education sciences

Article

Are We Aware of What Is Going on in a Student's Mind? Understanding Wrong Answers about Plant Tropisms and Connection between Student's Conceptions and Metacognition in Teacher and Learner Minds

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Received: 10 August 2018; Accepted: 27 September 2018; Published: 2 October 2018

Abstract: Problems with understanding concepts and mechanisms connected to plant movements have been diagnosed among biology students. Alternative conceptions in understanding these phenomena are marginally studied. The diagnosis was based on a sample survey of university students and their lecturers, which was quantitatively and qualitatively exploratory in nature (via a questionnaire). The research was performed in two stages, before and after the lectures and laboratory on plant movements. We diagnosed eight alternative conceptions before the academic training started. After the classes, most were not been verified, and in addition, 12 new conceptions were diagnosed. Additionally, we report that teachers are not aware of students' possible misunderstandings. They do not perceive students' troubles with switching between levels of representations, nor their alternative conceptions. A case of "curse of knowledge" was observed and academic teacher training is recommended. Additionally, the need for metacognition as a crucial element in laboratory activities seems supported by our presented results. Such metacognition refers to students as well as teachers, which leads to the conclusion that teachers should be aware of students' way of thinking and the development of knowledge in one's own mind.

Keywords: alternative conceptions; curse of knowledge; metacognition; learning outcomes; plant blindness; plant movement

1. Introduction

According to constructivist theory, learning is an active process in which students build their knowledge individually through combining experience, information from the environment, social interactions, understandings arising through language, etc. Additionally, what is difficult for teachers is that sometimes one's individual ideas may seem incoherent. For example, one child may use different conceptions to explain the same process, even when the arguments they use seem to conflict. Another difficulty is that students' alternative conceptions can remain even after they have been taught the scientifically correct fact or process [1]. A common interpretation of the constructivist view of learning is that students must be mentally active during learning [2]. Whereas cognition involves three general types of learning skills: cognitive strategies, problem solving strategies, and critical thinking skills, metacognition includes two main subcomponents: knowledge of cognition and regulation of cognition [3]. This mental activity involves such actions as what we know about our cognition, our declarative knowledge, procedural knowledge, and knowledge of why and when to use a particular strategy of learning and thinking. It also includes processes of planning, monitoring, and evaluation [4]. They can be collectivized into a major term called metacognition. While discussing metacognition, different definitions can be found: "Metacognition is probably best conceptualized as a set of interrelated constructs pertaining to cognition about cognition," [5] or "A metacognitive learner is one who understands the tasks of monitoring, integrating, and extending, their own learning" [6].

All these lead to the conclusion that in order to fully understand the subject, a learner needs to use their metacognitive skills. They need to be cognitively active and make use of many types of knowledge that are present in their mind. One approach could be introducing a successful conceptual change into the teaching process. Conceptual change is broadly understood as learning that changes some existing conceptions [7]. Pupils enter school with various ideas about the natural world. Learning biology starts in the community from the moment of birth, and concepts are influenced by the people around a child as well as other factors such as the media [8]. Many of these everyday notions are quite contrary to scientific findings, and in this paper, they will be labeled as alternative conceptions. When speaking of alternative conceptions in teaching biology, we mean the concepts that have peculiar interpretations in students' articulations that are not scientifically accurate [9–11]. As Treagust summarized, students' conceptions that are different from those generally accepted by the scientific community have been called "misconceptions", "preconceptions", "alternative frameworks", or "children science", and for that reason, we treat those expressions as synonyms [12].

Biology is a branch of science that works on a wide range of levels of matter organization, from molecules to the biosphere. Learning about all of them involves creation of both mental and didactical representations (or internal and external representations). While teaching, a process of simplification and switching between representations occurs with the aid of models, pictures, and symbols in order to help students to understand the content. The creation of models and representations is important in the production of knowledge. Johnston proposed, and it is still supported, that three major levels of representations exist in science and science education [13–15]. These are the macroscopic level, the sub-microscopic level, and the symbolic level. The macroscopic level is met directly during observational experience in the laboratory and everyday life, for example observing plants and animals, etc. The sub-microscopic level is met with during the representation of the inferred nature of chemical and biochemical entities (molecules, macromolecules, cells, and organs) and the relationships between them. These representations are expressed in concrete, visual, or verbal modes. The symbolic level is the representation of the identities of entities (molecules), such as DNA. The switching between these levels of representation is challenging for students, and it has to be stressed here that a full understanding of many phenomena involves the ability to make connections and move fluently between them.

1.1. Why Should We Bother about Alternative Conceptions in Teaching/Learning Context?

The processes of teaching and learning are inextricably linked to the process of building knowledge resources of a subject, often called personal knowledge. Knowledge itself is a concept still not well defined, and although we all feel and have our own understanding of what it is, everyone has their own description of this mental phenomena. There are also different types of knowledge distinguished by philosophers of science. Among them, there is conceptual knowledge (such as in the form of a concept, idea, or representation) in the brain that can be described by a model based on the synchronous activity of neuron groups called neural cell assemblies (NCA). According to this model, words (concepts, symbols) have their form and meaning. The form of symbols at the brain level is represented by local networks of neural microcircuits. The meaning of words is represented by the stimulation of brain activity, associated with phonology and spelling, combining the perception of the concept and its action, while activating the sensual, motor, pre-cortical, and other subcortical cortex [16]. For that reason, written or spoken language plays an important role in education, among others, which mediates between what is referred to as scientific knowledge and personal knowledge of children, provides a system of thinking and speaking about science, and is a method for communicating and sharing ideas [17]. In the educational process, language should be perceived as a system of signs and symbols used to explain and interpret phenomena related to categorization, labeling, conceptualization, and meaning [18]. All these elements contribute to conceptual knowledge and thus participate in the co-creation of personal knowledge. Such understanding of personal knowledge is the result of learning and personal effort.

There is a relationship between intuitive biological thinking and misconceptions [19–22]. Coley and Tanner provided a reconstruction idea of intuitive thinking and its categorization in accordance with Piaget's categories of cognitive constructs used by children in their processes of creating knowledge [22,23]. Educational researchers have pointed out that children and teenagers think and reason differently than adults. They use these mechanisms in building their own conceptions of different scientific issues: animism (plants and animals feel just like us), artificial connections (anthropocentric thinking, things happen because of humans, for example, sun shines so we could see everything), transduction thinking (in our thinking process, we connect two details together but not through deduction), teleological thinking (everything happens for a purpose, e.g., plants produce oxygen so people and animals could breathe), and essentialist thinking (there is an essential, unobservable feature, essence, or property that causes similarities in some particular groups e.g., all plants are the same).

Misconceptions (naive or alternative conceptions) cannot be pictured or characterized as a lack of knowledge or gaps in knowledge; they are a natural method of creating knowledge in a child's mind. The personal knowledge they acquire can significantly influence teaching and learning. This knowledge can be very resistant to change—the process of learning should concentrate on the process of proper understanding of mechanisms and phenomena. For example, many pupils believe that the weight increase in plants comes from water and soil, but only a few are able to establish a connection between photosynthesis and plant nourishment [24]. Students (as well as every human being) use their personal knowledge to understand scientific issues.

There are different sources of such unscientific (intuitive) conceptions in students' mind that are not related to students' ways of thinking. One source of alternative conceptions is errors in teaching. Some of the most common mistakes in teaching leading to alternative conceptions include: over-simplifications, inaccurate generalizations, the use of outdated data, incorrect interpretation of phenomena, and experiments inappropriately selected for explaining phenomena [25]. For example, exaggerated simplification at the early stages of education blurs the appropriate image of a situation and fixes in the memory a poorly-detailed scheme for resolving a given problem or poor understanding of a specific issue, which, in the case of later education, impedes critical thinking and solving problems. An example might be the representation of glucose ($C_6H_{12}O_6$) as the sole product of photosynthesis when the free glucose from this reaction is converted to sucrose or starch with the formula $(C_6H_{10}O_5)_n$, and the value n is given in thousands. Another example is the use of single arrows to depict the biochemistry of this process, which incorrectly suggests that it is a one-step process [25]. Hershey also saw reasons for the erroneous understanding of the processes taking place in plants, among others, in the marginal treatment of botany during introductory courses to biology, leaving pupils with the belief that biology is solely the study of the science of animals [26]. This tendency also seems to be maintained in textbooks, where at the level of elementary school, almost three times more zoological terms are found than botanical [27,28]. According to Wandersee and Schussler [29], authors of the theory known as plant blindness, interest in plants is much lower than interest in animals or humans [30,31]. Moreover, alternative conceptions created in the mind of students also often arise from their personal experience. A surprising example that appeared in the questionnaire prepared for this study was the answer of a student, who pointed out that they first became acquainted with the concept of the movements of plants in a glass cleaning agent TV commercial. Tekkaya rightly pointed out that if alternative conceptions are not quickly diagnosed and eliminated, they will have an adverse effect on the understanding of the material in the later stages of education, as a teacher usually plans teaching in relation to the basic curriculum, assuming that the pupils have already previously mastered the issues [9]. Besides, alternative conceptions in the scope of a given process make it difficult to understand, and mechanics on which the process is based are complicated, so the spiral of growing difficulties in understanding biological processes begins.

1.2. Understanding Plant Movement—Motivation for the Study

Problems with understanding concepts and mechanisms connected with the movement of plants have been identified among biology students at the Faculty of Adam Mickiewicz University in Poznań, Poland for several years. Studies on alternative concepts in understanding these particular phenomena are still marginally treated in analyses available in the literature, which is why we embarked on this study. Movement, reaction to stimuli, and growth are some of the basic characteristics of living organisms that include both plants and animals. However, students tend to attribute these characteristics only to animals and perceive plants as organisms that are less alive [32]. Thus, teachers should be able enhance students' knowledge of plants as being animate as well. At the same time, research about plant tropism and students' conceptions about plant tropism are very limited. For example, Lin described six misconceptions about plant tropism among high school students [33].

Plant tropisms play a fundamental role in shaping the growth form of plants, including in plant development, governing organ position, growth from the germination of a seed to the positioning of flowers for pollinators, and seed dispersal. Inquiry into plant tropistic responses is not new; Darwin studied them in the mid-1800s [34]. Although his work has now been recognized as an important contribution to plant biology, it was resoundingly rejected by his peers as discussed by Whippo and Hangarter [35]. Even though plant movement has fascinated school children, been the subject of books for the general public [36,37], and featured whimsically in TV commercials (Windex), the essence of the phenomenon and mechanisms that control plant movements are hardly understood by many students.

This study was designed to show whether the BA-level second year plant physiology course, where an experiment was used as an educational intervention, could verify students' alternative conceptions within the subject of plant movements. Those classes were conducted in the form of laboratory classes with behavioral assumptions in the foundation of the design. In these classes, students conduct experiments according to very specific instructions. Students do not formulate research questions or hypothesis. Students are only answering the questions and formulating conclusions. This situation is similar to that described in the literature as "guided discovery" [38,39]. Problems with this strategy are well documented in literature, but are still perceived by academic teachers as effective. Generally perceiving the laboratory activities seems to be especially important in the current era in which inquiry has played as a central role in science teaching and learning [40]. The problem seems to be more complex and includes elements such as the context of our knowledge of the human cognitive architecture, expert–novice differences, cognitive load, and many others [41]. On the one hand, teachers lack awareness of the problems that students are facing with learning the specific topic, as indicated by Millar who showed that the metacognitive skills (understood as being able to reflect) of a teacher seem to be problematic [42]. Such metacognitive skills and reflection should be a starting point in arising pedagogical content knowledge. Teachers need metacognition in order to adapt their teaching to the specific situation On the other hand, experiments and laboratory activities are perceived as effective in the teaching process. In Poland, this is the traditional form of conducting plant physiology courses. Academic teachers in Poland were commonly were not required to be prepared pedagogically for teaching. The courses and classes that are taken by in-service academic teachers are voluntary. Taking this into account, we may not describe pedagogical content knowledge among this group of people; we might instead describe their abilities of reflection and metacognition, as general skills every human being possesses. The authors of this publication could not influence the method of conducting or designing the classes. For that reason, the following research might serve as a starting point to stress the role of reflection on efficiency in conducting those classes in the current form. It might also be a point of developing pedagogical content knowledge in the next step.

First, we identified and determined the prevalence of students' misconceptions concerning plant movement. Next, we investigated whether, and to what extent, those misconceptions were subject to conceptual change in the course of discussing plant movements during the plant physiology course. We assumed that the traditional course with its active teaching methods, but not necessarily active learning, would not challenge the students' alternative conceptions, even when they learn a new concepts.

Notably, studies about students' conceptions about plant movement have been neglected. So far, as mentioned above, Lin described some conceptions about plant development including plant tropism [33]. Millar studied teachers' perception of the tropism experiments [42]. These were the only topic-related studies that we were able to find. More attention has been directed into tropism of tissues and bacteria than to plant tropism.

2. Materials and Methods

The identification of students' conceptions about plant tropism was based on quantitative-qualitative surveys prepared on the basis of two questionnaires: research tools 1 and 2. Additionally, in order to obtain a wider view of the problem, the first study group included university teachers, and the second undergraduate students.

For study group 1 (teachers), studies were carried out involving a group of 17 persons, 6 men and 11 women, including both professors and their assistants conducting lectures and plant physiology laboratories. The questionnaire was filled in by staff, who all taught the same course, at the Faculty of Biology of Adam Mickiewicz University in Poznań. Among the teachers were both women and men with different years of teaching experience, from 1 to 25, and different job positions (Ph.D. students, professor assistants, senior lecturers, and professors themselves).

Research tool 1 was the questionnaire. Teachers were asked to provide information about, among other things, in what form were their students acquainted with the phenomena of phototropism and gravitropism, what were the most common mistakes made by students when discussing these processes, and what are the causes of students' problems in understanding the tropism concept. The questionnaire is presented in Appendix A.

For study group 2 (students), the participants were a group of 104 s-year bachelor students participating in the plant physiology course at the Faculty of Biology of Adam Mickiewicz University in Poznań in 2013/2014 and 2015/2016. The group was age-matched but uneven in proportion of sex. In the group, there were 7 men and 97 women. The inequality of the group was caused by the fact that the entire group taking the plant physiology course was used in the study. The plant physiology course comprised 30 h of lectures, 10 h of seminars, and 60 h of practical exercises. The concepts of plant movements were discussed directly during a lecture and 13.5 h of practical exercises dedicated to plant growth (three sessions of 4.5 h each). During every practical exercise, students performed five experiments on plant tropisms. For each experiment, the students were obliged to write a report containing their results and conclusions. The conclusions were discussed with the teacher and, if necessary, corrected.

Research tool 2 was another purpose-designed questionnaire (Appendix B). The content validity of the questionnaire was established by two experienced biology academics. A pilot version of the questionnaire was completed by 21 biology students at Adam Mickiewicz University and the initial version of the questionnaire was revised. For example, some of the open questions were clarified by changing them to semi-open or closed items. The questionnaire's metrics asked for the participants' sex, age, and level of previous matriculation in biology. The questionnaire questions were chosen so as to be able to validate the correctness of defining both biological processes and the ability to use the learned definition. The questionnaire also asked whether, when, and how students were acquainted with the term *plant movements*. Moreover, the questions concerned general knowledge of the movements of plants including types of movements, definitions of tropism, and the extent to which phototropism, photonasty, and phototaxis are synonymous concepts. The remaining questions surveyed detailed knowledge in the scope of phototropism and gravitropism including: mechanism of movement, and the physiological significance of movement. The criteria for assessing the correctness of the answers to the questionnaire and the questionnaire itself are presented in Appendix B.

We formulated two hypotheses:

Hypothesis 1. *After the course of plant physiology, students will gain some scientific knowledge, so they will be able to explain phenomena about plant tropism and they furthermore will not use previous misconceptions or common-sense knowledge;*

Hypothesis 2. *Teachers are able to predict student achievements on learning about plant tropism and will indicate problems as well as possible solutions for dealing with student problems in understanding plant tropism.*

Analysis of the Results

For research tool 1, the teachers' answers were added up and analyzed quantitatively and qualitatively. In the next step, they were compared with the results of the students' questionnaire.

For research tool 2, the analysis method was based on Creswell [43]. To extract students' concepts, answers were analyzed in content analysis, then qualitative data were coded to quantitative data [44]. To ensure inter-rater reliability, two academic biology teachers participated in the process of creating the coding system and they independently analyzed the questionnaires. During calculation, the authors used joint probability of agreement. The initial coding agreement rate was 93% and any disagreements were settled by discussion. The authors developed the categories on the basis of students' answers (inductive approach).

In order to assess the statistical significance of changes in the results of a student's questionnaires before and after the plant physiology course, the Student *t*-test was applied, using generally available formulas for dependent groups. In order to check whether there was a connection between students' ability to define concepts of plants movements and using it in adequate situations, as well as check whether students combined various concepts with each other, the chi-square test analysis was used.

The statistical calculations were completed using a generally available calculator (http://www.socscistatistics.com).

3. Results

3.1. Questionnaire for Teachers

The questionnaire was completed by academic teachers conducting lectures and running the plant physiology laboratories (Table 1).

Table 1. Teachers' responses expressed as a percent of answers given by teachers in their questionnaire, on understanding student wrong answers about plant tropism (n = 17 evaluated teachers).

Questions and Answers	% of Given
1. In what form(s) were the students acquainted with the phenomena of phototropism and gravitropism?	
Experiment/experiments performed by the students	47%
Experiment/experiments perform by the students supported by teacher's theoretical introduction	27%
Students comment on experiment performed by the teacher	20%
Other	6%

Table 1. *Cont.*

Questions and Answers	% of Given
2. What percent of students, in the teacher's opinion, after becoming acquainted with content concerning phototropism and gravitropism, could properly explain these processes?	
The vast majority	14%
Majority	51%
Half	32%
Less than half	3%
3. What were the most common mistakes made by students when discussing phototropism and gravitropism?	
Lack of understanding the mechanisms of the process in general (from the stimulus to the response)	35%
Not taking into account or not understanding the varying sensitivity of shoot and root for the same concentration of auxin and the same the problem within the understanding of the mechanism of the reaction	35%
Lack of understanding that tropisms are the growth reactions	12%
Lack of understanding the mechanism of auxin action in the consequence also their role in elongation growth	10%
Ignorance of the place of the stimulus perception	8%
4. What are the causes of students' problems in understanding the tropisms concept?	
Lack of essential background	40%
Lack of observation of the progress of the process (student sees only the initial and final state)	27%
Lack of focus in the classroom	13%
Other	20%
5. What methods should be used to teach the tropisms concept in the future, in order to eliminate wrong answers?	
The use of video and/or animation to comment on the results of experiments	60%
Self-recording the phenomenon by students	35%
Other	5%

All the lecturers declared that all their students became familiar with the definitions and mechanisms of phototropism and geotropism during their course (Q1, Appendix A). Almost half of the respondents said that students became acquainted with the phenomenon of the plant movements through an experiment performed independently (Q2 and Q4, Appendix A, semi-open question). Sometimes an experiment prepared independently was supported by theoretical information or by a variety of multimedia teaching resources. Although 47% of teachers' answers indicated that students performed experiments by themselves, the definition of what is an experiment is fuzzy in this case. Among the answers given by lectures, we obtained: "The observation of the final state of the process in the experiment prepared by the student was introduced", or "They carried out experiments in the laboratory by following given instruction". The second category (Table 1) includes answers that refer to the support given by the teacher during a lecture in the form of a PowerPoint presentation or oral presentation. Five out of 17 teachers admitted that they carry out experiments by themselves and students were expected to watch it, "paying particular attention to the final stages of the experiment". Among the answer classified in the category "others", we received answers referring to watching a short movie or analyzing diagrams and scientific text. An example of the plant used in phototropism exercises most often pointed to by lecturers (more than half of the answers) were mustard seedlings, oat, or barley coleoptile. Cucumber seedlings were mentioned in about one third of the answers, and the smallest percentage of answers indicated the use of flax. Also, the duration of the teaching time had a spread from three hours to seven days (indicating in this case that students were supposed to visit the laboratory every day to observe the changes occurring in investigated plants). As an example of the plant used in teaching about gravitropism, lecturers indicated beans, flax, lupines, peas, maize, and cress. The observation period for lupine was determined to be 24–48 h, three to four days for flax, and five days for mustard. These experiments were related to the observation of the direction of root growth, under a variable angle to the gravity force. The next questions (Q3 and Q5, Appendix A) were closed-ended, and 11 out of 17 respondents emphasized that, in their opinion, the majority of students (that is, over half) could properly explain these processes after being familiarized with information on phototropism and gravitropism. Among the most common types of mistakes about plant tropism made by students (Q6, Appendix A, point 3 Table 1), teachers provided either more general or specific answers. A third of the teachers indicated a general lack of understanding about the mechanism of processes. Another rather general answer (two of the respondents) reported that students did not connect phototropism and gravitropism with plant growth, e.g., “students do not combine phototropism and gravitropism with plant growth movements; instead, they perceive them (phototropism and gravitropism) as *bending organs* toward the stimulus or in the opposite direction from the stimulus.” By providing more detailed answers, six of the respondents pointed out the fact that some students ignore the presence of a differentiated sensitivity of a shoot and root to auxins. Some of them admitted that “they cannot indicate the location of auxins action”, or “they may not understand the different sensitivity of shoot and root for the same auxin concentration”.

In response to the question of what could be the cause of the above mentioned problems (Q7, Appendix A; point 4, Table 1; semi-closed question), the teachers mainly indicated poor substantive preparation of students (40% of the answers). They answered: “they are just not prepared, do not study hard enough”, or “they do not possess proper content knowledge”. One-third of the teachers indicated difficulties resulting from the long-lasting nature of the process and the absence of its complex observation—students can often only see the initial and final state of the process.

The next question (Q8, Appendix A; point 5, Table 1) was open-ended and was supposed to determine whether teachers from the investigated group would propose alternative, new methods that could be helpful in teaching about tropism. The teachers suggested that teaching about the movements of plants should be supported by a film or animation or an experiment in which the students could film the process themselves. Another option given by teachers was to engage students in discussion, or add more teaching hours into the plant physiology course.

3.2. Questionnaire for Students

Changes in correct answers before and after plant physiology course are shown below (Tables 2 and 3, Appendix B).

Table 2. The significance in the changes in percentage of correct answers given by students (n = 104) before and after the plant physiology course, according to a Student *t*-test.

Question No. and Content	% of Correct Answers		Significance, $p \leq 0.05$
	Before	After	
Q1. List the types of plant movements.	6%	7%	Not significant
Q2. Are phototropism, photonasty, and phototaxis synonymous concepts?	4%	26%	Significant
Q3. Define tropisms.	11%	16%	Not significant
Q4. Describe the stages of a shoot responding to the directional effect of light.	6%	14%	Not significant
Q5. Describe the stages of a root responding to gravity.	6%	22%	Significant
Q6. Mark the organs that react to phototropic stimulus.	35%	57%	Significant
Q7. Explain the different responses of a shoot and root to the applied agar blocks.	15%	35%	Significant
Q8. Explain the differences in habits between trees growing in the forest or in the field.	16%	24%	Not significant
Q9. Indicate the physiological importance of gravitropism.	5%	21%	Significant

Table 3. The conceptions identified in students' answers to the questionnaire before plant physiology course.

Conceptions' Categories	Alternative Conceptions	% Occurrence of the Alternative Conception	
		Before	After
Division of plant movements	Plant movements are divided into phototropism and gravitropism	41%	30%
	Phototaxis, photonasty and phototropism are synonymous terms	15.5%	24%
Plant tropism movement definition	Phototropism is a positive response of the shoot to a light stimulus	65%	43%
	Gravitropism is a positive response of the root to the stimulus of gravity	63.8%	43%
	Tropism = movement	-	25.9%
	Phototropism is a chloroplast movement	-	3.4%
	Photo = sunlight	30%	-
The mechanism of plant tropisms	Auxin works the same way in the tropic reaction of the shoot and root	36%	22.4%
	Auxin inhibits the elongation of the shoot and accelerates the elongation of the root	30%	18.9%
	Auxin synthesizes the cells	-	12%
	The location of perception of a phototropic stimulus are internodes and the basis of phototropism is shoot apex domination	-	10.3%
	Auxin stimulates the cell division	-	6.9%
	Gravitropism is a positive response of the root to the stimulus of water	-	3.4%
The physiological importance of plant tropisms	Gravitropism embeds the plant in the soil	46.5%	17.2%
	Phototropism serves the plant to collect solar energy	-	5%
Other	Phototropism is a permanent reaction (not reversible)	-	3.4%
	Light is a limiting factor for plant growth (trees growing in the meadow are then lower)	-	1.85%

We developed a questionnaire to identify problems related to understanding the role of plant movements in plant biology. The questions were based on previously gathered data obtained from informal interviews at a biology high school, a questionnaire given to university teachers, class observations, student tests, and examinations from previous years and from previous research [26].

Studies were conducted using the same tool twice: before and after plant physiology course. The percentage of correct answers prior to the teaching varied from 4% (Q2), to 35% (Q6). In general, after the course, the proportion of correct answers increased. For example, for the most problematic question (Q2), 22% of the answers were correct. In total, 57% of respondents answered Q6 correctly after the classes. In both cases, this increase was statistically significant (Table 2). The significance of the changes in the percentage of correct answers before and after the course was also recorded for questions 5, 7, and 9 (Table 2). For questions 1, 3, 4, and 8 the changes were not statistically significant.

Moreover, by using the chi-squared test, dependencies were also determined between the ability to define concepts in the scope of the physiology of the plant movement and the ability to use these definitions. Whether students could combine various concepts with each other was analyzed. The analysis was carried out for the "after" questionnaire. There were no dependencies found either between the knowledge of the definition of tropisms and the ability to use it, nor between the knowledge of the mechanism of reaction, and the skillful use of it. For example, the correct definition of the process (Q3) by the same student was independent of the correct answer to the question for identifying organs that react to a phototropic/gravitropic stimuli positively or negatively (Q6). Knowledge of the mechanism of reaction (Q4) was not dependent on the correct answer to the question on the physiological importance of gravitropism (Q9), and the correct description of the mechanism of phototropism (Q4) did not affect the correct selection of the drawing demonstrating the bending of a shoot as a result of applying an agar block saturated with auxin (Q7). Also, the correct description by respondents of the mechanism of gravitropism (Q5) was independent of the correct choice of the drawing presenting the bending of the root, as a result of applying an agar block saturated with auxin (Q7).

In the content analysis of the questionnaire, the first question (Q1, Appendix B) was open, and quite complex. Students were supposed to list and shortly describe the types of movements of plants they know. Although we received only 6% (pre-test) and 7% (post-test) fully correct answers (Q1, Table 2), the observed increase was statistically insignificant. However, we have to admit that over 80% of remaining answers were not considered wrong, only incomplete, as they contained single correct information, e.g., noticing the division of movements due to the cause of movement, and almost omitting the division due to its mechanism.

In question 2 (Q2, Appendix B), checking whether students were able to differentiate phototropism, photonastias, and phototaxies, 41% of respondents on the pre-test and 25% on the post-test stated that these concepts mean the same or could not indicate a specific difference. Over 50% (on both pre and post-test) answered only the correct part, giving at least one feature that differs from the concept. The statistically significant increase in correct, almost complete answers was observed between pre-test and post-test (4% and 26%, respectively; Q2, Table 2), however no answer was complete. It was often said that phototropism is movement, but without the growth of the plant. Another example of an incorrect answer is the statement that "photonastia only occurs in lower organisms".

In the third question (Q3, Appendix B) students were expected to answer in their own words what is tropism. The pre-test answers, which did not link tropisms with the growth movement at all, accounted for 30%, and 59% of the respondents noticed that it was a reaction to an external stimulus. Among these 59%, 11% made the connection between reaction to a stimulus and plant growth. Also, 7% of students reported that this reaction is dependent on the direction of the stimulus, and 4% mentioned that it may be adapting the plant to dynamic changes in the environment. On the post-test, no answer was fully correct, and 16% of the responders gave a satisfactorily good answer, containing the information that it is a response to a stimulus, depending on its direction. Additionally, 5% of the answers were completely wrong, and 79% only contained the information that it was "a response to stimulus". This time on the post-test, no one mentioned that it is an adaptation of the plant to dynamic changes in the environment. The total percentage of correct answers on pre-test and post-test were 11% and 16%, respectively (Q3, Table 2). The observed difference was, however, statistically insignificant. In question 4 (Q4, Appendix B), students were asked to describe the stages of shoot response to the directional effect of light. On the pre-test, almost half of the respondents gave a completely wrong answer, not indicating the place of stimulus perception or not noticing the presence of the receptor for blue light and/or the place of auxin in this process. Of the answers, 50% mentioned at least one of the above or limited the reaction only to the leaf, bypassing the shoot, 6% gave a relatively correct answer, but lacked key information like loosening the structure of microfibrils due to the accumulation of auxins. Therefore, no answer was considered completely correct. On the post-test, 80% of the replies were imprecise, containing some of the correct information, and 14% of the respondents gave almost all the required information, taking into account the role of calcium ions and auxins. Every 10th respondent gave an incorrect answer, confusing the place of perception and not including hormones in the process. The increase in percentage of correct answers for this question between pre-test and post-test was 8%, from 6% on pre-test to 14% on the post-test. The observed change was, however, statistically insignificant (Q4, Table 2).

In question 5 (Q5, Appendix B), students were asked to describe the stages of a root's response to gravity. We observed a statistically significant increase in the percentage of correct answers between pre-test and post-test (6% and 22%, respectively; Q5, Table 2). On the post-test, over 60% of the respondents provided residual information on the question, and 16% of the answers were completely wrong, not containing any information about the role of amyloplasts, calcium ions, or auxins in this process. Only 3% of the answers were complete, and every fifth respondent provided correct information with minor errors, but 22% of all given answers were correct (including places of perception, role of the calcium ions, amyloplasts, auxins, etc.). The correct answer is provided in appendix B, and the difference in the amount of correct answers before and after the course to that question was statistically significant (Table 2).

Question 6 (Q6, Appendix B) was multiple choice. Students were supposed to mark the organs that react to a phototropic stimulus: leaf, shoot, and root, and those that react to gravitropic stimulus: shoot and root. These five items were correctly marked in 35% of the answers on the pre-test and in 57% of the answers on the post-test, indicating a significant difference on two points of measurement (Q6, Table 2). On the pre-test, the majority of students, 65%, indicated that only the shoot or leaf reacts to light and the roots react to gravity, which was only partially correct. A total of 26% of the answers could be considered incomplete, but correct, where some roots were forgotten, being classified as showing reactions to light stimulus. Only 9% of respondents gave a complete answer. On the post-test, 14% of the answers were assessed as good and complete answers, and 43% of answers contained almost correct information, as the reaction of the root to the phototropic stimulus was omitted. The same number of respondents gave a partially good answer, limiting the reaction to the given processes to the root in the case of gravitropism and the momentum regarding phototropism. No answer was completely wrong.

Question 7 (Q7, Appendix B) contained a description of an experiment, but in order to answer this question correctly, students had to understand the content. On the pre-test, 15% of answers were correct (Q7, Table 2), 67% of the answers were incorrect, and 18% of students did not made any attempt to answer. Most often, drawings I and II were chosen, and the attempt to justify them drew a situation opposite to that which was occurring in reality. Some 18% chose at least the correct drawing number, but did not justify their choice, 11% chose the correct drawing and indicated the participation of auxins in the process, but did not notice their different impact on the growth of momentum and root or their determination was incorrect, and 4% of the answers were complete. On the post-test, almost half were wrong due to the selection of incorrect figures (I and II), justifying it inaccurate with respect to reality. Additionally, 16% of the respondents gave a partially correct answer, choosing the correct figure (III), but not justifying the choice; 21% of the answers were correct, but pointing only to the role of auxins in the phenomenon; and 14% of complete and correct responses also contained information on the auxin's varying impact on momentum and root. However, in total, 35% of answers were considered correct and the observed improvement was statistically significant (Q7, Table 2).

In question 8 (Q8, Appendix B) students were supposed to explain the differences in appearance between trees growing in the forest or in the field. On the pre-test, the effect of phototropism on the plant habit in the meadow and in the forest was correctly described by 5% of respondents, pointing to positive phototropism of momentum and environmental difference, and 11% indicated environmental differences and justified them well, but ignored phototropism as the reason for this type of plant. Both types of these answers (16% in total) were, however, considered correct (Q8, Table 2). A total of 67% of responses indicated that the plants compete with each other for access to light, but was not related to tropics, and 17% were incorrect answers, stating, among others, that light inhibits the development of the entire plant, which is why the plants in the meadow are lower. On the post-test, the correct description of the impact of phototropism on the habit of the plant in the forest and meadow was given by 10% of respondents, indicating environmental differences together with justification. A further 14% gave a correct and complete answer, indicating also positive phototropism of the momentum. In total, 24% of responses were considered correct; however, the observed difference in the fraction of correct answers between pre- and post-test remained statistically insignificant (Q8,

Table 2). Over half of the students pointed to plant competition for light, but in isolation from the trophy context. Every fifth respondent answered wrongly.

In question 9 (Q9, Appendix B), students were asked to describe the physiological importance of gravitropism. On the pre-test, half of the given answers were wrong and students claimed that the aim of gravitropism is to primarily keep the plant in the ground. Also, 54% of the answers, which were only partially correct, contained information that the plant gained access to water and mineral salts due to gravitropism. The 3% of correct but incomplete answers pointed to the role of gravitropism in the direction of the growth of above-ground parts of the plant (shoot) up and underground (roots) down. Only 2% of answers, which were complete, also explained the role of gravitropism in the germinating plant. In total, 5% of pre-test answers were considered correct. On the post-test, every fourth respondent gave an incorrect answer, again pointing out that the general benefit for a plant reacting to gravity is keeping it in the ground. More than half of the students mentioned increased access to water and mineral salts, only 21% added that it is important in directing the growth of aboveground parts of the plant (shoot) up and underground (roots) down, and indicated that this is an important phenomenon for the germinating plant. The difference between correct answers given by students before and after the plant physiology course was statistically significant (Q9, Table 2).

3.3. Alternative Conceptions

Based on the analysis of the questionnaire conducted before the plant physiology course, eight main alternative conceptions were identified. We categorized them into four groups: (1) division of plant movements, (2) plant tropism movement definition, (3) the mechanism of plant tropisms, and (4) the physiological importance of plant tropisms. The percentage share of each ranged from 15.5% to 65%. The alternative conception that phototropism is only a response (+) of the shoot to a light stimulus, and gravitropism a response (+) of the root to the stimulus of gravity, was held by 65% of the respondents. Of the students, 47% said that gravitropism embeds the plant in the soil, and 41% that phototaxis, photonasty, and phototropism were synonymous terms, and the analysis of the questionnaire raised doubts about whether students understood what the word "synonymous" meant. More than 30% of respondents wrote that auxin works the same on tropic reactions of the shoot and root, or that it inhibits the elongation of the shoot and accelerates the elongation of the root. Up to 30% of the respondents associated the phototropic reaction as only a reaction to sunlight (Table 3).

3.4. Conceptions Identified after the Plant Physiology Course

A total of 18 alternative conceptions were identified after the course. They were categorized, as before, into four groups. An additional category, "other," was also formed, for alternative conceptions which did not suit those previously created. As many as 6 of the 18 alternative conceptions were ones that were also diagnosed in the first stage of the study. These conceptions occurred in a smaller number, but they still accounted for a significant percentage of answers (25–43%) (Table 3).

The conceptions that a phototropic reaction is a reaction only to sunlight, and that photonasty concerns only lower organisms, were not repeated. After the second stage of the study, the alternative conceptions that were identified were mostly categorized as relating to the mechanism of movement. Among them, the two most represented were: 12% of students wrote that shoot apex domination is at the basis of phototropism, whereas 10% of students wrote that the location of perception of a phototropic stimulus is internodes. Other errors identified in this category were marginally represented. A high percentage of new errors included the division of plant movements only into phototropism and gravitropism. This error occurred in 30% of the surveyed students. Furthermore, 25% of the respondents defined tropism in a very simplified way, presenting tropism as movement (tropism = movement).

4. Discussion

4.1. Analysis of Students' Answers

Problems with students understanding the terms and mechanisms related to the movement of plants have been noted by us for several years. They were recognized, among others, based on the interpretation of the experiments conducted by the students or on answers given during exams. The analysis of the study questionnaires suggests that students had shaped their personal knowledge about plant movements incorrectly at earlier stages of their education. Furthermore, this knowledge does not connect to other aspects of plant physiology such as plant growth, hormone regulation, and the adaptation of plants to changes in environmental conditions. The majority of students were not able to list the types of plant movement (only 7% of them listed them properly after the teaching cycle; Q1, Table 2) or to describe the stages of plant reaction on stimulus (Q4, Q5, Table 2). Regarding the diagnosed misconceptions, the majority were caused by oversimplification, lack of sufficient content knowledge, or an anthropomorphic view of tropism. The conceptions such as: "plant movements are divided into phototropism and gravitropism" or "tropism is movement of a plant" or "phototropism is a positive response of the shoot to a light stimulus" are examples of oversimplifications in how students think about these processes. Conceptions such as: "phototropism is a chloroplast movement" or "auxin synthesizes the cell" or "auxin stimulates cell division" indicates gaps in students' personal knowledge. Conceptions such as: "gravitropism is a positive response of the root into the ground caused by searching the water", or "phototropism is the positive reaction of shoot to the light due to grasping more source of energy" indicates that students' view of tropism is anthropomorphic. A similar observation, and the same alternative conception (connection to anthropomorphic view of tropism), was reported by Lin [33]. Oversimplifications are also indicated in the literature as a possible source of alternative conceptions [45,46]. Whereas oversimplification and lack of sufficient knowledge is quite understandable and a common source of alternative conceptions, the findings seem to strengthen the view that plants are of no immediate importance to students [47,48]. We experience what Wandersee and Schussler referred to "plant blindness" [29]. We are able to find plant blindness as a possible explanation partially because of an anthropomorphic (and even animistic) view detected among students, but also due to detected difficulties in perceiving plants as organisms that can move and react to stimuli but differently than animals. Students when explaining plants' tropism were using terms that are typical for animals, giving for examples terms such as: "bending," "turning," or "searching" as examples and connecting them with words such as "want" and "will" assuming that plants are like animals but a bit different. What we could also observe at the classes with students when they are asked about general concepts such as movement or response to stimuli they provide answers with examples from the animal kingdom even in the plant physiology course.

Our Hypothesis 1 stated that after the plant physiology course, students would gain some scientific knowledge such that when explaining phenomena about plant tropism and they would not use previous misconceptions or common-sense knowledge. Overall, students did gain some knowledge about plant tropism. In general, on five out of nine, items the results showed a significant difference between pre- and post-test (Table 2). The question is whether the amount of correct answers and the number of students who retained the knowledge are satisfactory? However, at the same time, we report that the number of alternative conceptions was higher after the course, and they were caused by the same major phenomena: oversimplification and anthropomorphic view of plant and of tropism. That situation seems to neither support nor overthrow our hypothesis, and clearly indicates that the process of constructing scientific knowledge on plant tropisms needs further research.

4.2. Do We Know What We Are Doing? Analysis of Teacher Answers

Academic teachers among the investigated group tended to perceive plant tropism as easy content for students. Our Hypothesis 2 stated that teachers are able to predict students' achievements on learning about plant tropism and would indicate problems as well as possible solutions for dealing with student problems in understanding plant tropism. This hypothesis was also only partially supported. Teachers showed a tendency to be optimistic in their judgements. Half of them (Table 1) stated that the majority of students would be able to properly explain the phenomena after the classes. However, in the questionnaires after the course, only 57% of students could indicate organs involved in plant tropism (Q6, Table 2), and just 35% could explain different responses of shoots and roots to exposure to hormones (Q7, Table 2). It is worth mentioning that these two questions were the ones answered in with the highest correct percentage rate. The remaining questions were answered properly by 26% or less of students (Table 2).

If these errors are not identified and eliminated by the teacher, they may have an adverse effect on understanding the taught material. However, the questionnaire that we conducted among academic teachers indicates that teachers do not have an awareness of the problem. They believe that most of the interpretation problems encountered by students is due to the lack of sufficient substantive preparation; that it is the failure of the students themselves. Academic teachers in the studied group have experience in conducting classes in plant physiology. They often correctly pointed out the causes of problems with the understanding of investigated phenomena. For example, they (indirectly) pointed to an anthropomorphic perception of tropisms, indicating that students do not combine phototropism and gravitropism with plant growth movements, and perceive them as "bending organs" toward the stimulus or stimulus.

There was no question directly asking academic teachers about their self-reflection of their work or methods they use to teach, although some questions were formulated as open, and could be treated as an indirect method of asking about their reflection. Opinions of the teaching staff were considerably consistent with the gathered data from research tool 2 in terms of the students' knowledge growth after the conducted classes, but cannot be considered relevant in explaining the growth in misconceptions. The observed results inspired us to formulate new areas to look for explanations that are connected to teaching and/or learning methods used at the university. Unawareness of student difficulties by teachers could reflect on the phenomenon called the "curse of knowledge," a term proposed by Camerer et al. [49]. We adopted it after Birch and Bloom [50] and Birch and Bernstein [51], and, "use it to refer to the tendency to be biased by one's own current knowledge state when trying to appreciate a more naive perspective, whether that more naive perspective is one's own earlier perspective (as in the hindsight bias) or someone else's perspective". It can be applied to a situation where teachers have difficulty teaching novices because they cannot put themselves in the position of the student. It seems that academics are now in a position where they should be supported with a workshop on teaching, didactics, and pedagogy. Such workshops would be advisable to help visualize the importance of the problem. It seems that such activities for academics involved in teaching could be "awareness workshops" where they could become familiar not only with some methods of teaching, but also with the theory of constructivism, new research about neurobiological aspects of how the brain works while learning, and the ways in which people learn. This clearly indicates the gaps in teaching when the teachers are thinking "our students do not study hard enough".

The need for reflection among academics is also necessary; they should be aware of the process of knowledge development, construction, the types of knowledge, and the role of alternative conceptions in this process. Reflection seems to be a first step in developing and working on their own pedagogical content knowledge. Lin et al. wrote about kinds of metacognition required by the teaching profession [52]. They described adaptive metacognition, which involves change to oneself and to one's environment in response to a wide range of classroom social and instructional variability, and highlights the role of critical event-based instruction in the teaching process. They claimed that goal-oriented strategy is required, and that clarifying the potential goals is the initial critical step in adaptive metacognition. Then, they stressed the role of social factors, collaboration, and reflection, particularly in the sense of finding common goals between student and teacher. Finally, they concluded that "metacognitive learning tries to integrate both specific cognitive skills (e.g., making decisions for specific problem situations) and general adaptive and social abilities (e.g., reflecting deeply on what types of information are needed or useful to make these types of decisions)". All these should help teachers develop proactive metacognitive capabilities. In the sense described in this paper, a gap between students' problems with learning this topic and teacher perception of such problems raises the issue of the importance of such skills among the investigated group.

Another issue is the way in which teachers perceive active learning. They quite often assumed that active teaching methods (such as students carrying out experiments by following given instruction) is the same as active learning, since the students are physically engaged in the process. While in active learning, student engagement is the starting point, the next should be reflection on one's own understanding of the content [46]. Teachers' understanding of active learning is that it is limited to physical engagement, which leads to deceptive active learning as described by, for example, Kane [53]. At the same time, it provides an argument for introducing additional pedagogical workshops for academic teachers in order to help them develop personal resources of pedagogical content knowledge.

4.3. Where Is the Problem?

A phenomenon such as plant growth is an example that, in order to be fully understood and pictured, this phenomenon must be understood on three levels. The student who is expected to learn about plant growth must be fluent in switching between three levels of representations: (1) the macroscopic level, (2) the sub-microscopic level, and (3) the symbolic level. It is hard to switch between these levels of representation, and it has to be stressed here that a full understanding of many phenomena involves the ability to make connections and move fluently between them. Wu and Shah proved that in chemistry education some students' conceptual errors were "due to difficulties in operating on the internal and external visuospatial representations" [54]. On the other hand, Harrison and Treagust, on a year-long study of student understanding in chemistry found that "students who were encouraged to use 'multiple particle models' displayed more scientific understanding of particles and their interactions than students who concentrated on a 'correct' or 'best analogical model'" [55]. Their results also indicated that when analogical models are presented on a regular basis and students are given more opportunities to explore model meaning and use, their understanding of abstract concepts is enhanced. It is particularly important that students use many models and operate on many levels of representation, since understanding connections among biological systems at the macro and micro levels is crucial to achieving biological literacy.

Our research confirms the findings of recalled developmental and social theories that the knowledge of a student about plant movement is a result of certain sequences of simplifications, over-generalizations, and the use of outdated data [26]. One-quarter of the students said that the physiological effect of gravitropism is keeping the plant in the soil, rooting it, and providing nutrition. Moreover, we also question whether students understood that tropism is a growth-movement response of a plant. The way plants move can appear so eerily human that in the late 1700s and early 1800s, Dr. Erasmus Darwin, Charles Darwin's grandfather, predicted that plants have multiple brains that can communicate with muscles to tell plants how to grow [56]. Returning to the essence of the problem, students are unaware of movement in this phenomenon; they do not see growth, so they do not define tropism as a growth-movement reaction. Indeed, the observation of movement in plants is so specific that, in this case, a shift occurs generally on a smaller scale and this process is characterized by different dynamics than the movement of animals. Ignoring that the students may have neglected their responsibilities and not learned the required definition, they cannot interpret the phenomenon. When one understands, then one can explain: Why is that so? What explains such events? How does this work? How can we prove it? Our students cannot.

The study demonstrates that the students' knowledge is fragmented, and particular concepts such as hormones, response to stimuli and tropism, are not really linked. Students had enormous problems with explaining this phenomenon as a whole, starting from a chemical molecule (auxin) and ending with the plant response. By that we can conclude that their personal knowledge is unstructured, meaning there are no complex thought constructs in it. Compartmentalization of concepts is a common problem in biology learning, which occurs when concepts are studied with little integration. Students may be able to correctly state the individual events but often do not understand the relationship between them [9,57–59]. Plant growth and development integrate hundreds of complex events (behavioral, biochemical, and molecular) that result in plant sensitivity to environmental changes. Of course, students have some information, they know some terms, but they are not ready to systematize the information, build their knowledge, and think in terms of cause and effect. In the study it can be seen that simply providing information to already existing knowledge does not change existing thought constructs in the recipients of the educational process—a phenomenon that was first noticed by Osborne and Wittrock [60]. When children come to school they are not like a *tabula rasa*; they have their own pre-knowledge, and as many researchers postulate, teachers need to familiarize themselves with it [61–63].

In the process of teaching, neither prior knowledge nor misconceptions can be avoided or ignored or removed. Both should be identified, confronted in the process of active teaching/learning, and transferred to scientific knowledge [64]. The prior knowledge and misconceptions are the resources for building more accurate, sophisticated scientific understanding. Therefore, the misconceptions should be treated as the foundation of future scientific knowledge. In the process of formal education, the misconceptions should be efficiently eliminated through the process of learning. Therefore, these conceptions are not wrong ideas to be fixed but rather common ways that pupils and students think, which can be important starting points for teaching and learning [65]. In the process of engaging learners in active learning and teacher feedback, there is a chance of reconstructing their conceptions into evidence-based scientific ideas [66].

Why then are naive conceptions so difficult to change? One possible answer is that they are created over a long period of time, or they represent the first knowledge of children, so they are deeply rooted as ideas prior to teaching. Naive knowledge is often based on information passed by parents, media, and teachers when they try to answer children's questions. It is inevitable. The teachers' awareness of students' pre-teaching conceptions can contribute to the improvement in teaching. We know that at a very early stage of development, people develop their own preconceptions more successfully than teaching and learning when we integrate alternative models through discussion and experiments such that students can experience that the new scientific model is more accurate and effective. All school-made misconceptions should be reflected, compared with scientific explanation, and through experiment, be shown as inaccurate. The teacher may challenge the misconceptions by models, experiments, and problem-solving teaching/learning methods [67]. Misconceptions are important sources of insight into the student thinking process, which can guide the teacher in the process of learning. Mayer and Thompson showed that what we teach students and what they actually learn can be quite different [2,68]. In the process of teaching, educators should identify the misconceptions and start the process of learning by letting students acquire new language through experience, discussion, and critical thinking [69,70].

In case of possessing fragmented knowledge, students are unable to verify alternative conceptions through the course, but, as our study showed, they can build new knowledge on the basis of the old conceptions. Increasing the number of alternative conceptions may attest to the fact that students are familiar with the new information and that they looked at the phenomenon in a new way; however, this process led to the formation of new erroneous beliefs and shows the lack of a sound structure to their knowledge. If we do nothing, the distorted definition of terms associated with plant movement, which is in the mind of the students and was formed along with the personal knowledge constructed by them (it is their immanent part), will be a barrier for defining and understanding the discussed terms academically, which is equivalent to the absence of a satisfactory educational effect.

As Sever et al. [70] stated, teaching science is generally based on concepts, thus experiments and observations should be an important method widely used in classrooms so that students can visualize these concepts in their minds. However, as Mayer postulated, active teaching does not necessarily mean active learning [2]. Our study supports this thesis. Although carrying out experiments is considered to be an active way of teaching, students are not always led to conceptual change about plants as living organisms that move. One way of solving this problem would be introducing into the teaching and learning process three steps recommended by Mayer, which are: (1) problem-solving rules with some freedom for students to allow them to become cognitively active in the process of sense making, (2) teaching conservation strategies, and (3) teaching programming concepts [2]. Possibly, one of the problems is that the classes are carried out in an artificial laboratory environment. The process looks more like observation than a real experiment. Students do not introduce any hypothesis or sophisticated cognitive activity to the laboratory exercises; they just follow the instructions given by protocol. Thus, the first suggestion given by Mayer is strongly recommended in order to allow this exercise to be more inquiry-based [2]. Sever et al. [70] showed in their research, that there was no significant difference in the effectiveness of the demonstration or videotaped experimental format. However, Sever et al. did not study the effectiveness of learning by conducting experiments that may activate students in the cognitive process or by introducing problem-based teaching.

Appreciating alternative conceptions as personal theories and elements of personal knowledge in students of biology is crucial for its success. According to the theory of schemes, what we understand is dependent on what we already know [61]. Considering that the previous knowledge of a student creates the conditions necessary to construct reliable knowledge, the diagnosis of alternative conceptions is a tool that allows a teacher to learn about students' previous knowledge.

Author Contributions: Conceptualization, E.S.-N. and E.R.; Data curation, E.S.-N., E.R., J.J. and M.A.; Formal analysis, E.R. and J.J.; Investigation, E.S.-N.; Methodology, E.S.-N. and E.R.; Project administration, E.S.-N. and Z.C.; Resources, E.R. and M.A.; Validation, E.R. and J.J.; Writing—original draft, E.S.-N. and E.R.; Writing—review & editing, E.S.-N., E.R. and Z.C.

Funding: This research received no external funding.

Acknowledgments: The authors of the article would like to thank to Justin Dillon for his suggestions and kind review of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Sex	Female	Male
Age	Years of teaching students: ☐ 0–5 years, ☐ 6–10 years, ☐ 11–15 years, ☐ 16–20 years, ☐ 21–25 years	Job position: ☐ PhD student, technical assistant, ☐ assistant professor, ☐ senior lecturer, ☐ professor

I would like to ask you to fill out the questionnaire below, which is an element of my research for a Bachelor thesis. The topic of the questionnaire is the issue of phototropism and geotropism. The questionnaire is anonymous and filling it out will take no more than 10 min. Thank you for your time.

* Question required

1. Were students taught the definitions and mechanisms of phototropism and geotropism during your course?

Please fill out the rest of the questionnaire only if you answered YES to the above question.

YES
NO

2. In what form did the students become familiar (acquainted) with the process of phototropism?

You can choose more than one answer.

- Theoretical discussion
- Observation of all phases during an experiment conducted by a teacher.

- Observation of the end phase of the process in an experiment conducted by a teacher.
- Observation of all phases during an experiment conducted by a student.
- Observation of the end phase of the process in an experiment conducted by a student.
- Multimedia presentation in the form of a film or animation
- Others

Please provide details about your classes: time, duration, and topic.

3. What portion of the students could independently and correctly explain the process of phototropism, after learning the subject in your classes?

- The vast majority of students understood the phenomena of phototropism
- The majority of students could explain in their own words the phenomena of phototropism
- Half of the students understood the phenomena of phototropism, but many of them did not
- Less than half of students understood the phenomena, and students had difficulties with understanding the phenomena of phototropism.

4. In what form did students learn the process of geotropism?

You can choose more than one answer.

- Theoretical discussion
- Observation of all phases during an experiment conducted by a teacher.
- Observation of the end phase of the process in an experiment conducted by a teacher.
- Observation of all phases during an experiment conducted by a student.
- Observation of the end phase of the process in an experiment conducted by a student.
- Multimedia presentation in a form of a film or an animation
- Others:

5. What portion of the students could independently and correctly explain the process of geotropism after becoming acquainted with the subject in your classes?

- The vast majority of students understood the phenomena of geotropism
- The majority of students were able to explain in their own words the phenomena of geotropism
- Half of the students understood the phenomena of geotropism, but many of them did not
- Less than half of students understood the phenomena, and students had difficulties with understanding the phenomena of geotropism

6. What kinds of mistakes were the most common among students concerning the phenomena of phototropism and geotropism?
7. In your opinion, what is the cause of the students' mistakes?

- Poor mastering of the topic by students
- Lack of the full concentration of students
- Difficulty in understanding of the process, which lasts for a few days, and the full observation of it is impeded.
- Others:

8. In your opinion, what other methods would be useful and helpful in teaching about tropism?

Appendix B

Sex	Female	Male	
Age	≤22 years old	23–45 years old	>45 years old
Passed matriculation in biology	basic	expanded	Passed subject other then biology

PLEASE RESPOND TO THE QUESTIONS STRICTLY IN ORDER OF APPEARANCE.

Are you acquainted with the term "plant movements"?

a. No, I have never heard of it
b. Yes, I have heard of it at an earlier stage of education
c. Yes, I learned about it through plant physiology class

How were you acquainted with the term "plant movements"? (You are able to choose more than one answer)

d. Lecture
e. By performing an experiment*
f. Experiment demonstration*
g. Film or animation about plant tropism
h. Other (write an example) . . . .

* If you remember, please describe this experiment . . . .

1. Q (Question): List the types of movements of plants known to you.

A (Answer): A full answer (The criteria for assessing the correctness of the answers contained in the questionnaire. The presented answers are model and ideal. Correct answers were those which were right substantially and included the answer to the posed question.) was one that contained the following elements: a. division of movements due to the mechanism of movement, i.e.: turgor movements, growth, and growth-turgor movements, and b. division of movements in terms of the cause of the movement (stimulus), namely: taxes, nastic movements, and tropisms.

2. Q: Are phototropism, photonasty, and phototaxis synonymous concepts? Justify.

A: Phototropism is a growth movement, the plant's response to light, dependent on the direction of the stimulus; photonasty is the plant's response to light, independent of the direction of the stimulus and its intensity; phototaxis is a locomotive movement caused by light, the direction of movement depends on the directional gradient of the stimulus.

3. Q: Define the concept tropisms.

A: Tropisms—these are a kind of growth movements caused by an external stimulus, whose direction of action depends on adapting the plant to the dynamic changes in the environment.

4. Q: Describe the stages of a shoot response to the directional effect of light (considering the place of the perception of the stimulus, the direction of the bend, and the role of hormones in the process).

A: A full answer was one that contained the following: the place of perception of the stimulus is the vertex/cone of growth, and reception of the stimulus is by the blue light receptor. The effect: as a result of unilateral illumination, electrical potential appears between the illuminated and shaded side of the shoot, where the illuminated side becomes electronegative, the change in the potential between the protoplasma and the external environment of the cell is a signal for the transport of auxins from the location of their synthesis (apex of the shoot) to the shaded side of the shoot. The accumulation of auxins on the shaded side of the shoot causes a loosening in the structures of the microfibrils of cell walls, with all the inherent consequences (acidic growth theory), which cause stronger expanding and elongating growth on that side of the shoot, and consequently directional bending toward the working stimulus.

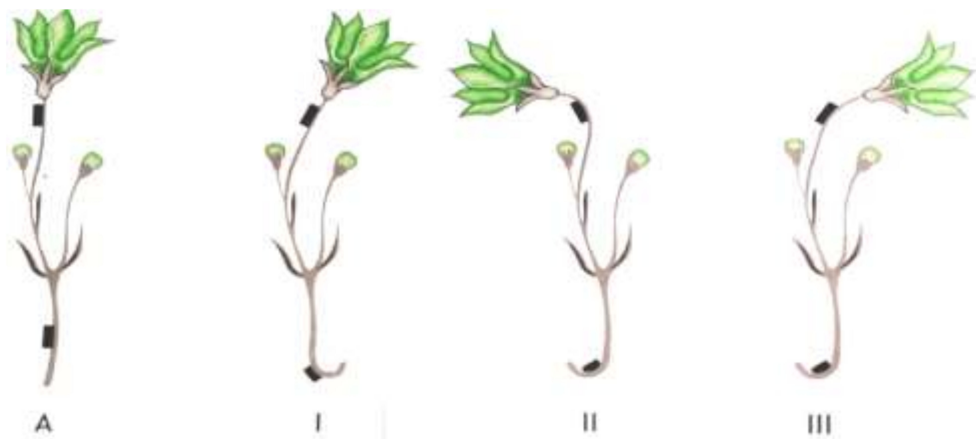
5. Q: Describe the stages of a root response to the gravity (considering the place of the perception of the stimulus, the direction of the bend and the role of hormones in the process).

A: Places of perception of the stimulus is the root cap adjacent to the apex of growth, reception of the stimulus is through mechanoreceptors of the endoplasmic reticulum pressed by starch statoliths of amyloplasts, and efflux of calcium ion from cisternae of endoplasmic reticulum. The calcium signal is a signal for the transport of auxins from the place of their synthesis/apex of the shoot to the place in which the gravitropic reaction appears, to the elongation sphere of the root. In a root placed horizontally, a large accumulation of auxins occurs at its bottom side. This inhibits elongation growth, whereas a smaller concentration of auxins on the top side enables growth, and as a result, directional bending of the root toward the acting stimulus occurs.

6. Q: Underline the correct answers (you can select more than one correct answer).

The following react to a phototropic stimulus: **A:** a. leaf, b. shoot, c. root, d. I don't know.
Q: The following react to gravitropic stimulus: **A:** a. leaf, b. shoot, c. root, d. I don't know.
The full answer was: the following react to a phototropic stimulus: leaf, shoot, root; the following react to a gravitropic stimulus: shoot and root.

7. Q: Agar blocks were applied to one side of the shoot and root of a several-day-old seedling of a certain plant that contained the same concentration of auxins within the physiological range (the figure shows the location of the blocks), and then the seedlings were placed in the dark. The three consecutive drawings show the potential effect observed after 24 h, assuming a typical course of the experiment.



Mark the drawing that correctly demonstrates the direction of the bending of the shoot and root and for a justification of the choice, auxins from agar blocks accelerate: 1) elongating the cells of the shoot to which the block is attached, or 2) inhibition of elongation growth of the cells of the root to which the block is attached.

A: III

8. Q: Trees growing in a forest are taller, though less branched than the trees of the same species growing in a field (free space, e.g., a meadow). Explain the observed phenomenon in light of your knowledge of the movements of plants.

A: The full answer was considered to be that in a meadow, light determines phototropic reaction both of the main shoot and side shoots. In a thick forest, above all, the main shoot takes in the light stimulus (other parts of the plant can be shaded) indicating growth and movement reactions in its direction.

9. Q: Provide the physiological importance of gravitropism.

A: In the responses, above all, information was required stating that the gravitational field is essential for spatial orientation of plants and that this reaction is an important component of the physiological processes, e.g., germination.

Thank you very much for your attention

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