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# **The impact of inquiry-based learning in a botanical garden on conceptual change in biology**

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## **Abstract**

The results of many past studies indicate that inquiry-based learning has a considerable impact on the conceptual understanding of students. There are, however, a limited number of studies that have examined the long-term effects of inquiry-based learning on conceptual understanding among students. The purpose of this study is to determine whether an inquiry-based learning environment in botanical garden improves the conceptual understanding of biological concepts in students over the long term. Seventy-nine 9th graders participated in inquiry-based learning biology lessons in a botanical garden, while seventy-two 9th graders participated in traditional biology lessons at school. The results showed that inquiry-based learning in a botanical garden has a positive impact on the correct scientific knowledge compared to traditional teaching at school. In addition, the learning activities in a botanical garden help students to overcome the typical resistant misconceptions related to photosynthesis and respiration. Even though the number of the correct scientific answers from the students in the experimental group slightly decreased between the post-test and delayed post-test, they still outperformed the students in the regular classroom three months later. Eventually, specially designed interventions could help in the implementation of conceptual change and to alter previous misconceptions to scientifically correct concepts.

Keywords: secondary/high school; outdoor science; biology education

## **Introduction**

Photosynthesis and respiration in plants are core processes in nature conditioning the balance of oxygen and carbon dioxide and transferring energy to food chains; however, only a small percentage of students are familiar with the fundamentals of photosynthesis and plant respiration or the benefits of these processes for the environment (Ahopelto et al., 2011; Aleknavičiūtė et al., 2023; Mikkilä-Erdmann, 2001). It is difficult for students to understand how photosynthesis and respiration work together and how solar energy from the sun's rays is converted into the chemical energy that is then used by animals and bacteria. Understanding these concepts is crucial, for example, for people to understand the consequences of extreme levels of carbon dioxide in the atmosphere. Previous research has shown the various misconceptions related to photosynthesis and respiration demonstrated by different age groups (Brown & Schwartz, 2009; Yip, 1998). It is also known that conventional teaching that does not effectively support students' active knowledge construction is not effective in fostering conceptual change (Stofflett & Stoddart, 1994).

The purpose of this study was to examine the effectiveness of inquiry-based learning intervention on the concepts of photosynthesis and respiration in the setting of a botanical garden. The intervention was designed based on the prior literature regarding the learning challenges related to these topics. The aim was to analyse how the intervention managed to enhance proper scientific understanding and help students to overcome their misconceptions.

### ***Intervention studies on photosynthesis and respiration***

Photosynthesis and respiration are among the most widely studied biological concepts in conceptual change research; based on a recent meta-analysis, the most effective interventions in supporting the learning of these concepts utilised refutational texts (Aleknavičiūtė et al., 2023). Refutational text refers to a type of argumentative writing that aims to challenge or refute a particular misconception.

It is a form of persuasive writing in which the author presents counterarguments or contradictory evidence to weaken or undermine the validity of the readers' misconceptions (Mikkilä-Erdmann, 2001). Refutational texts have been widely and successfully used in supporting the learning of the conceptual understanding of photosynthesis and/or respiration (Al Khawaldeh & Al Olaimat, 2010; Alparslan et al., 2003; Mikkilä-Erdmann, 2001; Södervik et al., 2015). Based on the meta-analysis (Aleknavičiūtė et al., 2023), another effective intervention type in supporting the learning of photosynthesis and/or respiration utilised a hands-on approach (Lumpe & Staver, 1995; Sert Çibik et al., 2008). Refutation and hands-on activities were also applied in the intervention used in the present study.

The majority of past intervention studies have used pretest and immediate post-test design (Aleknavičiūtė et al., 2023) in evaluating the impact of interventions. Even though it is known that misconceptions can be extremely stable and learners often return to their previous misconceptions after some time (Happs, 1985; Hewson & Thorley, 1989), most prior intervention studies did not control the long-term effects of the interventions with delayed post-tests (Aleknavičiūtė et al., 2023); this would be important on controlling the stability of the conceptual change effects of interventions (Garcia I Grau et al., 2021). The few studies that included a delayed post-test have shown that usually the intervention impact on conceptual understanding slightly decreases (Ahopelto et al., 2011) or remains stable (Al Khawaldeh, 2007).

### ***Inquiry-based learning in supporting learning***

An inquiry-based approach to learning involves active, student-centred and self-directed learning in which students participate actively in the learning process (Spronken-Smith & Walker, 2010). Some researchers have claimed that direct teaching results in better learning gains than inquiry-based learning (Zhang et al., 2022), but a recent comprehensive review by de Jong et al. (2023) showed that the inquiry approach could be beneficial, especially when students' independent activities are supplemented with direct instruction and high-level teacher support. Kidman and Casinader (2017)

summarised the findings from various domains in science learning and concluded that inquiry-based learning promotes a deep understanding of scientific concepts, cultivates critical thinking skills and fosters a lifelong fascination with nature. Other researchers have proposed that inquiry-based learning encourages active engagement, exploration and investigation by placing students at the centre of the learning process (Onyema et al., 2019). An important benefit of inquiry-based learning is that it stimulates students' curiosity and sense of wonder. By asking questions, generating hypotheses and seeking answers through hands-on experience, students are encouraged to go beyond simply memorising facts and theories (Miller et al., 2010).

Students can learn crucial scientific skills such as observation, experimentation, data analysis and interpretation through inquiry-based learning. Through experimentation, data collection and analysis and drawing conclusions based on evidence, they can learn how to design and conduct experiments (De Jong et al., 2023; Sutiani, 2021). These skills are fundamental to the scientific method and are transferable to a wide variety of real-world contexts (Duran & Dökme, 2016). By exploring the principles and mechanisms behind natural phenomena rather than simply memorising facts, students are given the opportunity to develop a deeper understanding of the subject matter (Akaygun & Adadan, 2021; Sandoval & Reiser, 2004).

Inquiry-based learning can also support conceptual change (Mataka & Taibu, 2020; Şimşek & Kabapınar, 2010) even after a short intervention (Van der Graaf, 2020). It is important to note that inquiry-based learning is not only valuable and effective in the classroom setting, but it can also be used as a method to organise meaningful outdoor learning activities (Barfod & Daugbjerg, 2018).

### ***The role of outdoor education in supporting learning***

Outdoor education (OE) refers to teaching and learning activities in authentic, natural environments such as forests or gardens, where students can connect their theoretical thinking with real experiences in the field (Jeronen et al., 2016). Nowadays, in highly urbanised habitats, children spend most of their time indoors, which is problematic in terms of their disconnection from nature (Chawla, 2020;

Harris, 2021; Sustainable Development Commission, 2011). Learning outdoors provides an opportunity for students to learn about a subject in a more hands-on and immersive way than they can in the classroom, which supports their understanding of diversity and complex interrelations (Rickson et al., 2004). OE is also known to support learning among those pupils who are the most challenging to motivate (Szczytko et al., 2018).

Learning out of the classroom can improve values, attitudes and educational skills (Wattchow 2006; Öhman & Sandell 2016). OE has positive impacts on academic achievements, development of self-regulated learning and creativity (Kim, 2011; Waite & Pratt 2017). It helps to prepare students to be active citizens (Torkos & Egerau, 2020) and supports the development of cooperation, leadership and problem-solving and decision-making skills (Humberstone & Stan, 2011; McArdle et al., 2013). Previous studies have demonstrated OE's positive impact on students' emotions (Loynes, 2002; McNair, 2012; Thomas & Harding 2011), empathy (McArdle et al., 2013), self-esteem (Humberstone & Stan, 2011) and career choices (Tran, 2011). Outdoor spaces provide a rich context for students to learn about science, allowing them to engage in scientific practices and explore scientific content (Stevenson et al., 2021).

A botanical garden can be a captivating outdoor educational environment that promotes inquiry-based learning, enabling individuals to discover the wonders of the world of plants. The diverse botanical specimens on display can be investigated and questions may be answered by engaging in inquiry-based learning. The first established botanical gardens were mainly used for the study of medicinal plants (Powledge, 2011) and, over time, more functions of botanical gardens have evolved. Climate change plays a significant role in the evolving functions of botanical gardens (Oldfield, 2010). To fight against climate change there is a need to understand how nature is functioning to understand how biotic and abiotic factors are inter-related. It has been proposed that botanical gardens should focus on three major functions: public education, ex-situ conservation and scientific research (Willison, 2006; Wyse Jackson & Sutherland, 2000).

Morgan et al. (2009) found that activities in botanical gardens positively affected academic and interdisciplinary skills and increased environmental awareness, and several studies have shown that visits to botanical garden supported positive attitudes toward nature (Gül İri & Çil, 2020; Larson et al., 2010; Williams et al., 2015). Kissi and Dreesmann (2018) highlighted that participation in activities in botanical gardens positively influenced 5th through 9th graders' knowledge about and attitudes towards plants and nature.

Though relatively few studies have investigated OE's impact on conceptual change, there is already some evidence of positive effects (e.g. Demirbas, 2017; Stewart, 2002; Tal, 2004), but the evidence is still mixed. Learning in botanical gardens can support conceptual change since students have direct encounters with nature and the lessons at these sites are more engaging and socially interactive than in the classroom (Hofstein et al., 2001). Sellmann and Bogner (2012) proved that the 10th graders' knowledge gain about climate change was successful after a one-day intervention in a botanical garden. OE taking place in botanical gardens can be a valuable learning environment to foster students to reach a conceptual change if the activities support active knowledge construction (Mettis et al., 2023). The aim of the study by Kubisch and Heyne (2015) was to discover whether a conceptual change process can be fostered by confronting students with their misconceptions in a botanical garden. All students benefit from the outdoor experience, but they failed to show that confronting alternative conceptions in botanical garden environment would enhance conceptual change. Similarly, Ince and Costu (2017) did not find evidence that an informal learning environment (including a botanical garden) would impact students' understanding of scientific concepts.

### ***Research aim and questions***

The results of many past studies indicate that inquiry-based learning has a considerable impact on the conceptual understanding of students. There are, however, limited studies that have examined the long-term effects of inquiry-based learning on conceptual understanding. The purpose of this study

was to examine whether inquiry-based learning improves conceptual change in a stable way. This study was prompted by the following research questions:

(1) How will the conceptual understanding of photosynthesis and respiration develop in students participating in inquiry-based learning in botanical garden compared to students learning the same content in regular classrooms?

(H1) Based on the results from previous studies (e.g. Demirbas, 2017; Mataka & Taibu, 2020; Mettis et al., 2023; Şimşek & Kabapınar, 2010; Tal, 2004; van der Graaf, 2020), we hypothesised that the students participating in inquiry-based learning in a botanical garden will develop a better conceptual understanding of photosynthesis and respiration compared to the students learning in regular classrooms.

(2) How are students participating in inquiry-based learning in botanical garden overcoming misconceptions about photosynthesis and respiration compared to students learning in regular classrooms?

(H2) Based on previous studies (e.g. Demirbas, 2017; Mataka & Taibu, 2020; Mettis et al., 2023; Şimşek & Kabapınar, 2010; Tal, 2004; van der Graaf, 2020), we hypothesised that the students participating in inquiry-based learning in botanical garden would overcome more misconceptions about photosynthesis and respiration compared to the students learning in regular classrooms.

(3.) What are the long-term effects on the conceptual understanding of photosynthesis and respiration of inquiry-based learning in botanical gardens compared with the learning in regular classrooms?

(H3) Based on previous studies (e.g. Ahopelto et al., 2011; Al Khawaldeh, 2007), we hypothesised that the long-term effect on the conceptual understanding of photosynthesis and respiration of inquiry-based learning in botanical gardens would be more stable when compared with students' achievements in regular classrooms.

## **Research methodology**

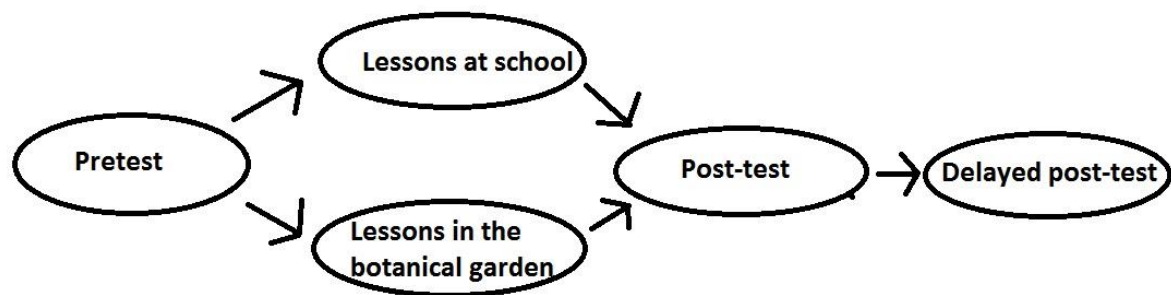
### ***Participants***

The target population of 9th grade students were selected based on a previous large-scale survey study on 7th to 11th grade students' conceptual understanding of photosynthesis and respiration (Vančugovienė et al., 2024). The sampling was applied based on geographical proximity (distance from school to the botanical garden). Four city schools were asked to participate in the study; two schools declined to participate. It was not possible to assign individual participants randomly to different groups; whole classrooms were assigned to the experimental group (N=79) and other whole classrooms were assigned to the control group (N=72).

The research was conducted in accordance with the Belmont Report (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979). The permission to perform the study was received from the university ethics committee. The parents of the students were given informed consent forms mediated by the schools, and only the children of the parents who signed the informed consent form data was used in this study.

### ***Research design and measurements***

Figure 1. Research design.



The data consisted of pretest, post-test delayed and post-test collection (Figure 1). All the students completed the pre-test one week before the intervention lessons started. The week after the intervention lessons, all the students completed the post-test. Three months after the intervention lessons, all the students completed the delayed post-test. The tests were completed during lessons at school and controlled by the teachers. All three test were the same. The test consisted of two parts.

The first part asked for general information (gender, age, biology subject mark). The second part was of a two-tier type regarding photosynthesis and respiration created by Haslam and Treagust (1987). The original test was translated into Lithuanian. This version was checked by two biology scientists and two biology teachers and clarified using their comments. This was done to ensure that the test would align with Lithuanian curricula and the newest scientific knowledge about photosynthesis and respiration. The clarified version was translated back into English by a professional biologist in order to ensure that the original meaning of the questions remained. The Lithuanian version was tested in a pilot test in several Lithuanian schools.

The test was created to diagnose conceptual understanding and was based on previous research on students' misconceptions about photosynthesis and respiration. In each of the 14 questions, the students were asked to select one answer from the several options provided (from two to four options in each question). In the second tier, the students were asked to provide an explanation for why they chose their particular answer in the first tier by selecting one of the provided explanations. In the second tier there was an option to write student's own answer. Two biologists with expertise in conceptual change research classified the answer and explanation alternatives. In each task, one alternative was based on the correct scientific understanding and the alternative answer and explanation options represented typical misconceptions or other erroneous non-scientific explanations (see Vosniadou, 2012). Each of own words answers was evaluated independently by the authors and rated as scientifically correct answers, misconceptions recognised in earlier research or otherwise erroneously non-scientific. The explanations allowed the researchers to determine whether a student simply guessed or remembered the right answer in the first tier or if he or she demonstrated scientific conceptual understanding. To complete the whole test in each measurement times required one lesson (45 minutes). The correct scientific variable was scored one (1) if the student chose both the scientifically correct answer and the scientifically correct explanation and zero (0) if only one or none of the choices was scientifically correct. In addition, the misconception variable was always

scored one (1) when a misconception answer or misconception explanation was given. Cronbach's alpha for the correct scientific variable in pretest, post-test and delayed post-tests was .63, .77 and .81 and, for the misconception variable, .65, .68 and .69, respectively. The reliabilities were satisfactory for knowledge tests (Schneider & Stern, 2010). See the Appendix for the test.

### ***Intervention***

The intervention consisted of various activities and it was a four lessons programme. The intervention took place during the students' biology lessons. Four 45 minutes lessons were dedicated to the intervention. All the lessons took place in both outdoor and indoor botanical garden. All the lessons were led by the qualified educator of the botanical garden. The educator had the formal education required to teach at school (including the biological training focusing on photosynthesis and respiration and the pedagogical training). In addition, the educator had individual training in the context of conceptual change theories and was involved in planning the experimental group lessons. The main features of the intervention were the use of conceptual change theory (Vosniadou et al., 2001), inquiry-based learning supplemented with direct instruction and a hands-on approach in the botanical gardens. The lessons covered the same information provided in the biology textbook for 9th graders. The intervention methods were selected based on the principles of inquiry based learning and previous findings that have showed that active learning and hands-on activities can enhance conceptual change (Aleknavičiūtė et al., 2023; Constantinou et al., 2018). The photosynthesis and



respiration concepts were taught by taking into account the micro-, mezzo- and macro-levels aspects of these concepts, highlighting those details that have been known to display typical misconceptions as reported in previous studies. All four lessons were carefully planned and discussed by the co-authors, two of whom have backgrounds in biology. The intervention lessons were tested in a pilot study.

Figure 2. Lessons in the botanical garden.

The first lesson was dedicated to the micro-level conceptual understanding and took place outdoors. The students were split randomly into four groups. Each group received a model of a cell – two groups received a plant cell model, and two groups received an animal cell model. The visual aspects of a model can help to make an explanation more comprehensible (Mayer, 1993). The students were asked to discuss in groups what their model showed and what they knew about that object. The students were asked to present their findings after the discussions, during which time the groups could complement each other. The participants were encouraged to express or acknowledge an opposing point of view and to refute previous findings when providing explanations (refutational approach – see Kowalski & Taylor, 2017). All the discussions during this intervention were organised based on this refutational approach. The development of discursive arguments and communication with others are considered as the features of inquiry-based learning framework (Constantinou et al., 2018). After this task, the attention was focused on two organelles: chloroplast and mitochondria. The purpose of this task was to discuss in groups what processes take place in the organelle they studied. The students were asked to write down everything they knew about these processes, after which, they were asked to present their findings. After the discussions groups could complement each other. The third task involved using microscopes to study the samples. The students were asked to discuss in groups what they saw under the microscopes and to draw the objects. The drawing activity can be effective in overcoming misconceptions because the activity has the potential to foster metaconceptual awareness and to help create cognitive conflict (Murtonen et al., 2018). After that, the students presented their

findings to the other groups. The development of systematic observational skills, questioning and recording for the purpose of establishing credible evidence are considered as features of inquiry-based learning (Wolf & Fraser, 2008). The first lesson was completed with a reflexion game in which the educator asked complex questions that required complex explanations. Self-explanations have proved effective for supporting conceptual change (Chi & VanLehn, 1991).

The second lesson was dedicated to the mezzo-level conceptual understanding and took place outdoors. The students were split into groups and asked to discuss what was needed for a plant to survive. After the discussions, all the groups listed their ideas and the educator wrote them on the board. Four ideas were chosen to test: light, water, soil and carbon dioxide. Then, the educator presented the scientific method consisting of hypothesis formulation, experiment, results analysis and conclusion. The importance of a control group was highlighted. Making predictions and hypotheses and testing them by conducting experiments helps students to gain a metaconceptual awareness, which is involved in the process of conceptual change (Vosniadou et al., 2001). The students were assigned randomly to each of the groups dealing with one of the factors needed for plants to survive (suggested by students). While in the groups, they were asked to discuss how to design an experiment that could be used to check whether the assigned factor was needed for the plant to survive. The students presented the experiment designs they had created. The educator provided feedback and highlighted the most important issues. The students constructed the experimental conditions using real plants that were provided to them. For conceptual change, it is important to understand that beliefs about the physical world are hypotheses that can be tested and refuted (Sinatra & Pintrich 2003; Wisner & Smith 2008; Vosniadou, 2003). Students were provided with questions, methods and materials and were challenged to discover relationships between variables, an activity widely applied in inquiry-based learning (Kuhn & Dean, 2005). The plants were left for one week under the constructed conditions. The educator cared of all the plants during that week. The third lesson was dedicated to the mezzo-level conceptual understanding and took place indoors in the botanical garden laboratory.

The students were split into the same four groups and were asked to memorise their experimental designs and hypotheses. After that, plants were brought to the laboratory, the students discussed the results and formulated conclusions. Each group presented their findings. After that, the students performed two short experiments using the scientific method. The students were asked to create hypotheses; the educator did not disclose whether they were right or wrong. This follows position of Vosniadou and Skopeliti (2014) that it is more fruitful to help students to understand that scientific explanations offer a different perspective with greater explanatory power than their original conceptions, rather than directly telling them that their ideas are incorrect and need to be revised. After the hypotheses were created, the students performed their experiments. Active student involvement in learning processes while emphasizing supporting knowledge claims with observations and experiences is one of the features of inquiry-based learning (Linn et al., 2004). The first was related to the production of oxygen; the water plant elodea was used for this. The second was related to the production of glucose and the conversion to starch. Houseplants were used for this; a portion of their leaves were left in the dark and covered in foil and the other parts of the leaves were left under a light. The students were searching for a starch in the houseplants' leaves. The students were encouraged to explain their findings whilst performing the experiments. Explaining in the moment is known to have a positive impact on understanding (Berry, 1983; Chi & VanLehn, 1991). After the discussions in groups, the results were presented to all the students in the class.

The fourth lesson was dedicated to the macro-level conceptual understanding. The approach to teaching about photosynthesis and respiration on the three levels – micro, mezzo and macro - refers to a systemic understanding. The undifferentiated holistic view rarely evolves into a systemic understanding, which is a result of a long-term process that requires the mastery of a complex framework that encompasses biological concepts as well as nonbiological ones (Caravita et al., 1989). The fourth lesson took place both outdoors in the botanical garden and in the greenhouse. The main aim of the fourth lesson was to apply an orienteering game. Tackling of authentic learning activities

is considered as a feature of inquiry-based learning (Linn et al., 1996). Previous studies have shown that the orienteering game can increase the participants' motivation (Fränti et al., 2017; Kim, 2010; Tammaro et al., 2017), which is an important factor in 'warm' conceptual change. 'Warm' conceptual change states that, although students may possess similar background knowledge, they may not be motivated to resolve the discrepancies between their knowledge and the new concepts (Sinatra, 2005). Therefore, motivation is an important aspect and should be considered in conceptual change studies (Pintrich et al., 1993). In addition, the learning environment should promote the students' verbal explanations, questions, criticisms and evaluations to support their thinking and knowledge construction (Mason, 2001). A botanical garden is the example of this kind of learning environment. Each group received a map on which ten plants were marked. Each group had to search for these plants. Active participation in collaborative group work and communication with others are considered as features of inquiry-based learning framework (Constantinou et al., 2018). Next to the plants were hidden envelopes with a task related to that specific plant. The tasks were related to the plants' adaptations to perform photosynthesis or respiration in different environments. The students were told to take the task from the envelope, investigate the plant and write down the answer. After they had found all 10 plants, they were told to return to the starting position. When all the groups had returned, questions and answers were discussed together with the educator.

### ***Control group lessons***

The students in the traditional teaching group had their biology lessons in their regular classrooms. The lessons were conducted by the biology teacher. The teacher had the formal education required to teach at school (including biological training focusing on photosynthesis and respiration and the pedagogical training – the same level as the educator of the intervention group). However, in terms of training, only the training on conceptual change theories makes the difference – the control group teacher did not have any training in conceptual change theories. Four 45 minutes lessons were dedicated to photosynthesis and respiration concepts. The control group students were being taught

using the typical Lithuanian biology textbook for the 9th grade. Three of the lessons were theoretical and one involved laboratory work. All the theoretical lessons had the same structure. At the beginning of the lesson, the teacher presented the lesson goals and tasks. The teacher assigned one student to read a paragraph of the textbook, after which, the teacher asked a question related to the paragraph. Then, the teacher instructed another student to read the next paragraph; the lesson continued until the complete section was read. The students were then asked to open their exercise books and individually perform a given exercise. After a while, the teacher asked a student to present how he or she performed the given exercise. The lesson ended when all the exercises were performed and clarified. The fourth lesson involved laboratory work. The students were divided into pairs. Each pair received a microscope and a sample of leaf cells that they were asked to discuss in pairs and draw in their notebooks. When this task was completed, each pair received a water plant elodea. The students were asked to prepare a sample, investigate it under a microscope and discuss and draw it. All the tasks had to be completed in pairs; there was no possibility of seeing the work of the other pairs or discussing their work with the other pairs. This lab work had some elements of inquiry-based learning, like making observations. However, students were provided with detailed procedures and expected outcomes, leaving little space for creativity or independent thinking. The teacher guided the students through the entire process, limiting their opportunities for inquiry. According to Bunterm et al. (2014), this model could be called confirmation inquiry, in which questions, procedures, and solutions are offered by the teacher.

### ***Data analysis***

The normality of the correct scientific knowledge and the misconception variables of both groups in all the measurement points were tested with skewness and kurtosis values. Because the sample size included fewer than 300 students, the z-test of skewness and kurtosis values were conducted (Mishra et al., 2019). Box's M test was conducted to test the equality of covariance matrixes and Mauchly's test was used to test the sphericity. The repeated measures ANOVA was conducted to examine how

intervention impacted the students' conceptual understanding. To analyse if there was a statistically significant difference between the experimental and control groups' delayed post-test values, an ANCOVA was applied. Eta squared effect sizes were estimated for all the comparisons of the experimental and control groups. The missing data was handled using listwise deletion in SPSS.

## Results

The impact of the intervention was evaluated in terms of the immediate changes in the correct scientific answers and misconceptions answers after the experiment and long-term changes three month later. The descriptive statistics of the scientifically correct answers and misconceptions in the pretest, post-test and delayed post-test are presented in Table 1.

Table 1. Descriptive statistics of scientifically correct answers and misconceptions in pretest, post-test and delayed post-test.

	N	Mean	Std. Dev.	Skewness (Std. Error)	Kurtosis (Std. Error)
Pretest correct	145	5.53	2.484	.581 (.160)	.500 (.318)
Post-test correct	136	5.74	3.054	.661 (.165)	-.155 (.329)
Delayed post-test correct	137	5.54	3.268	.619 (.163)	-.157 (.324)
Pretest misconceptions	145	5.83	2.918	-.392 (.201)	-.454 (.400)
Post-test misconceptions	136	5.58	3.131	.039 (.208)	-.850 (.413)
Delayed post-test misconceptions	137	5.81	3.271	-.118 (.207)	-.995 (.411)

To evaluate whether the correct scientific knowledge variables met the criteria of the repeated ANOVA, the normality of the variables and equality of the covariate matrixes were checked. The skewness and kurtosis values on the scientifically correct knowledge variables of both groups ( $-1 < v < 1$ ) show that they are normally distributed in all the measurement points. Because the sample size was smaller than 300, a z-test was applied for the skewness and kurtosis values. All the z-values were

within the frames of approximate normal ( $-3.29 < z < 3.29$ ) for medium-sized samples ( $50 \leq n < 300$ ). According to the Box's M test ( $p=.171$ ), the covariance matrixes of the correct scientific knowledge variables are equal. A repeated measures ANOVA was performed to evaluate the effect of the experimental treatment on the correct scientific knowledge. The means and standard deviations for the correct scientific knowledge in the measurement points are presented in Table 2.

Table 2. Means and standard deviations of scientifically correct answers variables of experimental and control groups in pre-, post- and delayed post-tests.

	Pretest scores mean (SD)	Post-test scores mean (SD)	Delayed post-test scores mean (SD)
Experimental group	4.87 (2.538)	7.00 (3.497)	6.29 (3.877)
Control group	5.00 (2.340)	4.98 (2.599)	5.40 (3.072)

The Mauchly's test indicated that the assumption of sphericity was met:  $\chi^2(2) = 1.670$ ,  $p = .434$ . Therefore, the sphericity assumed option was used. The interaction effect of group and time on the correct scientific knowledge was  $F(2)=9.813$ ,  $p < .001$ , partial  $\eta^2 = .077$ , indicating that the scientifically correct answers increased in the experimental group more than in the control group with moderate effect size.

To evaluate if the misconception variables met the criteria of repeated ANOVA, the normality of the variables and equality of the covariate matrixes were checked. The skewness and kurtosis values of the misconception variables of both groups ( $-1 < v < 1$ ) show that they are approximately normally distributed in all the measurement points. Because the sample size was smaller than 300, the z-test was also applied for the skewness and kurtosis values. All the z-values were within the frames of approximate normal ( $-3.29 < z < 3.29$ ) given for medium-sized samples ( $50 \leq n < 300$ ) (Mishra et al., 2019). According to the Box's M test ( $p=.40$ ), the covariance matrixes of the misconceptions variables are equal. A repeated-measures ANOVA was performed to evaluate the effect of the experimental treatment on the misconceptions. The means and standard deviations of misconception in pre-, post- and delayed post-test are presented in Table 3.

Table 3. Means and standard deviations of the misconception variables of experimental and control groups in pre-, post- and delayed post-tests.

	Pretest scores mean (SD)	Post-test scores mean (SD)	Delayed post-test scores mean (SD)
Experimental group	5.79 (3.390)	4.62 (3.235)	5.10 (3.439)
Control group	5.56 (2.595)	6.53 (2.867)	6.22 (3.074)

The Mauchly's test indicated that the assumption of sphericity was met,  $\chi^2(2) = 2.03$ ,  $p = .362$ ; therefore, the sphericity assumed test was used. The interaction effect of group and time on the misconceptions was  $F(2)=8.33$ ,  $p < .001$ , partial  $\eta^2 = .065$ , indicating that the amount of misconception answers decreased in the experimental group significantly more than in the control group with medium effect size.

The long-term effects of the intervention were controlled by ANCOVA where the pretest variables were used as covariant and the delayed post-test variables as dependent variables. The experiment had a small- to medium-size long-term effect on the increase in correct scientific knowledge  $F(1)=4.198$ ,  $p < .05$ , partial  $\eta^2 = .032$ . The experiment had a medium size long-term effect on the decrease in misconceptions:  $F(1)=8.174$ ,  $p = .005$ , partial  $\eta^2 = .060$ .

## Discussion

The aim of this study was to investigate the impact of inquiry-based learning in a botanical garden on 9th grade students' conceptual understanding of photosynthesis and respiration when compared with traditional teaching and the stability of conceptual change in the long term. The results showed that the intervention had a positive impact on the students' learning of correct scientific knowledge when compared to the effects of traditional teaching at school. In addition, the learning activities in the botanical garden helped students to overcome the misconceptions typical of students' knowledge of photosynthesis and respiration. The results also showed that, though the level of the experimental students' conceptual understanding somewhat decreased after the post-test, they still outperformed

the students in regular classroom teaching three months later in terms of more correct scientific knowledge and fewer misconceptions.

Our results confirmed the first hypothesis. The students' participation in the intervention developed a better conceptual understanding of photosynthesis and respiration compared to the students learning in regular classrooms. This finding is in alignment with that of Sandoval and Reiser (2004), which stated that an inquiry-based approach helps students develop a deeper understanding of the subject matter. In addition, our first finding is in line with that of Akaygun and Adadan (2021), who found that a conceptual framework develops when using inquiry-based teaching. Since the inquiry-based learning was supplemented with direct instruction and teacher guidance in our study, the findings also correspond with those of de Jong et al. (2023), that a combination of inquiry and direct instruction may often be the best approach to support students' science learning; they oppose those of Zhang et al. (2022), who claimed that direct teaching alone results in better learning than that in inquiry-based learning. In many prior studies, the outcome measures were based solely on the enrichment of knowledge and little on measuring deeper conceptual change (Aleknavičiūtė et al., 2023). In our study, we used a strict measure of the increase of scientific conceptual understanding. Surprisingly, the results show that the control group that was attending traditional biology lessons about photosynthesis and respiration in school did not improve at all from the pretest to the post-test. This is aligning with earlier studies that showed that traditional teaching is not effective in supporting deeper conceptual change in students (Stofflett & Stoddart, 1994). Traditional teaching may lead to memorising facts typically measured in school tests rather than deep conceptual understanding.

Our results also confirm the second hypothesis. The students who participated in inquiry-based learning in the botanical garden overcame more misconceptions about photosynthesis and respiration compared to the students learning in regular classrooms. This aligns with previous studies in physics education that showed that the use of the conceptual change approach in teaching leads to a decrease in misconceptions (Taşlıdere, 2013). Our second finding lends additional credence to the

research literature that has found that active learning helps to reduce misconceptions (Nehm & Reilly, 2007). Conceptual understanding, which should be one of the goals of teaching and learning (Ristanto et al., 2018), is described not only as a means of scientifically correct knowledge gain, but also as a way to decrease the misconceptions that are often resistant to change in traditional teaching.

Our study results also confirm the third hypothesis. Though there was a small decrease in the results of the experimental group from the post-test to the delayed post-test, the conceptual understanding of the experimental group was still better than that of the control group students after three months. Conceptual change is usually a slow and gradual process that is not easily gained (Vosniadou, 2012); measuring achievements solely immediately after an intervention can be misleading. The students could learn to give correct answers but did not change their thinking. In other words, they did not experience conceptual change. This indicates that many of the students in the experimental group experienced stable conceptual change in their understanding of photosynthesis and respiration, which is in line with previous studies (Al Khawaldeh, 2007). However, there was a slight improvement in the scientifically correct answers in the control group between the post-test and delayed post-test. We hypothesise that this could be explained with retest effects. Retest effects can be defined as a change in test scores resulting from retaking the same or a comparable cognitive ability test (Scharfen et al., 2018).

### **Pedagogical implications**

Specially designed interventions in rich contexts such as botanical gardens could help in enhancing a conceptual change in understanding complex concepts that is often difficult to achieve in traditional teaching. However, an important question is how to scale up the whole intervention model in regular schools, since not all schools are located close to botanical gardens. Despite this, some parts of the intervention could be applied easily in regular school contexts. In addition, other outdoor spaces, such as forests, city parks or even the school yard could be used to perform activities similar to those used

in this study. Also, the idea of using a systemic approach that supports the learning of a holistic view of complex concepts could be applied in classroom teaching (Caravita et al., 1989).

### **Limitations**

Certain limitations should be taken into account when interpreting the findings of this study. First, only two schools participated in the study, though more schools were contacted. We do not know what contributed to these certain schools' willingness to participate. There was only one teacher teaching the control group and one educator teaching the experimental group. It would be needed to repeat the study with more teachers and a larger sample. There was no randomisation when splitting the students into the groups because the only way to organise the experiment was to use whole school classes. The comparison was based on the mean values of the students in experimental and control groups. However, it is known that, even in a single classroom, there is an unobserved heterogeneity among students. Therefore, a person-oriented approach such as latent profile analysis could enrich the results by uncovering the intra-group differences. The results are based on the effects of the whole intervention but do not allow the analysis of the specific effects of the different components of this many-sided intervention. Therefore, we do not know which parts of the programme exactly worked and had an impact on students' conceptual understanding. Finally, not all the students were able to participate in all four lessons or in all three measurements. However, students' absences were because of external random reasons (like sickness and sports competitions) because all lessons were compulsory to attend; students could not choose to attend the lesson or not. In addition, all lessons were held during compulsory biology lessons. Hence, there is no possibility that students' attendance patterns varied in a meaningful way between the experimental and control groups.

### **Conclusions and future research**

Our study proved that inquiry-based learning improves the conceptual understanding of biological concepts such as photosynthesis and respiration in students over the long term. However, though the experimental group significantly improved from pretest, the means of the scientifically correct answer

scores in the post-test and delayed post-test are still far from the maximum scores. Therefore, additional research would be needed to evaluate why so many students were not able reach a better conceptual understanding during the experimental programme. A person-oriented approach could be used to study the unobserved heterogeneity among learners, and additional methods should be included to determine how students in different achievement profiles improve over time. To know which parts of the intervention worked the best, there should be in future more specific controlled experiments that focus on different aspects of the intervention. Similar teaching interventions in botanical gardens could be tested with other biological topics, as well.

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The authors report there are no competing interests to declare.

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### **Ethics Statement**

This study was granted ethics approval by the University Educational Research Institute Ethics Committee – permission number blinded for review.

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Appendix

Conceptual understanding test

**1. What kind of gas do green plants release the most in sunlight?**

A. Carbon dioxide gas

B. Oxygen gas

The reason for my answer is:

1. This gas is released in sunlight because green plants only respire during the daytime.
2. Green plants release this gas because in sunlight they do photosynthesis but do not respire.
3. *This gas, which is produced during photosynthesis, is produced in larger amounts than is necessary for the respiration of green plants and other processes, so the excess of this gas is released into the environment.*
4. This gas is waste, which is produced during photosynthesis, so green plants release this gas into the environment.

5 \_\_\_\_\_

**2. What kind of gas do green plants absorb from the environment in large quantities when there is an absence of light energy (in the dark)?**

A. Carbon dioxide gas

B. Oxygen gas

The reason for my answer is:

1. This gas is used for photosynthesis, which all stages take place constantly in green plants.
2. This gas is used for photosynthesis, which all stages occur in green plants when there is an absence of sunlight energy.
3. This gas is used for respiration, which occurs in green plants only when there is an absence of sunlight energy for photosynthesis.
4. *This gas is used for respiration, which takes place constantly in green plants.*

5 \_\_\_\_\_

**3. What kind of gas do green plants release the most in the dark?**

A. Carbon dioxide gas

B. Oxygen gas

The reason for my answer is:

1. *Green plants do not start to photosynthesize when there is an absence of sunlight energy, but they continue to respire, therefore they release this gas.*

2. Green plants release this gas during photosynthesis, which all stages take place in the absence of sunlight.

3. Green plants release this gas because they respire only in the absence of sunlight.

4. \_\_\_\_\_

**4. What kind of gas do green plants absorb the most in the sunlight?**

A. Carbon dioxide gas

B. Oxygen gas

The reason for my answer is:

1. *Green plants absorb this gas in the sunlight and produce their food from this gas.*

2. Animals need this gas for respiration in the presence of sunlight.

3. \_\_\_\_\_

**5. Plants respiration occurs in:**

A only in the roots' cells.

B in all plants' cells.

C only in the leaves' cells.

The reason for my answer is:

1. *All living cells need energy to live.*

2. Only leaves have special pores (stomates) needed for gas exchange.

3. Only roots have small pores to respire.

4. Only roots need energy to absorb water.

5 \_\_\_\_\_

**6. Respiration is:**

- A *A chemical process which occurs in all living plant and animal cells.*
- B A chemical process which occurs in plant cells, but not in animal cells.
- C A chemical process which occurs in animal cells, but not in plant cells.

The reason for my answer is:

1. Only plant cells receive energy to live during the respiration process.
2. *All live plant and animal cells receive energy to live through the respiration process.*
3. Energy for life is necessary only for animal cells because they cannot perform photosynthesis.

4 \_\_\_\_\_

**7. Which of the following statements about green plant respiration is the most accurate?**

- A It is a chemical process by which plants produce food from water and carbon dioxide.
- B It is a chemical process by which the energy stored in food is released using oxygen.*
- C It is the exchange of carbon dioxide and oxygen gases through the plant stomates only.
- D It is a process that does not occur in green plants when photosynthesis takes place.

The reason for my answer is:

1. Green plants never respire but only perform photosynthesis.
2. Green plants absorb carbon dioxide and release oxygen when they respire.
3. *Respiration provides energy for green plants to live.*
4. In green plants, respiration occurs only when there is an absence of sunlight.

5 \_\_\_\_\_

**8. When do green plants respire?**

A Only at night (in the dark, when there is an absence of sunlight)

B Only daytime (when there is sunlight energy)

C *All the time (whether there is light energy or not).*

The reason for my answer is:

1. Green plant cells can perform photosynthesis during the daytime when there is light energy, therefore they only respire at night when there is an absence of light energy.

2. *Green plants need energy to live, and respiration provides energy.*

3. Green plants do not respire; they only perform photosynthesis, which provides energy for the plants.

4 \_\_\_\_\_

**9. Which of the following equations best represents the respiratory process in plants?**

A Glucose + oxygen → energy + carbon dioxide + water.

B *Carbon dioxide + water → energy + glucose + oxygen.*

C Carbon dioxide + water  $\xrightarrow{\text{light energy and chlorophyll}}$  oxygen + glucose.

D Glucose + oxygen → carbon dioxide + water.

The reason for my answer is:

1. During respiration in the sunlight, green plants produce glucose using carbon dioxide and water.

2. Green plants use carbon dioxide and water to produce energy, while glucose and oxygen waste are generated during this process.

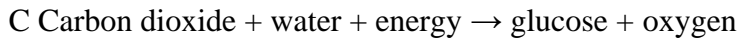
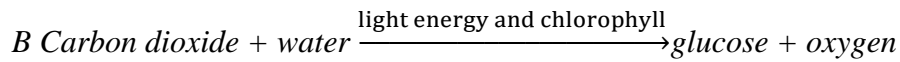
3. During respiration, green plants absorb oxygen and release carbon dioxide and water.

4. *During respiration, green plants get energy from glucose by using oxygen.*

5 \_\_\_\_\_

**10. Which of the following equations best represents the overall process of photosynthesis?**

A Glucose + oxygen  $\xrightarrow{\text{light energy and chlorophyll}}$  carbon dioxide + water.



The reason for my answer is:

1. In sunlight, a green pigment called chlorophyll binds to carbon dioxide to produce glucose and water.
2. *Plants, which contain chlorophyll, use sunlight energy to combine carbon dioxide and water to produce glucose and oxygen.*
3. The combination of glucose and oxygen under the action of chlorophyll and light energy forms carbon dioxide and water.

4 \_\_\_\_\_

**11. Which of the following factors is least important for the process of photosynthesis?**

- A *The amount of oxygen.*
- B The amount of carbon dioxide.
- C The amount of chlorophyll.
- D The amount of light.

The reason for my answer is:

1. Photosynthesis can take place without sunlight's energy.
2. Non-green plants, such as fungi that do not contain chlorophyll or similar pigments, can also perform photosynthesis.
3. Photosynthesis cannot take place without carbon dioxide.
4. *Oxygen is not required for photosynthesis; it is a product of photosynthesis.*

5 \_\_\_\_\_

**12. The most important benefit for green plants during photosynthesis is:**

- A Removal of carbon dioxide from the air.
- B *Conversion of light energy into chemical energy.*

C Production of energy.

The reason for my answer is:

1. Photosynthesis provides energy for plant growth.
2. *During photosynthesis, solar energy is converted into the energy of chemical bonds and stored in glucose molecules.*
- 3 Leaves absorb carbon dioxide through their stomata during photosynthesis.
- 4 \_\_\_\_\_

**13. Which of the following statements about green plant photosynthesis is the most accurate?**

- A *It is a chemical process by which plants produce food from water and carbon dioxide.*
- B It is a chemical process by which the energy stored in food is released using oxygen.
- C It is a process that does not occur in green plants when respiration takes place.
- D It is a process, all stages of which take place in plants day and night.

The reason for my answer is:

1. Plants photosynthesize only during the day and respire at night.
2. During photosynthesis, plants obtain energy, which is necessary for all living organisms.
3. *Plants use glucose for food, which they produce during photosynthesis from inorganic materials.*
4. In plants, all stages of photosynthesis take place all the time.
- 5 \_\_\_\_\_

**14. Which of the following comparisons of photosynthesis and respiration processes in green plants is correct?**

- A Photosynthesis occurs only in green plants. Respiration occurs only in animals.
- B Photosynthesis occurs in all plants. Respiration occurs only in all animals.
- C *Photosynthesis starts in green plants in the presence of light energy. Respiration occurs in all plants and all animals at all times.*
- D Photosynthesis starts in green plants in the presence of light energy. Respiration occurs in all plants only in the absence of light energy and always in animals.

The reason for my answer is:

1. Green plants perform photosynthesis and do not respire at all.
2. Green plants perform photosynthesis during the day and respire at night (when there is an absent of light energy).
3. *Respiration is a continuous process in all living organisms. Photosynthesis starts only when there is light energy.*
4. Plants respire when they cannot get enough energy from photosynthesis (e.g., at night); animals respire constantly because they cannot perform photosynthesis.

5 \_\_\_\_\_