

THE EFFECTIVENESS OF A CONSTRUCTIVIST TEACHING MODEL ON STUDENTS' UNDERSTANDING OF PHOTOSYNTHESIS

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Introduction

Nowadays people live in times characterised by great social turmoil. We have witnessed a decline of important ideologies and we have been coping with a rise of new threats to humanity and ethics. In addition, the development of science and technology today is extremely fast, faster than ever. Therefore, the school must prepare students to become independent, responsible, creative individuals with critical minds and possessing a lifelong affinity for learning in order to be able to face the challenges of modern times. The aim of any education institution is to ensure that during schooling students receive dynamic, comprehensive, and applicable knowledge that will help them gain deeper understanding of natural and social phenomena. Changes in social relations, rapid development of emerging technologies, and new developments in the learning sciences are requiring educators to move beyond traditional teaching models. In recent decades, the constructivist theory of teaching and learning has been gaining ground, mostly with regard to the teaching of mathematics and science (Treagust, Duit, & Fraser, 1996; Lord, 1997; Matthews, 2002; Liang & Gabel, 2005; Cakici & Yavuz, 2010; Alsharif, 2014).

As established by many researchers (e.g. Brooks & Brooks, 1993; Richardson, 1997; Cooperstein & Kocevar-Weidinger, 2004) the focal point of the constructivist approach is an interactive teacher-student relationship, which allows students to co-create their learning process with an aim to acquire knowledge and apply their own mental activity to develop skills and acquire concepts. In the learning process, students construct new, meaningful knowledge on the basis of their background, experience, personal qualities, and the environment (Piaget, 1971; Vygotsky, 1978). Von Glasersfeld (1995) explains that teachers must identify the cognitive structure of a student before they can help students modify their conceptual structures. As emphasized by



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Abstract. *Photosynthesis is one of the fundamental processes on Earth and it ranks among the most demanding science concepts for students, associated with a number of misconceptions. For improving students' understanding and learning outcomes the constructivist approach has proven to be one of the most effective. In this research the constructivist teaching model of photosynthesis (CTMP) was designed and its effectiveness on students' understanding was tested. Students (N=201) from Slovenian primary schools (aged 11–12 years) participated in the research. CTMP was used in the experimental group (EG), while the traditional teaching approach was used in the control group (CG). Students' learning achievements were evaluated using the paper-and-pencil tests. The test items were classified into three groups based on Bloom's taxonomy: (1) knowledge, (2) comprehension and application, and (3) analysis, synthesis, evaluation. Mann-Whitney U-test showed that the EG had better learning outcomes than the CG. Statistically significant differences were found at the highest cognitive level. The CTMP contributes to the improvement of teaching and learning of photosynthesis, fosters the development of higher-order thinking and offers opportunity for integration of the constructivist approach in science classes, which will help to increase the quality of acquired knowledge and to raise the level of scientific literacy of the population.*

Key words: *teaching about photosynthesis, constructivist approach, Bloom's taxonomy, primary school.*

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Uzuntiryaki (2003), in class students should be able to raise questions freely, make their own findings and conclusions, conduct experiments, analyse, predict, set and test hypotheses, etc.

Numerous studies have shown that constructivist approach is effective, as it improves the students' understanding and learning outcomes (Kim, 2005; Çalik et al., 2007; Cakici & Yavuz, 2010). It has also been established that the constructivist approach increases students' interest for science concepts (Parker & Gerber, 2000). Students prefer constructivist approach since it allows them to be more active during class (Kim, 2005), exchange opinions with their peers, conduct practical work, take fewer notes, and have more fun (Uzuntiryaki, 2003).

In biology classes, students learn important science concepts that form the basis of their understanding of numerous Earth processes. One of them is photosynthesis, a fundamental process that occurs in plants. Barker and Carr (1989) define photosynthesis as the most important biochemical process on Earth. On account of its relevance, photosynthesis is part of the syllabus for science subjects of various levels of the education system, from primary schools to universities (Métioui, Matoussi & Trudel, 2015). Due to its complexity, the process also ranks among the most demanding science concepts (Marmaroti & Galanopolou, 2006; Güneş, Güneş & Hoplan, 2011). Photosynthesis is associated with a number of misconceptions, which is one of the reasons for poor understanding of the process. The most common misconceptions are:

- Plants get food from the soil (Driver et al., 1994; Özay & Öztas, 2003; Hershey, 2004; Tlala, Kibirige & Osodo, 2014);
- Carbon dioxide, water, and minerals are food for plants (Driver et al., 1994);
- Plants get their energy from the soil, fertilizers, and the sun (D'Avanzo, 2003);
- Plant roots are like an animal's mouth – plants absorb food through roots (D'Avanzo, 2003);
- Plants perform photosynthesis during the day, and breathe only during the night (Hazel & Prosser, 1994; Hershey, 2004).

Most researches regarding teaching photosynthesis focused mainly on the identification of students' misconceptions. These studies were conducted at various levels of the education system: among primary school students (Bell 1985; Eisen, Stavy & Yaakobi, 1987), secondary school students (Haslam & Treagust, 1987; Amir & Tamir, 1994; Özay & Öztas, 2003; Marmaroti & Galanopolou, 2006), and even college, university students (Hazel & Prosser, 1994; Carlsson, 2002; Köse, 2008) and trainee teachers (Dolenc Orbančić & Battelli, 2011; Ahopelto et al., 2011; Ameyaw, 2016). Rode and Skribe Dimec (2012) compared the conceptions about photosynthesis of primary school students, university students and experienced teachers. These studies showed that similar misconceptions, as presented above, were present in all age groups.

Considering that numerous misconceptions of the photosynthesis process are present at all levels of schooling, the choice of the teaching method is crucial. Some studies have been conducted on the topic of teaching photosynthesis, in which the authors for a better understanding of photosynthesis proposed different activities (Ross, Tronson & Ritchie, 2005; Akpınar, 2007), inquiry-based learning (O'Connell, 2008; Ray & Beardsley, 2008; Käpylä et al. 2009; Günes et al., 2011), drama methods (Carlsson, 2003), using technology to overcome misconceptions about photosynthesis (Kıcı, 2012), using conceptual change model (Akpınar, 2007; Tlala et al., 2014), etc.

Biology and science teachers constantly need to search for and test innovative approaches to facilitate students' understanding of fundamental science concepts like photosynthesis. A lot of existing researches were focused on how constructivist approach can benefit learning, but there was a limited research about the effect of constructivist approach on learning photosynthesis, especially designed for primary school. In an effort to improve the understanding of the concept of photosynthesis, a five-phase constructivist teaching model of photosynthesis (CTMP) for 5th grade primary school students was developed. Its effectiveness was tested in real classroom environment, in primary schools, and compared with the traditional, teacher-centred approach. The research questions guiding this research were:

1. Is there any significant difference in students' achievement between the experimental group (CTMP) and control group (traditional approach) after the treatment?
2. Is there any significant difference in solving items at level of knowledge (the lowest level of Bloom's taxonomy) between the experimental group (CTMP) and control group (traditional approach) after the treatment?
3. Is there any significant difference in solving items at level of comprehension and application (the intermediate levels of Bloom's taxonomy) between the experimental group (CTMP) and control group (traditional approach) after the treatment?



4. Is there any significant difference in solving items at level of analysis, synthesis, evaluation (the highest levels of Bloom's taxonomy) between the experimental group (CTMP) and control group (traditional approach) after the treatment?

The main difference of the present research in comparison to other studies is the analysis of the effect of the CTMP on solving tasks at different level of Bloom's taxonomy of cognitive domain.

Methodology of Research

Research Design

The five-phase constructivist teaching model of photosynthesis (CTMP) was designed on the basis of the findings obtained in the action research, which has been performed during the scholastic year 2012/13. The action research was conducted in four 5th grade classes of primary school. Firstly, main principles for the photosynthesis lessons were developed by researchers, with the objective to correct students' misconceptions about plant nutrition and to enhance their understanding of photosynthesis. Secondly, in collaboration with four teachers the constructivist teaching model of photosynthesis was developed and after that teachers adopted it in their classrooms. Classroom implementation was observed persistently by researchers. Throughout the action research, classroom activities were monitored, assessed, and improved until the final constructivist teaching model of photosynthesis (CTMP) was designed.

The effectiveness of the developed model (CTMP) was then tested using experimental research, which is the only type of research that directly attempts to influence a particular variable, and it is the only type that can really test hypotheses about cause-and-effect relationships (Fraenkel & Wallen, 2003). The non-randomized experiment was conducted. The two-group posttest-only experiment (Trochim, 2000) involved two groups of students: the experiment group (EG) received CTMP, while the control group (CG) received traditional lecture style teaching of photosynthesis. Pre-test was used in order to determine whether groups are homogenous and comparable (in science knowledge) prior to the treatment and the post-test was used to determine whether the two groups are different (in photosynthesis knowledge) after the treatment. The representation of the research design is shown below (Figure 1).

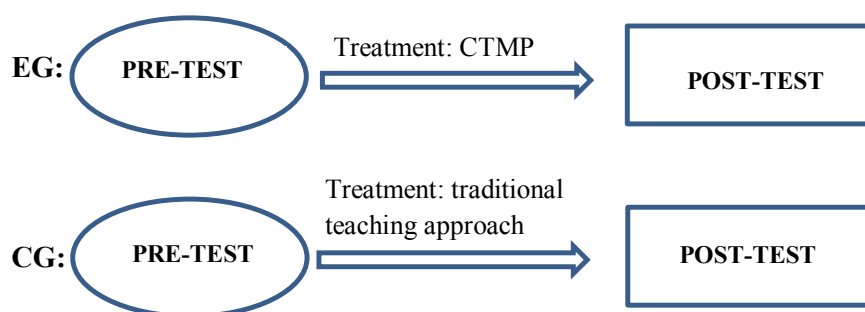


Figure 1: Research design.

Sample of Research

A total of 201 students from Slovenian primary schools were included in the research. In Slovenia children enter primary schooling at about the age of 6 and finish at about the age of 15. Photosynthesis is part of the 5th grade syllabus of primary schools. Therefore, the research included two 5th grade classes from each of the four selected schools (students aged 11–12 years). One class in each school acted as the EG, and the other as the CG. All classes had a similar number of students. The socio-economic status of the students in both groups was similar. The selected schools are located in the urban environment and have good conditions for work. Before conducting the research, approval was obtained from the parents and school authority. The research included a total of eight



class teachers, and their students (N=201); 103 students in the EG and 98 students in the CG.

Instrument

Prior to the research students were informed about the research. Their parents and school authority gave permission to carry out the research. The anonymity has been guaranteed.

Pre-test

The first step of the experimental research was to test the students for their background knowledge of science concepts, both in the EG as well as in the CG, in order to prove the initial equivalence of pre-knowledge between the groups. Two weeks before the treatment, students took the pre-test. The pre-test consisted of 10 items, which were designed to assess general science knowledge. The items were based on the objectives of the subject matter. Several items were adopted from TIMSS (Trends in International Mathematics and Science Study, 2009), while the others were developed by researchers for the purpose of this research. The pre-test included open-ended and multiple-choice items. Some of them were scored with two points because they consisted of two questions. The total score for the pre-test was 19 points. Sample item of pre-test is given as follows (Figure 2):

Q1: A girl wanted to play on a seesaw with her little brother. Which picture shows the best way for the girl, who weighed 50 kg (kilograms), to balance her brother, who weighed 25 kg?

Figure 2: Example of a pre-test item (TIMSS, 2009).

Post-test

A few days after the photosynthesis class, the students from the EG and CG were given a post-test. The aim of the post-test was to find out the level of students' knowledge of photosynthesis after the treatment. The post-test compiled for the purpose of this research consisted of 10 items related to photosynthesis. The post-test was composed of different question-types (multiple-choice items, essay type, true-false items, short answers, fill-in-the-blank items). Therefore items were scored with different numbers of points (1-4 points). The total score for the post-test was 29 points. Sample item of post-test is given as follows (Figure 3):

Q1: A plastic bag filled with air is wrapped over the plants, as shown in the figure. Then we put the plant with the bag in a dark place for a few days. How has changed the gas mixture in the bag in a few days?

- The amount of oxygen and carbon dioxide has increased.
- The amount of oxygen and carbon dioxide remained unchanged.
- The amount of oxygen has increased, the carbon dioxide has decreased.
- The amount of carbon dioxide has increased and the oxygen has decreased.

Figure 3: Example of a post-test item (TIMSS, 2009).

The pre-test and post-test both contained items that were classified into three groups based on Bloom's taxonomy of cognitive domain: three items were at the level of knowledge (the lowest level of Bloom's taxonomy), four addressed the levels of comprehension and application (the intermediate levels of Bloom's taxonomy), and three targeted highest-order thought, i.e. analysis, synthesis, and evaluation (the highest levels of Bloom's taxonomy). Each test item was ranked at the highest level of Bloom's taxonomy required for its solution. For example, if the student needed to describe a process in his own words, it was considered that the item tests comprehension.

Both tests were administered to a pilot study group (N=51). The content validity of the pre-test and post-test was examined and verified by three experienced science teachers who had more than 15 years of professional experience. Items were discussed with teachers in the content area and their expert opinions were used to determine and ascertain validity of the instruments.

The reliability was obtained through Cronbach's coefficient α . The reliability for the pre-test was 0.70 and for the post-test 0.74. As stated by Nunnally (1978), the reliability of 0.70 or better can be accepted.

Treatment

Control Group

The teachers of the CG used a traditional teaching approach. In accordance with Prince & Felder (2006), the traditional approach is defined as deductive teaching, beginning with the presentation of basic principles in lectures and proceeding to the repetition and application of the lecture content by the students. The learning content of photosynthesis was delivered in a lecture format (4 lessons), with accompanying visual material in the form of PowerPoint presentation, using the text book and whole class discussion. Photosynthesis was presented with minimal grounding in students' prior knowledge and little grounding in their experience.

Experimental Group

In the EG, in which classes were held on the basis of the developed model, selected teachers were first presented with the CTMP, informed about the performance of specific activities, and presented with teaching materials which had been prepared for the purpose (descriptions of experiments, students' worksheets). CTMP consisted of 4 lessons. Photosynthesis topic was taught in five phases, in accordance with the constructivist approach proposed by Needham (1987) and Hashim & Kasbolah (2012). The application of the CTMP is explained in the following:

1. Phase of generating ideas: Before the start of the class, the teacher elicited students' preconceptions about plant nutrition. The teacher obtained this information by asking students to answer several short questions. The teacher then used the elicited preconceptions to prepare further knowledge-building activities.
2. Orientation phase: The teacher divided the students into smaller groups. Each group was given a plant to observe (with all its parts). On the basis of plant observation and exchange of opinions in the group, the students were able to complete the worksheet that required them to mark the main body parts of the plant, and the functions they perform. When the students finished work, a discussion between the teacher and the group followed. The discussion focused on plant nutrition.
3. Phase of reconstructing ideas: The teacher prepared a series of activities designed to help students reconstruct their existing preconceptions regarding plant nutrition. This phase was divided into two parts: The first part was group work aimed at solving problem tasks, and the second was dedicated to experimental work. The problem tasks for the first part were based on students' preconceptions in order to create a cognitive conflict between students' conceptions and the scientific truth. Problem tasks helped students construct new, scientific findings. When working in groups, students talked to each other, exchanged and justified opinions, and worked with their peers to create new knowledge together. In this part of the class, the only role of the teacher was to co-ordinate the work of groups and assist students who needed help. The objective of the first problem task was to bring the students to the conclusion what plants use as food. In the second and third tasks, the students were given a description of the experiments which had formed the basis for understanding the concept of photosynthesis. The history of photosynthesis discoveries was explored, because it was important for students to contrast their own preconceptions with the conceptions of photosynthesis through time. Besides, the students can see that science has also had to develop over time. Van Helmont's experiment was described, which disproved the theory that plants get food from the soil through roots. Since this is relatively common belief among students, the choice of the experiment was perfectly reasonable, as it presents cognitive conflict or dissatisfaction with the existing conceptions. Another experiment was presented: the Priestley's test, which proved that plants release oxygen that is vital for the breathing of all forms of life. Upon completion of all three tasks, students were asked to engage in an individual



activity: they had to describe the role of plants on Earth by using their knowledge of science and integrating it with knowledge of other subjects. The second part was experimental work, which was designed to encourage students to investigate what plants need in the process of photosynthesis and what the products of this reaction are. Students performed simple experiments to ascertain these facts. Certain experiments were carried out as a demonstration, for safety reasons. For each experiment, students received a worksheet to record their observations and findings. Students wrote down all questions and dilemmas that arose during the solving of tasks on post-its, which were pasted on the board at the end of the activity.

4. Phase of application: Students solved various tasks that required them to use the acquired knowledge in new situations. Students and their teachers gain feedback on understanding of photosynthesis, and highlight the areas where problems persist. The group discussion that followed addressed all queries arising in the phase of reconstructing ideas. The teacher encouraged the students to explain their ideas.
5. Reflection phase: At the end, the students prepared a concept map which helped the teacher to verify their understanding of photosynthesis and identify any potential areas of deficient knowledge. After the end of the learning process it was established how students' preconceptions about plant nutrition had changed (the same questions as used in the first phase for eliciting students' ideas about plant nutrition). The students were able to compare their newly formed conceptions with their previous beliefs, and assess their own progress. This gave them a feeling of co-responsibility for their learning outcome and provided them with feedback about the effectiveness of the learning process.

Data Analysis

Evaluation criteria were prepared for each test in advance to evaluate the scores of specific items. In order to determine the homogeneity of EG and CG before the treatment, pre-test scores were analysed. For determination of the effectiveness of the CTMP on students' achievement, post-test scores were statistically analysed by teaching methods as the independent variable, score achievement of the students as dependent variable. The scores were analysed using Statistical Package for Social Sciences (SPSS) version 21.0 and graphically presented with Excel 2010. Due to the fact the distribution of the dependent variable was not normal and due to the small sample size the differences in learning achievement and knowledge level (according to Bloom's taxonomy) between groups were calculated using the Mann-Whitney U-test (Fink & Kosecoff, 1998).

Results of Research

Homogeneity of Groups before the Treatment: Pre-test Knowledge

In order to have homogeneity of experimental and control group pre-test scores were considered. The test of previously acquired science knowledge (pre-test) administered before the start of the experiment indicated that there are no statistically significant differences ($U=4682.00$; $p=.375$) in knowledge between the groups (EG and CG). Mean pre-test score of the EG students was higher than CG students' mean score, but the difference was not significant (Table 1).

Table 1. Mann-Whitney U-test results regarding EG and CG students' pre-test scores.

Group	N	Mean	Mean rank	Mann-Whitney U-test	
				U	p
Experimental	103	11.38	104.54	4682.00	.375
Control	98	10.93	97.28		

It was also established that there were no statistically significant group differences in solving items at various cognitive levels of Bloom's taxonomy (Table 2). It can be concluded that EG and CG were similar in prior knowledge, so the groups were homogeneous.



Table 2. Mann-Whitney U-test results regarding EG and CG students' pre-test scores (Bloom's taxonomy categories).

Bloom's taxonomy categories	Group	N	Mean rank	Mann-Whitney U-test	
				U	p
Knowledge	EG	103	104.89	4646.50	.326
	CG	98	96.91		
Comprehension, application	EG	103	102.49	4894.00	.707
	CG	98	99.44		
Analysis, synthesis, evaluation	EG	103	104.28	4709.00	.408
	CG	98	97.55		

Determining Statistically Significant Group Differences in Photosynthesis Learning Outcomes After the Treatment

To determine whether the difference between groups in photosynthesis learning outcomes after the treatment was statistically significant, the Mann-Whitney U-test was used. Table 3 shows the results of the post-test for the EG and CG after the photosynthesis class.

Table 3. Mann-Whitney U-test results regarding EG and CG students' post-test scores.

Group	N	Mean	Mean rank	Mann-Whitney U-test	
				U	p
Experimental	103	20.33	119.00	3193.00	.000***
Control	98	17.15	82.08		

*** significant at the $p < .001$ level

As it is presented in Table 3, there was a significant difference between EG and CG. In doing photosynthesis-related items students in the EG scored higher than those in the CG.

Table 4 gives results of the post-test for the EG and CG at various levels of Bloom's taxonomy of cognitive domain.

Table 4. Mann-Whitney U-test results regarding EG and CG students' post-test scores (Bloom's taxonomy categories).

Bloom's taxonomy categories	Group	N	Mean rank	Mann-Whitney U-test	
				U	p
Knowledge	EG	103	113.48	3762.00	.002**
	CG	98	87.89		
Comprehension, application	EG	103	107.67	4359.50	.095
	CG	98	93.98		
Analysis, synthesis, evaluation	EG	103	126.05	2466.50	.000***
	CG	98	74.67		

**significant at the $p < .01$ level

*** significant at the $p < .001$ level



At the lowest cognitive level (knowledge), statistically significant differences between groups were observed (Table 4). Students in the EG were more successful in solving items that assess knowledge than students in the CG. The EG scored an average of 6.29 out of 8 points, while students in the CG scored 0.56 points less (5.73).

At the comprehension and application level, there were no statistically significant differences between the scores of both groups, although students in the EG performed better in these items (Table 4). The EG reached an average of 9.15 out of 13 points, while the CG scored an average of 8.52 points (4.9 % less).

Group differences were greatest for the highest-level items, where the EG scored a quarter more points than the CG (25.1 % more). The average of points scored in the highest-level items was 4.93 of 8 points in the EG. The average score for CG students was 2.92 points. At the end of the treatment, students in the EG demonstrated a higher ability of solving items at the level of analysis, synthesis, and evaluation than students in the CG (Table 4).

Figure 4 shows that the EG scored better than the CG at all three levels, although the difference was greatest at the highest cognitive level of Bloom's taxonomy.

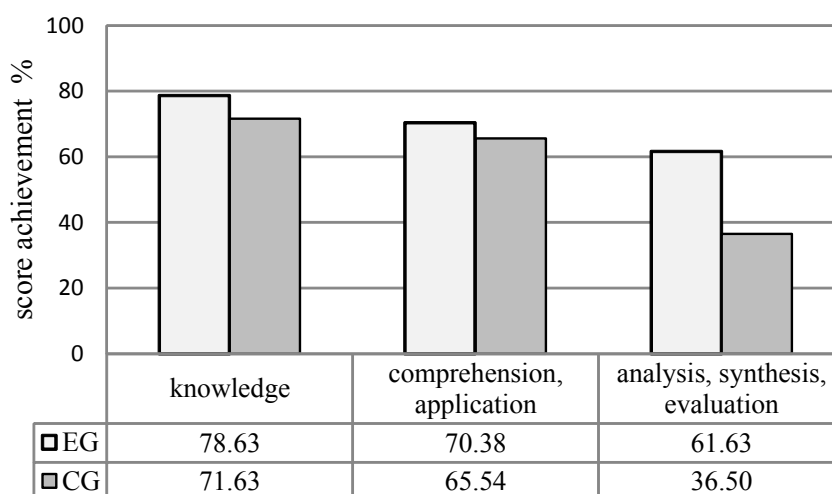


Figure 4: Students' post-test score achievement (the relation between the average number of points achieved and the total number of points, expressed as a percentage).

To illustrate students' responses to post-test items, the most demanding item and the easiest one are presented below.

The most demanding item for both groups was "How can you design an experiment to prove that light is essential to produce food in plants?". The item was classified at the highest level of Bloom's taxonomy and was an essay question. When students' responses to this item were analysed the results showed that 44.7% of EG students and only 10.2 % of CG students correctly designed the experiment.

For the EG the easiest item of the post-test was a multiple-choice question related to plant nutrition ("Where do plants get their food?"). The item was classified in the intermediate group (comprehension, application). When the responses to this item were evaluated the results showed that 70.9% of EG students and 48.0% of CG students responded correctly.

The easiest item for the CG students was a true-false question and it was classified at the level of knowledge. The item consisted of 4 statements about photosynthesis process. The CG were more successful in solving this item in comparison with the EG. 52.4% students of the EG and 66.3% of the CG correctly defined all four statements. The CG had more correct responses to the statement related to the definition of chlorophyll than the students of the EG ("Chlorophyll is a term used for green pigments in plants."). The students of the EG had better results with the statement related to the process of plant respiration ("Plant respiration occurs during the day and during the night.") than the CG.



Discussion

The effectiveness of the constructivist approach on students' understanding of photosynthesis was determined in this research. The experimental group received CTMP, while the control group traditional teaching approach to photosynthesis (teacher-centred). The pre-test results showed that students of both groups were similar in prior general science knowledge.

The first research question was focused on the detection of statistically significant difference in students' achievement between the EG and CG after the treatment. The results of the post-test indicated that the CTMP had a significant effect on the students' achievement when compared with the traditional approach. It is assumed that the EG had better learning outcomes because the students in that group built their knowledge through experiments, peer discussions within the group, class discussions with their teacher, and linked their knowledge with experience throughout the process. The higher score of EG can also be attributed to the cognitive conflict between students' preconceptions and the scientific truth, which is the basis of the constructivist approach. The effectiveness of the constructivist approach in terms of acquired knowledge over the traditional approach was also ascertained in other science teaching studies (e.g.: Lord, 1997; Uzuntiryaki, 2003; Çalik et al., 2007; Cakici & Yavuz, 2010; Tabago, 2011).

As proved by many authors (Driver et al., 1994; Özay & Öztas, 2003; Hershey, 2004; Tlala, Kibirige & Osodo, 2014) the most common misconception about plant nutrition is that plants get their food from the soil. Therefore in the post-test a question related to this misconception was included. In the first phase of CTMP the teacher elicited students' preconceptions about plant nutrition in the EG, while in CG not. Responses on the post-test item about plant nutrition showed that the majority of students of the EG did not have misconceptions about plant nutrition. This was in accordance with the research of Akpınar (2007), in which the author highlighted that providing students' active participation in class and considering students' misconceptions might contribute to getting rid of misconceptions. On the other hand the percentage of CG students with the misconception that plants get their food from the soil was higher than in the EG. So, it can be concluded that the constructivist approach not only increased the students' achievement but also helped the students to correct their misconceptions. As stated by Akpınar (2007) instructing students with traditional teaching approach could not be influential for eradicating students' misconceptions.

As stated above, the main difference of the present research in comparison to other studies was the analysis of the effect of the CTMP on solving tasks at different levels of Bloom's taxonomy of cognitive domain. So the second research question was focused on the detection of statistically significant difference in solving items at the level of knowledge (the lowest level of Bloom's taxonomy) between groups. Results showed that there was a statistically significant difference in solving tasks at the lowest cognitive level (knowledge) between EG and CG. Students from the EG have shown better knowledge of photosynthesis in comparison to CG students. EG achieved better results probably because they had actively constructed their knowledge and reconciled new information with previous knowledge.

The aim of the third research question was to know whether between EG and CG there is a difference in solving items at the level of comprehension and application. The outcome of the research was unexpected: no statistical difference between the groups was found, although the EG performed better in these items. The reason for this result might be in grouping six Bloom's categories into three groups (lowest, intermediate, highest level) as it is used in national external assessment of knowledge (Matura: a school-leaving exam required for the completion of secondary education and for university entrance) in Slovenia. Different result might have been obtained if the Bloom's categories of knowledge and comprehension had been in the same group and the category of application in a separate group. The results might have also been affected by the type of questions, such as indicated by Kubiak & Prokop (2007).

The last research question was focused on the detection of statistically significant difference in solving items at the highest cognitive level (analysis, synthesis, evaluation) between groups. EG had a statistically significant higher percentage of correct responses on the highest-level items than CG. Probably the CTMP contributed to better learning outcomes by creating a learning environment, in which students participated more actively, worked in groups, used their peers as sources of learning and by encouraging students to formulate their own questions. Students taught with traditional approach had difficulty in connecting concepts and applying their knowledge to problem solving situations. This is in line with the findings reported by Lord (1998).

The result of the research is very promising; it can be concluded that the CTMP contributes to more successful



problem solving (analysis, synthesis, and evaluation). This is in accordance with Kariž Merhar (2008), who introduced the constructivist approach to teaching physics for oscillations and waves, and conducted an analysis which confirmed that students taught using the constructivist approach achieve better results in more demanding tasks. This is extremely important in contemporary education. Educators must be aware that students need to develop skills and abilities that will foster creativity and divergent thinking in solving problems.

In many international environments, constructivism is already part of school curriculum and a solid basis for any school dedicated to pursuing the following goal: comprehension-based meaningful knowledge for all students (Plut Pregelj, 2004). Slovenian syllabi for science subjects show increased emphasis on active involvement of students, and a shift in focus towards long-term, high-quality knowledge. Practice in schools, however, often shows a different picture. Teachers complain that students are unable to apply in practice what they have learnt in school (Patry, 2004). In Slovenian primary schools, the focus is frequently on developing lower- and intermediate-order of cognitive skills such as knowledge, comprehension, and application. Learning by heart is sometimes encouraged, while higher-order cognitive skills (analysis, synthesis, and evaluation) are frequently neglected. Not enough attention is paid to creative thinking and developing skills and abilities needed in problem solving, deduction, prediction, evaluation, and generalization. As indicated by the results of the research, the constructivist approach fosters the development of higher-order thinking skills, and offers support to inquiry, hands-on experience, and exchange of opinions.

The researchers also noticed that students of the EG had more motivation for learning than students taught with traditional approach. Burrowes (2003) stated that traditional approach mainly relies upon lecturing facts, forcing students to memorize, resulting in lack of motivation. On the other hand, the constructivist approach motivates students, they are more engaged, they have more fun, and frequently they leave class with a feeling of accomplishment (Uzuntiryaki, 2003; Cooperstein & Kovac-Weidinger, 2004; Kim, 2005).

Conclusions and Implications for Teaching

Photosynthesis is a complicated process, hard to understand, and students often learn the concept by heart, without understanding its fundamentals. This leads to misconceptions which in time become so firmly rooted in the mind schemes of students that they are hard to change. In light of the above, this research makes an important contribution to the learning and teaching of photosynthesis in primary school, when students for the first time learn about this topic.

When the results were considered, CTMP was found to be more effective than the treatment based on traditional teaching approach. The results obtained from collected data are listed below:

- There is a statistically significant difference between the post-test scores of the EG and CG ($U=3193.00$; $p<.001$).
- There is a statistically significant difference in solving tasks at the lowest cognitive level (knowledge) between EG and CG ($U=3762.00$, $p<.01$).
- There is no statistically significant difference in solving tasks at the cognitive level of comprehension and application between EG and CG.
- There is a statistically significant difference in solving tasks at the highest cognitive level (analysis, synthesis, evaluation) between EG and CG ($U=2466.50$, $p<.001$).

The developed model (CTMP) embraces the issues that arise in the learning and teaching of photosynthesis and takes into account all elements of the process: students, teachers, and the learning content. The proven positive effects of constructivist approach in teaching this concept can motivate teachers who are not yet using this approach in their teaching. For teachers who already use this approach, the research will provide sound arguments in support of its further use.

Application of the constructivist approach in school practice will require a planned and systematic introduction of this approach into teacher training schools. Therefore, the present research and its findings make an effective starting point to introduce constructivism-based teaching to future teachers. Only if future teachers experience the constructivist approach during their studies, they will be able to transfer it into their teaching styles, which are a product of knowledge, pedagogical beliefs, and experience gained in the course of training. However, if constructivist approach is not, or rarely, used in the training of future teachers, it is much less possible to expect teachers to start applying this approach when they start teaching.



In order to ensure attainment of increasingly demanding objectives of the contemporary education system, the actual classes need to be based on the top findings of educational sciences. Therefore, the central aim of this research and its findings was to contribute to the improvement of teaching photosynthesis as the basis for the understanding of important science concepts. What was found particularly important is to ensure better integration of constructivist approach in science classes, which will help increase the quality of acquired knowledge and scientific literacy of the population.

The research could be further developed by determining the effectiveness in regard to acquired knowledge after a lapse of certain period of time, e.g. one year. This would allow us to make more reliable assessments of the effectiveness of CTMP. In addition, a photosynthesis teaching model for various education levels could be designed. Such a model would be an upgrade of the CTMP and could include interactive learning environments (e.g. use of ICT) to increase students' interest and improve understanding. The CTMP can form the basis for teaching other demanding science contents and is a step forward towards the co-operation between practicing teachers and researchers.

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