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EFFECTS OF EXPERIMENTS FOR STUDENTS' UNDERSTANDING OF PLANT NUTRITION

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Abstract

The experiment is important in biology classes. It is associated with many objectives. But what role does it play in the development of science-related conceptions for plant nutrition? Plant nutrition is part of a scientific education. Students often find it difficult to understand. Many of them hold pre-existing conceptions which are not in line with the generally accepted scientific view. The aim of this study is to clarify whether experiments which are embedded in a constructivist learning environment support the development of more scientific ideas. It also examines whether doing experiments has got an effect on emotional aspects such as interest or motivation.

279 students at the entry-level of secondary education participated in the study. A written test was constructed to capture the students' conceptions about plant nutrition in the pre-post design and a follow-up. The emotional aspects were collected by a questionnaire in the pre-post design. The students got a treatment which consisted of a teaching unit on plant nutrition. It was embedded in a learning environment in which many or no experiments were done. The results show that an experimental experience supports a conceptual change with a long lasting influence.

Keywords: experiments, plant nutrition, constructivism, conceptual change, secondary school

1. Introduction

It is generally agreed that students bring certain ideas and phenomena to science lessons which are well established in their ways of thinking. But many of these pre-existing conceptions are incompatible with currently accepted scientific knowledge (Duit, 2003). They are often resilient and difficult to change by teaching. Many of these conceptions are proved in everyday life. This can be one reason of profound learning difficulties. New aspects are based on what is already known (Duit, 1993). To consider students' conceptions is therefore essential for subsequent learning.

1.1 Existing research

Intensive research on students' conceptions about plant nutrition took place in the 1980s. Most of the research was done in Anglo-American countries. Recent studies are hardly present. Most of the existing works are exploratory cross-sectional studies. They focus students' conceptions about plant nutrition after science teaching (e.g. Haslam & Treagust, 1987; Stavy et al, 1987). The results of these studies show two similarities. On the one hand they show that students think that plants absorb their nutrients from the environment, especially from the soil. Students often do not understand that plants are autotrophic organisms. On the other hand almost all the studies show that it is very difficult to change the pre-existing conceptions despite science teaching.

Although the topic of plant nutrition plays an important role in science lessons at secondary school, the development of students' conceptions based on methodically and didactically coordinated teaching modules is hardly found in the existing research.

1.2 Theoretical background

There is agreement among education scientists that the adoption of appropriate scientific conceptions is a constructive process. The constructivist approach is seen as a perspective for understanding, interpreting and influencing student learning in science (Hewson & Thorley, 1989). It recognizes the influence the pre-existing experience has on the way phenomena are perceived and interpreted and emphasises the active construction of meaning (Driver & Oldham, 1986). Such constructivist learning environments are based on authentic problems and direct experience. They enable students being active as well as discovering new explanations. They are also characterised by emotional involvement and self-regulated learning (Gerstenmeier & Mandl, 1995; Driver & Oldham, 1986). A typical learning environment of this kind encourages activities like experimentation. While planning and conducting experiments students are confronted with challenging and authentic tasks. They are able to self-regulate their learning as well as to generate explanations.

But up to now it is not clarified what role experiments actually play in the process of conceptual change. Research results demonstrate that pre-existing conceptions cannot be abolished easily and replaced by scientific ones (e.g. Haslam & Treagust, 1987; Stavy et al, 1987). But how to initiate the process by which such changes occur? According to Strike and Posner (1992) a conceptual change is based on four conditions: dissatisfaction, intelligibility, plausibility and fruitfulness. The idea of conceptual change is not to extinguish and replace the pre-existing conceptions. Furthermore, the aim of science teaching should be to make students aware that in scientific contexts the scientific conception is more viable than the everyday conception (Treagust & Duit, 2008).

2. Questions

According to the theoretical models and the analysis of previous research the following questions were examined.

1. What kind of role do experiments play in the development of scientific conceptions about plant nutrition?
2. Do students experience the emotional aspects of a constructivist environment better when it attaches importance to experiments or when it does not?

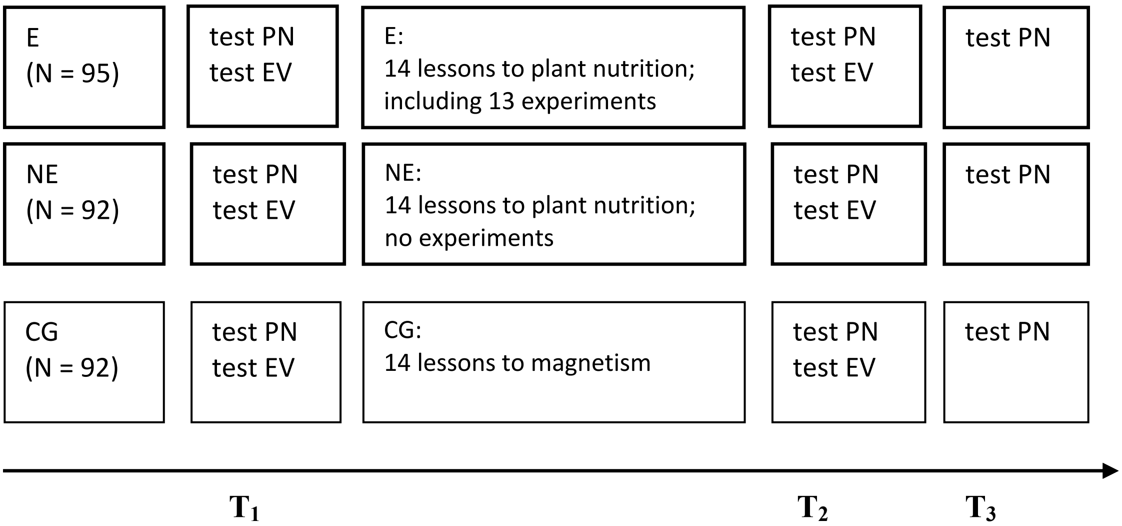
3. Work plan

3.1 Sampling

In the present intervention study two teaching concepts about plant nutrition were developed. They were embedded in a constructivist environment. One of the learning environment included experiments (E) the other did not (NE). There was also a control group (CG) to capture the overall effect of the treatment as well as the methodological artifacts. The students in the control group did not deal with the topic of plant nutrition. They got lessons to the topic of magnetism. The investigation took place in the subject of Science. It involved nine school classes (N= 279) at the entry-level of secondary education. They came from two different schools. The students were 11-12 years old. The classes were randomly assigned to the experimental groups and the control group (cluster sample). Each group included three school classes ($N_E = 95$; $N_{NE} = 92$; $N_{CG} = 92$).

3.2 Instruments

The study was organized as a repeated measures design (Figure 1). With the help of a questionnaire the students' conceptions about plant nutrition were collected. The questionnaire was used three times in all the groups. The pretest took place before the intervention started. The posttest was handed out right after finishing the treatment. The follow-up-test took place after ten weeks. The questionnaire included a total of fourteen tasks with open and closed answer format. The tasks were embedded in situations which were not treated in the classroom. The alternative answers to the closed questions were generated using group interviews. The tasks were scored and a total value was generated. (Cronbach's α [pretest, posttest, follow-up test] = .43, .90, .91).



test PN: test plant nutrition
test EV: test emotional variables

Figure 1. Work plan.

The written test instrument to the emotional variables was adopted and modified from Blumberg (2008). It was handed out to all the groups as a pre- and posttest. At the posttest the instrument was used in an expanded form. The scales, the number of items and the reliabilities are shown in Figure 2. The response scale for all the items was a four-point Likert-Scale (1 = lowest approval; 4 = highest approval).

Scales (number of items)	α (pretest)	α (posttest)
interest (11)	.92	.94
non-school related interest (5)	.75	.83
intrinsic motivation (5)	.80	.88
extrinsic motivation (4)	.64	.74
self-efficacy (6)	.84	.86
self-concept (3)	.87	.87
feeling of being successful (6)	---	.91
feeling of being competent (7)	---	.89
importance of the lessons (8)	---	.91
autonomy (14)	---	.92

Figure 2. Emotional variables (scales, number of items, reliabilities).

The data were examined by the analysis of variance to see the effect of the treatment. Furthermore, the individual items of the students' conceptions to plant nutrition were analyzed using frequencies and the non-parametric Friedman-Test (see Field, 2009). The aim was to determine the conceptions of the students to the different points in time and to find out how they developed within the experimental groups and the control group.

3.3 Lessons

The teaching concepts in the two experimental groups consisted of fourteen lessons on plant nutrition. The lessons can be grouped into five thematic blocks: nutrients and energy, living conditions of plants, water balance in plants, air composition as well as photosynthesis and solar energy. The blocks did not only focus on plant nutrition. They also integrated other scientific conceptions which support an understanding of the process (e. g. water balance in plants). The students in the experimental group E usually did one experiment in each lesson. They worked in groups of three to four students. Very important was that the experiments were not repeated just like a recipe in a cookbook. The groups had to find a research question and to plan and carry out the experiment independently. The materials were provided by the teacher. There were thirteen experiments altogether. The students in the experimental group NE did not do any experiments on their own. Only two experiments were demonstrated by the teacher. The students also worked in small groups. They used illustrations, texts, models or film sequences instead. (Example: While the students in the experimental group E tried to find out what influences the photosynthesis rate with the help of an experiment, the students in the group NE watched a film to that topic.)

The content of the lessons, the chronological sequences of the lessons as well as the teacher were identical in both groups. The teacher was not the subject teacher of the students. It was an external person. The lessons in both groups were embedded in a constructivist learning environment. So the students were enabled and encouraged being active, discovering new explanations and find their own path of successful learning. It was also given enough time and space to discuss the ideas with classmates and to review and reflect them. Results were recorded, interpreted and compared with the previously expressed conceptions. The students' conceptions were visualized throughout the unit and presented by the teacher again and again. This should help the students to think about existing conceptions and to develop adequate ones. The only difference in the two experimental groups was the experiment. Whenever the students in the experimental group E did an experiment, the students in the other group NE worked with an alternative.

The students in the control group (CG) did not deal with plant nutrition at all. The topic of their lessons was magnetism. The teachers were instructed to teach as they usually do. The lessons were not embedded in a constructivist environment. The teachers were the subject teachers of the students.

4. Results

The analyzed data show that the groups do not differ at the beginning of the intervention (Figure 3). If you put the focus on the control group (CG) you can see, that the arithmetic mean is quite low and almost constant at all the three points in time. That is different in the two experimental groups. The descriptive data indicate an increase in learning.

Regarding the effects of the intervention the repeated measures analysis shows a significant interaction effect (F (2, 275) = 10.45, $p \leq .001$, $\eta^2_p = 0.71$) and group effect (F (2, 275) = 363.84, $p \leq .001$, $\eta^2_p = .726$). The total value of the post- and follow-up tests to the students' conceptions about plant nutrition was used for it. The data of the pretest were considered as a covariate. This result indicates that the groups develop differently over the time and that the differences remain even after removing the data of the pretest.

	M (SD)		
measuring time	**E**	**NE**	**CG**
	(N = 95)	**(N = 92)**	**(N = 92)**
t_1	4.17 (2.64)	3.96 (2.91)	3.66 (2.37)
t_2	20.06 (5.56)	18.12 (5.67)	3.80 (2.40)
t_3	21.52 (6.00)	17.15 (6.35)	3.76 (2.72)
scale 0-34 (test results)			

Figure 3. Descriptive data of the scale to the students' conceptions about plant nutrition.

A detailed look at the two experimental groups with the help of the analysis of covariance shows a significant group effect in the posttest (F (1, 183) = 4.19, $p \leq .05$, $\eta^2_p = .022$) and in the follow-up test (F (1, 183) = 20.85, $p \leq .001$, $\eta^2_p = .102$). The significant effect is in favour of the experimental group E (Figure 3). Immediately after the intervention the difference between the two experimental groups only shows a small effect. But ten weeks later a quite strong effect is recognizable. The descriptive data indicate that the treatment has affected the memory performance of the students in different ways (Figure 3). The arithmetic mean of the experimental group E is in the follow-up test higher than in the posttest. This can indicate that the students developed more adequate conceptions. In the experimental group NE it is just the other way round. The children there seem to forget some of the established science-related conceptions.

If you have a closer look at the students' conceptions you can see that they have many different conceptions about plant nutrition at the entry-level of secondary education. The analysis of the individual items in the pretest shows, that the children often assume that plants absorb their nutrients from the environment. An example out of the questionnaire to the students' conceptions about plant nutrition illustrates this (Figure 4).

How does the sugar get into the fruit?				
	pre frequency %	**post frequency %**	**follow-up frequency %**	**Friedman-Test**
Through minerals from the soil, the fruit is sweet.				
E	52	7	4	p ≤.001
NE	55	7	7	p ≤.001
CG	53	50	47	p = n. s.
The plant takes the sugar from the soil.				
E	33	8	5	p ≤.001
NE	37	3	10	p ≤.001
CG	44	41	41	p = n. s.
Honeybees make the fruit sweet.				
E	24	1	1	p ≤.001
NE	25	1	1	p ≤.001
CG	28	24	29	p = n. s.
The fruit is sweet due to the growth of its own.				
E	27	10	3	p ≤.001
NE	20	4	1	p ≤.001
CG	37	34	36	p = n. s.
The water the plant absorbs contains sugar.				
E	17	3	0	p ≤.001
NE	19	2	2	p ≤.001
CG	17	22	19	p = n. s.
The plant produces the sugar in the leaves.				
E	15	81	84	p ≤.001
NE	21	73	84	p ≤.001
CG	17	27	25	p = n. s.

Figure 4. An example out of the questionnaire to students' conceptions about plant nutrition.

Conceptions where the soil plays an important role are quite dominant in the pretest. About half of the students think that fruits are sweet through minerals from the soil. More than a third assumes that the plant absorbs the sugar from the soil. The development of the percentage frequencies shows that at the post- and follow-up-test fewer students of the experimental groups use these inadequate conceptions (Figure 4). This can also be observed with the other conceptions which are not in line with the scientifically accepted view. On the contrary, the scientifically accepted conception (plans produce the sugar in the leaves) is evident in the two experimental groups. There is an increase to over eighty percent. In the control group (CG) this development is not visible. This is manifest in the results of the Friedman-Test. In the control group (CG) the results are not significant, in the experimental groups they are (Figure 4). The students in the experimental groups are usually able to understand the process of plant nutrition, its importance and the fundamental factors. They are also able to develop scientific conceptions. This development cannot be observed in the control group (CG).

The analysis of covariance to the emotional aspects shows that eight out of ten scales have significant group differences (Figure 5).

	M (SD)			**group effect**
scale (1-4)	**E** **(N = 95)**	**NE** **(N = 92)**	**CG** **(N = 92)**	
interest	3.23 (.69)	3.18 (.64)	3.08 (.72)	F (2, 273) = 3.79; $p \leq .05$; $\eta^2_p = .027$
non-school related interest	2.06 (.69)	2.22 (.80)	1.99 (.58)	F (2, 273) = 3.57; $p \leq .05$; $\eta^2_p = .025$
intrinsic motivation	3.01 (.83)	3.19 (.75)	2.87 (.82)	F (2, 273) = 5.39; $p \leq .01$; $\eta^2_p = .038$
extrinsic motivation	2.27 (.75)	2.46 (.88)	2.49 (.68)	F (2, 273) = 1.37; p = n. s.; $\eta^2_p = .010$
self-efficacy	3.26 (.65)	3.31 (.55)	3.17 (.64)	F (2, 273) = 3.63; $p \leq .05$; $\eta^2_p = .026$
self-concept	2.69 (.67)	2.76 (.69)	2.69 (.58)	F (2, 273) = 1.48; p = n. s.; $\eta^2_p = .011$
feeling of being successful	3.19 (.74)	3.14 (.73)	2.70 (.78)	F (2, 273) = 20.87; $p \leq .001$; $\eta^2_p = .133$
feeling of being competent	3.01 (.67)	3.09 (.73)	2.92 (.71)	F (2, 273) = 3.77; $p \leq .05$; $\eta^2_p = .027$
importance of the lessons	2.99 (.75)	2.99 (.76)	2.66 (.77)	F (2, 273) = 10.86; $p \leq .001$; $\eta^2_p = .074$
autonomy	3.08 (.65)	2.90 (.68)	2.31 (.61)	F (2, 273) = 42.51; $p \leq .001$; $\eta^2_p = .237$

Figure 5. Descriptive data and test statistics of the scales to the emotional variables (posttest).

Contrasts, which compare the mean values of the experimental groups with the mean values of the control group, pointed out that the experimental groups differ from the control group. It is most clearly at the variable of autonomy. Here you can find a very strong effect (Figure 5). The variables of extrinsic motivation as well as the ability to self-concept turn out to be stable characteristic values. The comparison between the experimental group E and the experimental group NE only shows a significant difference relating to the variable of autonomy (F (1, 184) = 4.12, $p \leq .05$, $\eta^2_p = .022$). It is in favour of the experimental group E. The learners in the experimental group E obviously feel more independent than in the classroom than the students in the experimental group NE do.

5. Summary and Discussion

The results show that students at the beginning of secondary school have a number of different conceptions about plant nutrition. They do often not agree with the science-related conceptions. Very dominant is the idea that plants absorb their food from the environment. The conception that plants synthesize their nutrients itself is hardly represented. This corresponds with previous research findings (e.g. Eisen & Stavy, 1988; Bell, 1985; Marmaroti & Galanopoulou, 2006). This idea is clear and also supported by the experience of the learners. Human beings absorb food as well as animals. This can be observed in everyday life. So it is not surprising that students think that plants absorb their nutrients from the environment as well.

The results in the present study show that students are able to develop scientific conceptions about plant nutrition. Numerous studies which determined the learners' conceptions after science teaching could not or only hardly notice that (e.g. Haslam & Treagust, 1987; Marmaroti & Galanopoulou, 2006). However, the results also show that the teaching in the learning environment with experiments is superior to the teaching in the learning environment without any experiments. It is especially obvious in the long term effect. The learners in the group with no experiments tend to forget science-related conceptions in the course of time. In the group working with experiments an increase can be observed.

One possible explanation to that phenomenon gives the theory of cognitive load (Sweller, 1994). It emphasizes the important function of the working memory. Its capacity is considered to be limited in the processing of new information. The success in the experimental group E is obviously based on the capacity of the working memory. Doing experiments is complex. It requires cognitive, affective, psychomotor and social skills. At the time of the posttest the working memory is apparently strained. After a period of ten weeks, however, a further development of science-related conceptions can be observed by the learners who did the experiments. Possibly there was a transfer of information into the long-term memory. The present results suggest that self-experimentation helped the learners to anchor information more deeply.

Regarding the results of the emotional aspects the study shows that the experimental groups do not differ at all – apart from one exception. Only the experience of autonomy differs in favour of the students who worked with experiments. The feeling of making own decisions, developing own ideas or planning one's action is obviously more noticed in that group. Self-directed learning is important to anchor knowledge (Schiefele & Streblow, 2005). This may also explain the rise of scientific conceptions from the posttest to the follow-up-test.

No matter whether the learning environment included experiments or not – there were many positive emotional effects in both experimental groups. This result suggests that experimentation in the classroom does not necessarily lead to a higher motivation or greater interest as often postulated in science teaching. Apparently it is more important that the lessons are embedded in a learning environment which supports the development of these emotional aspects. The constructivist learning environment in the present study obviously offered that chance.

The study is based on a quasi-experimental design with a relatively small sample. Therefore you have to be careful to generalize the results. It is important to replicate the findings.

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