepts are not materials, events or creatures but they are units of thought assembled into certain groups. They exist in ideas and only the examples of the concepts are found in the real world [9]. Students may develop ideas about certain events and concepts before they are given any formal instruction in science education [10]. It has been shown in the studies conducted so far that most students have misconceptions regarding science subjects [11, 12]. Photosynthesis is one of these subjects that have a lot of misconceptions associated with it [1].

In the last decade, there have been a number of studies focusing on students' conceptual development about photosynthesis at middle and secondary schools [1, 13, 14, 15]. Photosynthesis refers to the process in which the organic matters are synthesized from inorganic sources by using the energy of light [16]. The energy from the sunlight is captured by means of photosynthesis and is stored as carbohydrate in plant tissues [17]. According to another definition, photosynthesis is a process that the energy in sunlight is captured and made in to organic compounds to support metabolic processes in all living things [18]. Photosynthesis plays a central role in understanding many aspects of living systems. All living things depend directly or indirectly on photosynthesis for their food [19]. More importantly, an understanding of photosynthesis is a pre-requisite for any systematic understanding of ecology [14]. Food chains and food webs begin with photosynthesis. Photosynthesis plays essential roles in the flow of energy through ecosystems. Clearly, it is quite complex and an important subject. Because of the importance and the difficulty of the subject, science teachers seek for alternative teaching approaches in their teaching of photosynthesis [14, 20].

Concept maps, utilizing paper and pencil approach, are now extensively used in science learning and teaching [21-24]. They consist of nodes and links. Nodes represent concepts and links show the relationships between concepts [25, 26].

Concept maps are consistent with the theories of knowledge representation and constructivist learning [21]. They are usually expected to reduce understanding and comprehension difficulties [27]. It is reported that they are more useful for visual learners, who can memorize information contained in a picture and for learners who have good synthesis skills [23]. These semantic networks can also be used to foster conceptual learning, critical thinking, analysis, synthesis, and the development of shared meaning [28].

Concept maps are active learning tools with numerous uses in science classrooms, including planning, teaching, revision and assessment and are also described as the most important meta-cognitive tools in science education [29, 30] stated that they can assist learning from text. They have been used in the training of teachers to increase their awareness of the subject taught and by students to reach a better understanding of certain information. Literature reports a lot of finding on the benefits of concept mapping as assisting learning, comprehending particularly complex communications, refining meaning and literary framework, improved clarity, and successful understanding of texts [25, 26, 31, 32].

Most researchers report that CCMs have many advantages in the teaching of science concepts [20, 21, 33-35]. However, some other researchers identified certain weaknesses of constructing concept maps using paper and pencil. Huang and Linn [36] indicated that CCMs offer some difficulties in the construction process. It was also reported that students often need to spend considerable amounts of time and effort revising and maintaining concept maps, and consequently they may not focus on the body of knowledge [37]. Science teachers spend significant amount of time and effort evaluating students' concept maps [23].

Researchers agree that concept mapping by using paper and pencil is inconvenient for interactions and feedback between learners and instructors and also its construction is complex and difficult for learners, especially for novice students.

To summarize, some of the disadvantages reported about CCMs are that:

- It is inconvenient for a teacher to provide appropriate feedback to students during concept mapping process
- The construction of a concept map is complex and difficult for students.
- Concept maps constructed using paper and pencil are difficult to revise.
- The paper-and-pencil concept maps are not an efficient tool for evaluation [23, 38, 39].

Because of the mentioned disadvantages of paper and pencil concept maps, researchers built web-supported concept map systems to help students construct concept maps more easily [38, 40]. After the development of the World Wide Web (www), different computer and web-supported concept mapping systems have been developed by researchers [23, 37, 39, 41]. In addition, some researchers state that important interactive learning tools such as concept maps need to be developed by science teachers, educators and investigators by using effective software [42, 43]

The researchers developing computer and web-supported concept maps have generally focused on students' achievements [44-47.] But, how WSCMs affects cognitive development and changes misconceptions have not been determined yet. Particularly, there is no such study on photosynthesis. The aim of this study was to determine the effects of the web-supported and classical concept maps on students' cognitive development and to measure its effectiveness in dispelling scientific misconceptions. As the focus of the study, photosynthesis was selected.

2. Material and method

2. 1. Web-supported concept maps

The steps below were followed during the development of WSCMs;

- The content analysis of the concept maps was checked by area experts including science teachers, science educators and biologists at the faculty of education.
- Some CCMs were selected from the literature by the authors and they were examined by science experts.
- The selected CCMs were transferred to the computer by using Dreamweaver 4, Fireworks 4 (from Macromedia Software Company) and JavaScript software (Fig. 1)
- The maps consisted of 8-16 nodes and arrows linking them on the WSCM. Each node offered 6-8 concepts to students to make a selection among them.

2. 2. Data collection instruments

In this study, the Photosynthesis Achievement Test (PAT) and the Photosynthesis Concept Test (PCT) were used as data collection tools.

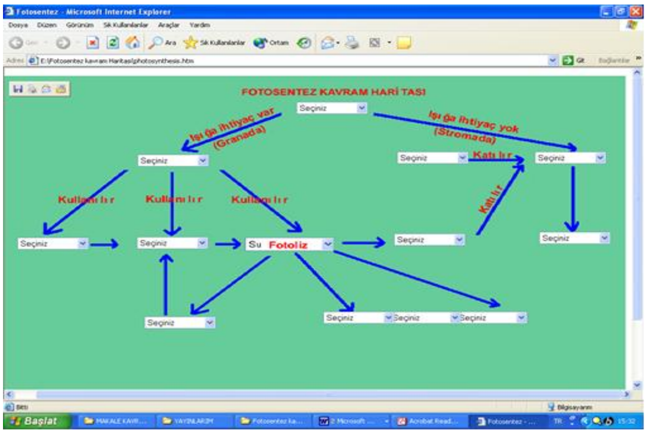


Fig. 1. A sample web-supported concept map.

2. 2. 1. Photosynthesis achievement test (PAT)

The PAT was developed by the authors of this study and its content validity and reliability were checked following the methods described by other researchers [48-50]. The PAT items, consisting of 25-item multiple-choice tests (including 5 items at knowledge level, 11 at comprehension level, and 9 at application level), were selected from the textbooks and preparation books written for the University Entrance Examination. The knowledge level items were arranged according to the levels of behavioral objectives in the Biology Curriculum. Following this, these items were grouped into three levels of the cognitive domain (knowledge, comprehension, and application) of Bloom's taxonomy [51]. *Knowledge* items involved recall or recognition of ideas or concepts; *comprehension* items emphasized students' understanding of ideas or concepts; *application* items required students to apply the acquired knowledge or application of knowledge on new situations [52]. Sample questions are given below (Table 1). The reliability of the test (r=0.81) was determined by using Spearman's rank order correlation formula.

2. 2. 2. Photosynthesis concept test (PCT)

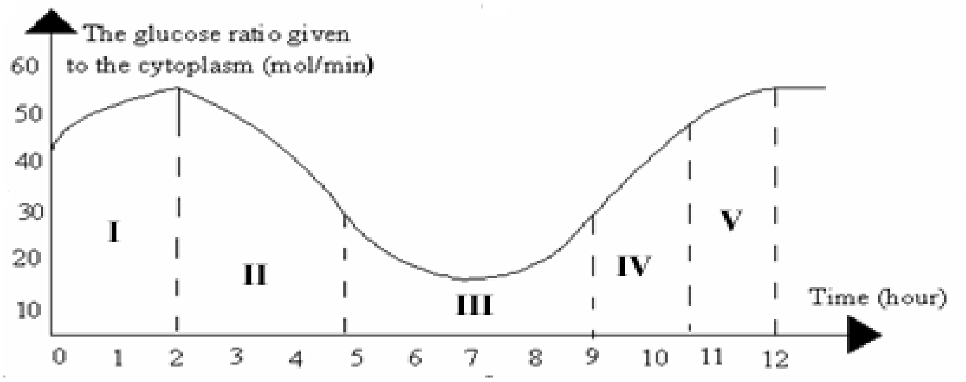
To determine the students' concept changing processes, a written test was designed about photosynthesis subject. The test contained 13 questions, including both open-ended and multiple-choice items. The PCT was modified on the basis of the related literature [18].

The test was divided into two parts. In the first part, there were two main concepts about photosynthesis; respiration and food. In the second part, we sought to reveal conceptual difficulties concerning students' understanding of how plants and animals use substance and energy. In addition, students were asked to explain their ideas about the relationship between photosynthesis and respiration. Finally, students were asked to explain why plants are called as producers.

2. 3. Sample

Two experienced science teachers and 74 students from one high school in Trabzon center participated to the study. The sample was randomly assigned into two groups; experimental group (n=37), and control group (n=37). While the experimental group was taught using WSCMs, the control group continued their instructions using CCMs.

Table 1. Sample questions asked in PAT

Knowledge level	Which of the following living things does not use CO_2 molecule found in atmosphere? a) Euglena b) Bread Mold c) Blue-Green Algae d) Water Mosses e) Insectivorous Plants	**I.** Ferrodoxin **II.** Plastokinon **III.** Cytochrome **IV. NADPH$_2$** Which of the above components do not transport electron in the cyclic photophosphorylation? a) Only **I** **d) Only IV** b) Only **II** **e) II** and **III** c) Only **III**
Comprehension level	Which are the most important characteristics of a green plant maintaining its existence in a light environment containing only O_2, H_2O, CO_2, minerals and vitamins? a) It can produce CO_2 b) It can synthesize carbohydrate c) It can take vitamins as ready e) It can reproduce as asexual	Which of the following reactions does not happen during the cyclic Photophosphorylation? a) The reduction of the KL_a b) The oxidation of the KL_b c) The reduction of the ferrodoxin d) The making up of the ATP e) The reduction of the cytochrome
Application level	 The above graph shows the relationships between time and the amount of the glucose transferred to cytoplasm by chloroplasts found in the leaf of a green plant: Which of the followings can not be said for the time interval marked as III? a) The rate of photosynthesis is the lowest b) The light density is the lowest c) The temperature is the lowest d) The cell respiration is the fastest e) Only green light is sent to the leaf	

2. 4. Procedure

With an experimental research design, present study was carried out during the fall semester of 2008-2009 academic years in a high school for four weeks. Data collecting tools were applied at the beginning and end of the study as pre-and post- tests. CCMs and WSCMs were introduced by the researchers to the science teacher before the educational sessions. In the teaching process, first the teacher drew CCMs on the blackboard together with the control group students and also the students drew CCMs on their notebooks.WSCMs were drawn via computer by the students individually. Following this they were presented via data-show by the teacher to the students in the EG. In addition, the students had opportunity to work on the WSCMs in the EG.

2. 5. Data analysis

In order to compare the differences between the CG and the EG for the PAT and PCT the independent t-test was applied.

3. Results

3. 1. Students' achievement

Table 2 below shows means, standard deviations and t-test values of PAT administered as pre- and post tests to both groups.

Table 2. Means, Standard Deviations and t-test values of PAT results

Tests	Groups	N	Mean	Standard Deviation	t-test	P
Pre-test	EG	37	52.08	15.19	0.773	0.348
	CG	37	52.72	9.73		
Post-test	EG	37	75.22	18.68	2.743	.000
	CG	37	65.76	15.68		

In the beginning of the study, Table 2 shows that the pre-test mean scores of the EG and the CG was 52.08 and 52.72, respectively. These scores specify that the knowledge levels of both groups were very close to each other and there was no statistically significant difference between the groups ($t=0.773$, $p>0.05$). At the end of the educational sessions, the post-test mean scores were found 75.22 and 65.76 for the EG and the CG, respectively (approximately 23% change occurred in EG) and the difference between the groups were found statistically significant after the study ($t=2.743$, $p<0.05$). This means that WSCMs increased the students' achievement more than CCMs did.

3. 2. Cognitive development

The effect of using WSCM and CCM on students' cognitive development at different levels based on the PAT results is given in Table 3.

As seen in Table 3, regarding achievement at knowledge level, average gain score of the students in the CG was slightly higher than their counterparts in the EG (16.80% versus 16.00%). On the other hand at comprehension and application levels, students in the EG received much higher scores than those in the CG (26.6and 10.54%, versus 21.56% and 14.78%, respectively). This may imply that using WSCM is quite influential on students' higher cognitive levels of learning compared to CCM which helped the majority of the students reach the knowledge level only

Fig. 2 shows the cognitive development of the two groups after the educational sessions. While CCMs have partly positive effects on knowledge level when compared to the EG, WSCMs were more effective both comprehension and application level of cognitive domain in the EG.

3. 3. Misconception

In order to explore students' misconceptions about photosynthesis, a PCT was administered before and after the teaching of the subject. The categories of misconceptions were formed based on the responses students gave to the test items are given in Table 4.

As presented in Table 4, we looked at the percentages of the responses for each question in the pre-test before the study. In general, there was not much difference between the groups in terms of the students' prior knowledge and misconceptions. For example, the percentages of the responses showing misconceptions for general definition of photosynthesis in the EG and

Table 3. The Effect of using WSCMs and CCMs on the Students' Cognitive Levels

Cognitive Levels	Questions	Pre-test (%)		Post-test (%)		(%)Gain scores		Average Gain scores (%)	
		EG	CG	EG	CG	EG	CG	EG	CG
Knowledge	1	56	68	66	76	10	8	16.00	16.80
	2	52	44	70	68	18	24		
	3	48	52	66	64	18	12		
	4	60	36	76	56	14	20		
	5	44	60	62	80	18	20		
Comprehension	6	48	56	56	60	8	4	26.6	10.54
	7	64	64	76	80	12	16		
	8	44	44	88	52	44	8		
	9	48	36	84	52	36	16		
	10	64	52	80	60	16	8		
	11	52	68	68	72	16	4		
	12	32	24	84	46	52	22		
	13	40	32	92	52	52	20		
	14	52	44	84	64	32	20		
	15	52	48	72	68	20	20		
	16	64	56	68	60	4	6		
Application	17	44	72	60	72	16	0	18.90	15.50
	18	52	76	88	84	36	8		
	19	46	68	76	76	30	6		
	20	66	56	70	72	4	16		
	21	44	32	52	56	8	24		
	22	48	52	84	64	36	12		
	23	44	32	60	68	16	36		
	24	56	48	66	60	10	12		
	25	52	46	72	68	20	22		

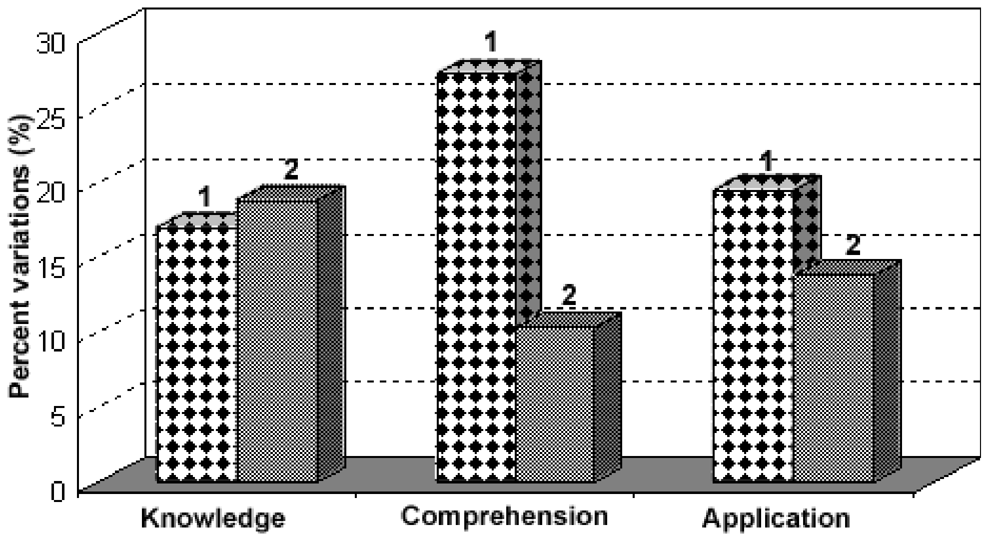


Fig. 2. Effects of WSCMs and CCMs on the Students' Cognitive Levels (EG:1, CG:2).

Table 4. Results of the pre- and post-tests concerning misconceptions

CATEGORIES OF MISCONCEPTIONS	Pre-test		Post-test	
	EG	CG	EG	CG
1. Photosynthesis	%	%	%	%
a. Green plants make photosynthesis to produce energy	16	23	7	11
b. Photosynthesis is only a gas exchange event	24	20	6	21
c. Photosynthesis is the conversion of sunlight into food	8	7	1	7
2. Food for a plant				
Plants' food is water, sunlight, air, fertilizer, and inorganic minerals	52	47	23	32
3. Nutrition of plants				
Plants get their food from the soil through their roots	58	57	8	25
4. Sources of energy for plants				
Plants get their energy from water, air, soil, worms, insects, and fertilizer	79	77	24	17
5. Sources of energy for humans				
Humans get their energy from air, water, sun, and exercise	15	34	3	37
6. Chemical reaction for photosynthesis				
a. $6CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$ + Energy	5	7	0	8
b. $6CO_2 + 6\ H_2O$ + Energy $\longrightarrow C_6H_{12}O_6 + 6O_2$	5	6	0	1
c. $CO_2 \longrightarrow O_2$ + Glucose	3	8	1	0

the CG were 48% and 50% respectively. However, regarding the items related to the sources of energy for humans, the number of the students who had misconceptions in the CG was about twice as much as those in the EG. The weakest areas for the students in both groups were food for a plant, nutrition of plants and sources of energy for plants. Below we examined some of the concepts in detail.

3. 4. Misconceptions about photosynthesis

The students' responses indicated that they held misconceptions about photosynthesis choosing the incorrect choices, a, b, and c in question 1 by 16%, 24% and 8%, respectively, in the EG and 23%, 20% and 7%, respectively, in the CG (Table 4). Analysis of this data shows before the sessions the number of students who had misconceptions regarding this item from both groups are close to each other. After the sessions, notable decreases in these numbers were observed in the EG (7%, 6% and 1%), whereas, in the CG such decrease was not the case, except for the item 1a (11 %). This may suggest that using WSCM was more effective than using CCM in changing students' misconceptions.

3. 5. Misconceptions concerning sources of energy for plants and humans

The results in Table 4 show that students had a misconception that "plants get their energy from water, air, soil, fertilizer, worms and insects". According to the pre test results the percentages of the students having such misconception was about 80 % in both the CG and the EG. After the educational sessions, this figure decreased to 24% in the EG and 17% in the CG. Clearly, using both WSCM and CCM had similar effects on changing students' misconceptions on energy sources for plants. However, regarding changing students misconceptions on the sources of energy for humans, using WSCM seemed to be more effective than using CCM. For example, before the sessions, the percentages of the students who had misconceptions about item 5 were 15% and 34% for the EG and the CG, respectively. After the sessions, these figures dropped to 3% in the EG whilst it slightly increased to 37% in the CG. This suggests that using CCMs was not effective on changing students' misconceptions to improve their understanding.

3. 6. Misconceptions related to the chemical reaction for photosynthesis

Students' misconceptions related to the chemical reaction of photosynthesis were also tested through the PCT. The misconceptions related to this item were grouped into three categories marked as 6a, b and c in Table 4. The pre-test results showed that the percentages of the students having misconceptions regarding the chemical reaction of photosynthesis were 5%, 5% and 3% in the EG and 7%, 6% and 8% in the CG. After the sessions, these figures decreased to 0%, 0% and %1 in the EG; 8%, 1% and 0% in the CG.

4. Discussion and conclusion

Many researchers argue that CCMs provide important contribution to science learning and teaching concerning student achievement [20, 25, 26, 27, 29, 30, 33, 34, 46, 47, 53]. In addition, some others reported that they have some weaknesses and could influence science performance in teaching and learning process [23, 36, 37, 38, 41]. The findings of this study showed that student achievement increase in the two groups after the educational sessions in general. But, this increase ratio was 23 % in the EG and 13 % in the CG (see Table 2). This result concerning the effects of CCMs on students' achievement is consistent with the philosophy of the latter group. Our finding supports other studies that the use of Web-based learning can improve students' scientific achievement [1, 54].

However, in regard to students' cognitive development, there were some differences between the groups studied. The data obtained from PAT illustrated that CCMs have some positive effect on the cognitive development at the knowledge level in the CG when compared to the EG. WSCMs were quite influential on both the comprehension and application levels of cognitive domain in the EG. According to Çepni et al. [1] technology supported science materials can increase achievement of students at comprehension and comprehension levels. Tjaden & Martin [55] also stated that such materials did not make significant difference between the experimental and the control groups on the higher-level achievement tests. These results were interesting to the authors that using CCMs was more effective at knowledge level than using WSCMs (see Table 3 and Fig. 2). From this perspective, the material may be seen as insufficient at knowledge level. This also shows that misconceptions may be reduced and/or dispelled if teaching-learning activities are given with interactive tools as WSCMs.

Overcoming misconceptions is very crucial during the learning processes of individuals. Therefore, a lot of researchers reported that traditional teaching approaches are not particularly effective at changing misconceptions [1, 56-72]. One of the alternative ways of overcoming this problem can be developing and using WSCMs in science classrooms [39, 58, 59, 60]. In this study, WSCMs provided a significant contribution for students to understand photosynthesis without having many misconceptions in the EG (Table 4). This finding can result from often receiving feed-back of the experimental group students. In this process, they could review and reconstruct relations among concepts. Thus, to decrease students' misconceptions can be possible by using web-supported interactive tools, especially in science learning and teaching. Besides, there were still some misconceptions in the experiment group even after the treatment. These misconceptions were generally related to the abstract concepts, such as energy sources for plants and their nutrients and thus to visualize and conceptualize them is difficult for students. Reducing misconceptions also depends on the teaching approach of these materials. We believe that one way of reducing students' misconceptions is to work with WSCMs not individually, but in groups.

As a result, it can be concluded that WSCMs could improve student achievement, change misconceptions to some extent, and improve cognitive levels.

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