

# Individual differences in secondary school students' conceptual knowledge: Latent profile analysis of biology concepts

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## ABSTRACT

Extensive research has been conducted on the misconceptions related to photosynthesis and respiration. However, most of these studies have failed to consider the heterogeneity of learners. In this study, latent profile analysis was used to determine the differences in students' understanding of biological concepts. Students' profiles were validated by relating them to their grade level, academic achievement in biology and sophistication of epistemic beliefs. Between the scientific and non-scientific understanding of photosynthesis and respiration, there were different conceptual profiles (prescientific, inaccurate preconceptions, fragmented and synthetic) in this cross-sectional study that helped in understanding the possible, qualitatively different steps between misconceptions and scientific understanding. Higher grade levels, higher biology grades and more sophisticated epistemic beliefs were related to a higher probability of belonging to the subgroups with more scientific conceptual knowledge.

*Educational relevance and implications:* Between the scientific and non-scientific understanding of photosynthesis and respiration, there were different conceptual profiles (prescientific, inaccurate preconceptions, fragmented and synthetic) that helped in understanding the steps from misconceptions to scientific understanding. Higher grade levels, higher biology grades and more sophisticated epistemic beliefs were related to a higher probability of belonging to the subgroups with more scientific conceptual knowledge. Teachers should be aware that a large amount of variance may present among students in terms of their level and quality of understanding of central biological topics. Accordingly, teachers should allocate time to understand the students' level and quality of prior knowledge. They should focus on helping learners integrate correct fragments of information into a full, systemic understanding as well as encourage them to critically evaluate and compare their existing conceptions with scientific explanations. To improve the understanding of science, teachers should address the topic of the nature of knowledge, taking into account key aspects of discipline-specific epistemic beliefs. This approach will help students understand the nature, foundation and principles underlying scientific research and the empirical grounds for its acceptance.

## 1. Introduction

Students spend a considerable amount of time in schools and universities studying scientific concepts. However, many students still have an insufficient understanding or harbour some misconceptions about scientific concepts, which are persistent and resistant to change. These misconceptions do not align with scientific knowledge and could have originated from their childhood, everyday experiences or cultural conventions as a way to describe phenomena using everyday language (Shtulman & Legare, 2020). Prior knowledge is necessary for learning

scientific concepts, but as McCarthy and McNamara (2021) highlighted, such knowledge is multidimensional in nature, and some of its aspects can be harmful for learning correct scientific understanding (see also Simonsmeier et al., 2022).

Biology is a science concerned with the forms and mechanisms of life. Misconceptions related to biology could influence the public's understanding of ecological issues. Among the most important biological phenomena are plant photosynthesis and respiration processes. In many respects, life on earth depends on the ability of green plants to produce oxygen and transform solar energy into chemical energy for other

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organisms to use.

A significant amount of research has been conducted about the misconceptions related to photosynthesis and respiration, yet most of these studies failed to consider the heterogeneity of learners (Schneider & Hardy, 2013). It is important to understand that an 'average' learning pattern is often an inadequate description for many learners because it ignores the unobserved heterogeneity among them (Braasch et al., 2013; Hickendorff et al., 2018). Even within a single classroom, there is heterogeneity among students who have different learning profiles. Usually, students who struggle to learn exhibit only minimal improvement in their conceptual understanding after teaching, and their knowledge remains at a low level. Conversely, students who are high achievers in a school subject tend to acquire conceptual understanding that is closer to the scientific concepts taught in school. In addition, some students move towards obtaining an advanced conceptual understanding but never reach it. Traditional qualitative and quantitative studies do not consider the heterogeneity of learners, a situation that gives insight into pedagogical practices. However, advanced person-oriented approaches (Hickendorff et al., 2018) provide the opportunity to conduct studies that take the previously mentioned aspects into account and thus offer a deeper understanding of interindividual differences in conceptual learning.

Students also vary in their understanding of the nature of scientific knowledge. Some students are likely to revise their misconceptions and undergo conceptual change as a result of instructional intervention or regular teaching, whereas others with similar misconceptions will be more resistant to changing their conceptions. One important reason for this is assumed to lie in the interplay between students' ideas concerning the nature of knowledge/knowing and conceptual understanding, particularly epistemic beliefs and cognition (Amin & Levrini, 2018; Murphy & Alexander, 2013).

The current paper aimed to fill these gaps and determine the differences in biological conceptual understanding between students. Latent profile analysis (LPA) was used to clarify the unobserved heterogeneity among learners. The objective was to examine factors that predict students' belonging to various profiles describing the phase they are in conceptual development.

### 1.1. Changing conceptions of conceptual change

The classical theoretical approaches to conceptual change (e.g. Posner et al., 1982), here relying on Kuhn's (1962) notion of scientific revolution and Piaget's concepts of assimilation and accommodation (Piaget, 1976), have described conceptual change as a relatively quick process in which specific earlier conceptions are replaced with new scientific concepts (Vosniadou, 2012). However, more recent research has challenged these assumptions of the classical view of conceptual change.

Studies on conceptual change have shown that, in most cases of science and mathematics learning, conceptual change is a slow process. Learners undergo several phases of constructing conceptual understanding instead of changing quickly from misconceptions to scientific concepts. Vosniadou (2012) highlighted the difference between various forms of misconceptions. These may include inaccurate preconceptions, which are initial ideas about features of the world that are incompatible with scientific knowledge structures. Students have developed preconceptions based on their everyday experience. During various phases of the learning process, students may have preconceptions and synthetic models. Synthetic models, as defined by Vosniadou (2012), refers to knowledge which students have learned during science teaching by adding elements of the scientific knowledge in preconceptions without changing the explanatory frameworks in which the preconceptions are embedded. In learning complex concepts such as photosynthesis and respiration, students can have various combinations of scientific concepts, preconceptions and synthetic models before they demonstrate a more stable comprehension of accepted scientific concepts (McMullen

et al., 2015; Schneider & Hardy, 2013; Vosniadou, 2012).

There is also growing scientific evidence that misconceptions are not always replaced by scientific concepts but typically coexist with them (Potvin & Cyr, 2017; Shtulman & Legare, 2020; Vosniadou et al., 2018). A consequence of this is that conceptual change can be described as learning the skill to inhibit inadequate concepts in particular situations and regulate the use of various concepts according to the requirements of the situation.

Vosniadou (2012) argued that conceptual change research should move from considering changes in single units to those taking place in knowledge systems that consist of complex substructures. Many of the challenging concepts dealt with in science and mathematics classrooms consist of complex relationships between sub-concepts (Dauer et al., 2022). Recent studies have focused on analysing the conceptual change taking place within complex conceptual networks of scientific and technical knowledge. For example, in their study on students' conceptions of the mechanics of materials, Brown et al. (2018) found that students did not have just a single misconception but a few typical combinations of scientific and non-scientific concepts. The seminal work of Vosniadou and Brewer (1992) showed that the research on conceptual change should not be limited to the dichotomous classification of students' knowledge into scientific concepts and misconceptions. In the present study, we use the term "inaccurate preconceptions" to refer to misconceptions stemming from different explanatory frameworks rather than correct scientific concepts and the term "synthetic model" to refer to misconceptions that integrate inaccurate preconceptions and elements of correct scientific knowledge.

### 1.2. Conceptual understanding and grade level

Grade level typically refers to the amount of exposure or experience that students have had with concepts that are repeatedly taught throughout the educational sequence (Westbrook & Marek, 1992). Students should improve their understanding of various concepts as they progress through each grade because the same concepts are dealt with each year at increasingly higher cognitive levels (Bruner, 1960), and they have more activities and experiences related to the same concepts. Studies supporting this showed that 11th-grade students demonstrated better conceptual understanding of diffusion and osmosis compared with 9th-grade students (Tarakçı et al., 1999). Takaoglu (2018) showed that as the level progressed from 9th grade towards 11th grade, the number of students who responded correctly or partially correctly about energy concepts increased. In another study, students' conceptual understanding of lenses in geometric optics increased as they progressed from 8th grade to 12th grade (Tural, 2015).

Significant differences were also found in students' understanding of chemical change, the dissolution of a solid, conservation of atoms and periodicity when comparing students of different academic levels (junior high school physical science, high school chemistry and introductory college chemistry) (Abraham et al., 1994). Ayieko et al. (2022) found that students at the 4th grade level had greater misconceptions regarding fraction magnitude than those at the 8th grade level.

However, studies have also provided findings showing that students at different grades have the same or similar misconceptions. Uzun et al. (2013) examined students' understanding of light at different educational levels, ranging from primary school to higher education. The majority of the participants at all levels shared similar understandings of light, which meant that their conceptions or misconceptions about light did not necessarily change when they moved towards higher levels of the educational system. Saglam-Arslan (2010) demonstrated that beginners' misconceptions about energy were more likely to exist and were more varied than those of pre-experts and experts. However, students from all three groups defined energy in similar ways and possessed similar misconceptions. The study conducted by Westbrook and Marek (1991) indicated that none of the students across three grade levels (7th-grade life science students, 10th-grade biology students and college

zoology students) demonstrated a complete understanding of the diffusion concept. The grade levels did not show any significant difference in sound or partial understanding, misconceptions or 'no understanding'. The results of Kurnaz's (2012) study indicated that most of the students in grades 7–11 had misconceptions about astronomic concepts, which were generally similar in all grades. Tural (2015) also showed that there could even be a decline in conceptual understanding, for example, from grade 12 to higher education, about optics concepts.

### 1.3. Conceptual understanding and academic achievement in school examinations

Overall, academic achievement in various subjects is usually indicated by grades in school year reports, which are given by teachers based on several exams and observations of classroom behaviour assessing student achievement. However, it is unclear whether students' achievement in terms of grades in school report is reliable evidence of their conceptual understanding. For example, in their study, Entwistle and Entwistle (1991) concluded that traditional examinations do not consistently test deep, conceptual understanding. Several essential aspects contribute to achievement on school tests, and conceptual understanding is only one of them (Lestari et al., 2019). In principle, a conceptual understanding of the subject matter must be obtained to accomplish learning objectives (Ristanto et al., 2018). Some studies have shown a relationship between conceptual understanding and overall academic achievement in examinations. For example, higher education students' conceptual understanding of mathematics concepts and examination achievement in mathematics are related (Zakaria et al., 2010; Zulnaidi & Zakaria, 2010).

Some studies have focused on teaching interventions by separately analysing the impact on conceptual understanding and overall achievement in school examinations. Artun and Özsevgec (2018) showed that a teaching intervention had a positive impact on both conceptual understanding and academic achievement in environmental education among 7th graders, as evidenced by school test results. Aligned with this finding, teaching intervention had a positive impact on the examination achievements and conceptual understanding of 8th graders in physics (Safadi, 2017) and of 10th graders in chemistry (Bilgin & Geban, 2006). Different combinations of teaching methods also had similar impacts on the academic achievements and conceptual understanding of 3rd-grade students in the physics field (Wang & Tseng, 2018). However, Baragona (2009) had different findings; specifically, the intervention had no impact on the academic achievement and conceptual understanding of higher education students in biology. Some researchers have even reported more contradictory findings. Parson (2013) indicated that the intervention had a positive effect on the conceptual understanding of 5th graders but none on their achievements in regular science examinations.

### 1.4. Conceptual understanding and epistemic beliefs

Individuals' domain-specific epistemic cognition, namely a set of mental processes that involve the development of one's conceptions of knowledge, has long been of research interest (Amin & Levrini, 2018; Murphy & Alexander, 2013). Studies have shown that individuals' beliefs about knowledge and knowing have an impact on their conceptual understanding and learning (Greene et al., 2016; Hofer, 2018; Mason et al., 2008). Lin et al. (2012) found that university students with more sophisticated epistemic beliefs about scientific knowledge in biology applied deep learning strategies more frequently than did those with less sophisticated beliefs. Mason et al. (2013) showed that students' beliefs about the development of knowledge in science were related to their learning outcomes and goals in science. Many intervention studies aimed at enhancing conceptual change have indicated stronger effects in students with more sophisticated epistemic beliefs (Kendeou et al., 2016; Sinatra & Broughton, 2011; Trevors et al., 2017).

However, people with less sophisticated epistemic beliefs may struggle with understanding how domain-specific knowledge claims can be warranted, how individuals evaluate the use of evidence and how they assess the authority and expertise of science. These individuals may be less likely to question or re-evaluate their existing beliefs and could dismiss or reject information that contradicts their current beliefs. Hence, epistemic beliefs may also serve as barriers to conceptual change (Chan et al., 2011; Mason et al., 2013).

Discipline-specific epistemic beliefs relate to those beliefs about knowledge and knowing within a particular field. In various disciplines, these beliefs may differ according to the nature of knowledge construction, evidence evaluation and inquiry practices specific to each discipline (Rosman et al., 2017). The relation between conceptual change and discipline-specific epistemic beliefs highlights the influence of individuals' beliefs about knowledge and knowing within a specific discipline on their engagement in the process of revising or replacing existing concepts (Stathopoulou & Vosniadou, 2007). As students develop or revise their conceptual frameworks, their pre-existing epistemic beliefs about a discipline can act as a filter (Kutluca & Mercan, 2022), allowing them to interpret new information through the lens of these pre-existing beliefs.

### 1.5. Individual differences in conceptual change

From an educational point of view, it is important to focus on various subgroups of students who are at different phases of conceptual change, including possible mixtures of scientific knowledge with inaccurate preconceptions (Schneider & Hardy, 2013; Vosniadou, 2012). Students have been found to hold various combinations of scientific knowledge and inaccurate preconceptions. These different profiles of knowledge structures influence their learning steps in idiosyncratic ways, suggesting that these are crucial factors in designing learning environments that support positive conceptual change. However, many approaches to examining students' knowledge struggle to account for these more qualitative differences, especially in large samples.

Recently, the expansion of person-centred approaches, especially latent variable mixture models, has proven valuable in capturing these qualitative individual differences in conceptual change processes (Edelsbrunner et al., 2018; Schneider & Hardy, 2013). These results show the heterogeneity of students' conceptual frameworks during transitions towards scientifically correct understanding. This is demonstrated by the different combinations of scientific and inaccurate preconceptions observed among different subgroups of students at certain points of time. Overall, the use of latent variable mixture models to uncover hidden variations in the conceptual knowledge of students appears to be an extremely fruitful approach. In the present study, we applied these methods to examine students' knowledge in the domain of biology. The complexities of biological conceptual fields, especially interconnected concepts, may benefit from a person-centred examination.

Notably, the use of latent variable mixture models, such as LPA, allows for an examination of how students' profiles of conceptual knowledge are related to external variables, such as epistemic beliefs. Thus far, most of our existing knowledge about the relationship between students' conceptual change processes and epistemic beliefs has failed to consider the heterogeneity in students' knowledge and learning processes.

### 1.6. Prior studies on the conceptual challenges of learning photosynthesis and respiration

Photosynthesis and respiration are fundamental, interconnected biological topics that are taught continuously during one's years in school and at university. As fundamental energy reactions within plant cells, they are biological topics that are crucial for understanding the current global catastrophes related to food supplies, energy flow, climate change and other ecological principles (Janssen et al., 2014).

The learning challenge regarding these phenomena is typical in biology disciplines requiring a micro-, meso- and macro-level understanding from molecular processes to ecosystems and their interrelations (i.e. systemic understanding) (Verhoeff et al., 2018). These concepts have been studied extensively in different contexts (Aleknavičiūtė et al., 2023). Even though students improve their understanding as a result of teaching, it has been well established that this improvement is relatively minuscule and superficial (Hartley et al., 2011; Marmaroti & Galanopoulou, 2006). In addition, different age groups have shown similar misconceptions (Anderson et al., 1990), even among university students, including teacher-students and students majoring in biology (Södervik et al., 2015; Ahopelto et al., 2011; Brown & Schwartz, 2009; Yurtyapan & Kandemir, 2021).

One of the most common misconceptions related to photosynthesis is based on everyday experience that children learn, that is, plants need to be watered, or else they will die. Later on, people may learn that providing nutrients to the soil may help a suffering plant to recover. These observations often lead to the misconception that water and nutrients are 'food' for plants (Mikkilä-Erdmann, 2001). In everyday life, this misconception is sufficient; however, it shows a fundamental misunderstanding of the ontological difference between plants and animals, which again leads to an inappropriate understanding of the role of plants in the ecosystem (Södervik et al., 2021). Learning the scientific explanation suggests that one understands photosynthesising organisms produce their nourishment by themselves, contrary to animals that extract needed substances from the food they eat.

Another typical misconception is that many students perceive photosynthesis and respiration only as reverse processes of each other in terms of gas exchange or cannot even indicate the differences between these two processes (Amir & Tamir, 1995). Many students are unaware that plants respire (Brown & Schwartz, 2009; Capa et al., 2001). In addition, photosynthesis is considered by most students to be a process for producing energy; they do not realise that photosynthesis is a process that produces food, namely glucose, which is a source of energy. This misconception could be related to difficulties in understanding the concept of energy in general and assimilating the terms 'food' and 'energy' (Balci et al., 2006). Some students likewise believe that photosynthesis is the way in which plants produce new plants (Södervik et al., 2015).

### 1.7. Present study

According to Alexander's (2003) Model of Domain Learning students move from fragmented knowledge towards integrated knowledge in the domain. In complex domain areas such as photosynthesis, students who are still far from expertise can have relatively well-developed knowledge about some sub-topics but lack principled knowledge, which is a cohesive and well-integrated body of domain knowledge (Alexander, 2003). In the same classrooms, different students can be in different phases in their conceptual change and development towards integrated principled knowledge. Although several studies have focused on students' understanding of biological concepts, none have examined the subgroups of students with qualitatively different knowledge who are in different phases of learning photosynthesis and respiration. However, both biological processes are complex, consisting of multiple biochemical steps and different components at various system levels. The heterogeneity among students and their knowledge levels may challenge teachers and the quality of learning (Sinatra & Mason, 2008). Therefore, we aim to employ LPA to investigate the potential quantitative differences in students' knowledge of different aspects of photosynthesis and plant respiration. Students may have different learning profiles, with some demonstrating high scientific understanding in most tasks, some showing high misconceptions and some displaying various combinations of conceptual understanding, here referring to the transition phase from inaccurate preconceptions and synthetic models towards scientific understanding. Importantly, we aim to validate these different profiles

by relating them to the students' grade level, academic achievement in biology and epistemic beliefs. The present cross-sectional study addresses these issues by focusing on the following research questions:

1. What kinds of profiles of the various aspects of knowledge of photosynthesis and respiration do students have?
  - H1. Based on the findings of Schneider and Hardy (2013), we hypothesise that between students with a high level of scientific understanding and those who have knowledge dominated by inaccurate preconceptions, there will be subgroups of students who do not systematically give correct scientific answers but are still in the phase of transitioning towards scientific understanding.
2. How are students' profiles related to their grade level, academic achievement in biology and sophistication of epistemic beliefs?
  - H2. Based on previous findings in various scientific domains (e.g. Abraham et al., 1994; Ayieko et al., 2022; Takaoglu, 2018; Tarakçı et al., 1999; Tural, 2015; Uzun et al., 2013), we hypothesise that higher grade levels will be related to a higher probability of belonging to the subgroups with more scientifically correct conceptual knowledge. Nevertheless, certain misconceptions (inaccurate preconceptions or synthetic models) will still exist among students in the higher grades.
  - H3. Based on previous studies (e.g. Zakaria et al., 2010; Zulnaidi & Zakaria, 2010), we hypothesised that higher biology grades in the school year report will be related to a higher probability of belonging to subgroups with more scientifically correct conceptual knowledge.
  - H4. Based on previous studies, epistemic beliefs should support conceptual change (e.g. Greene et al., 2016; Hofer, 2018; Mason et al., 2008). Thus, we hypothesise that more sophisticated epistemic beliefs are related to the probability of belonging to subgroups with more correct scientific knowledge.

According to the Organisation for Economic Co-operation and Development (OECD, 2020), Lithuania's regional differences in several indicators, such as GDP per capita, productivity, employment and poverty, are among the largest in OECD countries. Thus, we control the regional effects when interpreting the results.

## 2. Methods

### 2.1. Participants

The participants included 1310 students from Lithuania. The study took place in 2021 in the autumn semester and focused on 7th, 8th, 9th, 10th and 11th graders. These grades were selected following the recommendations of Lithuanian biology teachers, highlighting which grades should have proper conceptual understanding about certain aspects of photosynthesis and respiration. Specifically, there were 174 (13.3 %) 7th graders, 126 (9.6 %) 8th graders, 372 (28.4 %) 9th graders, 432 (33 %) 10th graders and 206 (15.7 %) 11th graders. The gender proportion of the population was 57.8 % females and 42.2 % males, and there was an overall mean age of 15.1 years (SD = 1.98). The research was conducted in accordance with the Belmont Report (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979). This study was granted ethics approval by the Vytautas Magnus University Educational Research Institute Ethics Committee (permission number SA-EK-21-06). An informed consent form was provided to the parents, who were informed that they could withdraw their consent at any time. Students were informed about the study and their option to withdraw from the study at any time.

Seventeen schools from different Lithuanian counties (big cities, small towns and rural areas) were selected to participate so as to reach a variety of participants. The selection procedure consisted of two steps. The first step was to contact all university partner schools that had

7th–11th graders. Thirteen of the 94 partner schools agreed to participate. Given that these schools represented only 7 of the 10 counties, additional schools were contacted. During the second step, 107 additional schools received invitations, and seven schools agreed to participate. Altogether, there were 20 schools from all 10 counties in Lithuania. However, three schools declined to participate when the study began. Thus, there were 17 participating schools from nine counties. The number of participants from different counties of the country was in line with the population size in those regions, except for the two big cities, where one was underrepresented and the other overrepresented in the sample. However, the division of students between urban and rural areas was very similar to the distribution of the whole population.

According to Wurpts and Geiser (2014), traditional accounts suggest that a sample size of over 500 is sufficient for latent variable mixture models, but they noted that, with higher-quality indicators, a smaller sample size could suffice. Thus, the size of our sample met even the strictest criteria for LPA.

## 2.2. Measurements

All participants completed the test individually in the classroom during their lessons in the presence of their teacher. The time to complete the test was one lesson (45 min). The test consisted of three parts. The first part included background information questions, including grade level, gender, age and biology grade in the latest school year report (the overall level of achievement for a biology course, as determined by combining the marks of individual assessment items that make up the course from the latest school year report).

A Likert-type test about biology-specific epistemic beliefs was also used (Appendix 2). This 17-item biology-specific epistemic beliefs test was developed based on Hofer and Pintrich (1997). In formulating the items, some of the formulations from Bråten et al.'s (2009) test about epistemic beliefs in climate change were used. The test included the dimensions of certainty of knowledge, justification for knowing and source of knowledge. The simplicity dimension was not used because it had low reliability in our pilot study among young students. The Cronbach's alpha of the whole test was 0.84. The Cronbach's alpha values for the three sub-scales were 0.55 (Certainty), 0.66 (Source) and 0.80 (Justification). For the purposes of the present study, only the total score describing the sophistication of epistemic beliefs was used. Conceptual understanding test data used in this manuscript have been used in another paper, which concentrated on biological details and was published in another journal (Vančugovienė et al., 2023). The scoring of the test items, the analysis and the research questions were completely different from this paper, and the current results represent a substantial contribution on their own.

### 2.2.1. Conceptual understanding test

The second part was a conceptual understanding test (Haslam & Treagust, 1987) consisting of 13 two-tier-type questions dedicated to various subthemes of photosynthesis and respiration (Appendix 1). After every question, the students had to provide a reason for why they gave a specific answer.

The students had to choose only one of the several answers provided (depending on the question, two to four answers provided). Only one answer was scientifically correct; the others were described as synthetic models or inaccurate preconceptions. For example, one of the questions was, 'What is respiration?' The answer to this question—'The chemical process which occurs in all living cells of plants and animals'—is scientifically correct. Two other options—'A chemical process which occurs in plant cells but not in animal cells' and 'A chemical process which occurs only in animal cells but not in plant cells'—are synthetic models. A synthetic model is a statement that is partly correct and partly incorrect. An inaccurate preconception is an incorrect statement in all situations.

After the first tier, the second tier followed, during which students were asked to explain why they chose their answer. Students had to choose only one answer from several options provided (depending on the question, two to four answers were provided). In the second tier, only one answer was scientifically correct; others were described as synthetic models or inaccurate preconceptions. The students also had the option to write their own short answers. For example, taking into account the previously provided example (What is respiration?), in the second tier, four options were provided: 'Only plant cells obtain energy to live in this way' (inaccurate preconception), 'All living cells of plants and animals obtain energy to live through this process' (scientifically correct answer), 'Only animal cells need energy to live as they cannot photosynthesise' (synthetic model) or write your own answer. All answers written by the students themselves were evaluated and categorised as inaccurate preconceptions, synthetic models or scientifically correct answers.

Two biologists familiar with conceptual change theories classified the answers to the conceptual understanding test into three categories: correct scientific concepts, synthetic models (Vosniadou, 2012) and inaccurate preconceptions. Statements that were partly correct and partly incorrect were assigned to synthetic models. Statements that were scientifically incorrect were classified as inaccurate preconceptions. All questions were translated into Lithuanian, checked by two biology teachers and two biology scientists and clarified according to their comments to fit the Lithuanian curricula and newest scientific information. The reliability (Cohen's alpha) of the original version of the test was 0.72 (Haslam & Treagust, 1987). The reliability values of the Lithuanian version of the test were 0.721 (scientifically correct answers), 0.647 (inaccurate preconceptions) and 0.606 (synthetic models). The reliability of these three scales was satisfactory for knowledge tests (Schneider & Stern, 2010).

### 2.2.2. Preparation

A double-translation process was used for the test. The Lithuanian translation was translated back to English by a specialist in biology, and the similarity with the original version was checked. The pilot test took place in 2021 in two Lithuanian schools. In addition to answering the test, several students participated in individual semi-structured interviews to obtain more detailed information on how they interpreted the questions. The final version of the test was prepared based on the pilot test results and the students' comments from the interviews.

## 2.3. Data analysis

Profiles based on the students' varying conceptual understandings of photosynthesis and respiration were estimated using LPA. LPA was conducted using the correct scientific, synthetic model and inaccurate preconceptions subscales as indicators. The first- and second-tier responses were used, as described in Section 2.2.1, to perform data analysis. All responses were categorised individually, and sum scores were used. The students could obtain maximum scores of 20 inaccurate preconceptions, 18 synthetic models and 26 scientific concepts. These three scores were used as indicators of the students' conceptual knowledge of photosynthesis and respiration.

Latent profiles were estimated using Mplus version 8.0 (Muthén & Muthén, 1998–2017). The estimation method was the maximum likelihood with robust standard errors, which is a full information approach that can handle missing-at-random data. LPA models were carried out as mixture models, in which 1000 and 100 random start values were used in the first and second steps of model estimation, respectively, to ensure the validity of the solution (Geiser, 2013). Model fits were evaluated using a combination of statistical indicators and substantive theory to determine the most suitable number of latent classes and best-fitting models (Hickendorff et al., 2018; Nylund et al., 2007). Lower Akaike information criteria (AIC) and Bayesian information criteria (BIC) values indicate better-fitting models, discounting for overspecification.

Entropy values that approach 1 signify more certainty in the resulting classification. A significant result of the parametric bootstrapped likelihood ratio test (BLRT) and Lo–Mendell–Rubin (LMR) test suggested support for the k-class solution compared with the k-1-class solution. In other words, a significant result on this test suggested that the use of that model was more appropriate than a model that had one less class in it.

To validate the latent profiles, a three-step approach was employed to examine the relation between profile membership and students' grade levels, biology grades and epistemic beliefs (Asparouhov & Muthén, 2014). In the first step, profile structures were defined, and in the second step, probabilities of profile membership were assigned to each participant. In the third step, profiles were compared pairwise on an external variable. The odds ratios for membership in a particular profile compared to another are then calculated based the external variables. A higher odds ratio indicates a higher chance of being in the reference class when one has a higher value on the external variable. Importantly, the three-step approach does not affect profile membership but takes into account error in profile membership. Given that these analyses between six latent profiles and three dependent variables resulted in a large number of tests without preplanned hypotheses, we used Bonferroni correction in interpreting the *p*-values. To examine potential differences of the frequencies of latent profiles in various regions, we cross-tabulated them with the nine counties of Lithuania. In addition, general linear models with most likely latent profile memberships as fixed factors and counties as random factors were applied to examine the interaction effects of latent profiles and counties on biology grades and epistemic beliefs.

### 3. Results

The six-profile solution was chosen as the most appropriate because no minima were found for AIC or BIC nor non-significant BLRT (Table 1). The LMR adjusted likelihood ratio test revealed the six-profile solution to be more suitable than the five-profile solution, and the seven-profile solution did not appear to improve on the six-profile solution. Thus, the six-profile solution proved to be more appropriate than the others. The additional profile in the seven-profile model did not introduce any theoretically valuable information (a class with a parallel structure between two other similarly structured classes) and was, therefore, considered superfluous to the goals of the present study.

#### 3.1. Latent profiles

In total, six unique latent profiles were identified: inaccurate preconceptions, non-scientific, fragmented, synthetic, prescientific and scientific. The LPA results are presented in Fig. 1.

Two of the six profiles had very clear characteristics and were opposite to each other. Students in the scientific profile had a very low level of inaccurate preconceptions and synthetic responses but a high level of scientific concepts. This outcome shows a high amount of accurate scientific knowledge. The scientific profile included 10.7 % of all students. Students in the non-scientific profile had high levels of inaccurate preconceptions and synthetic responses but very low levels of scientific concepts. That shows a low amount of accurate scientific

**Table 1**  
Fit indices of models differing in the specified number of latent classes.

	AIC	BIC	LMRRT	BLRT	Entropy
2	10,211	10,262	<0.001	<0.001	0.73
3	9711	9783	<0.001	<0.001	0.80
4	9450	9543	<0.001	<0.001	0.81
5	9269	9383	0.01	<0.001	0.79
6	9076	9210	0.0005	<0.001	0.81
7	9002	9157	0.28	<0.001	0.79
8	8905	9081	0.21	<0.001	0.80
9	8822	9019	0.053	<0.001	0.81

knowledge. The non-scientific profile included 12.2 % of the students.

The prescientific profile had similarities with the scientific profile; students in these two profiles had higher amounts of scientific concepts compared to the other four profiles. The prescientific profile was characterised by fairly low levels of inaccurate preconceptions and synthetic responses and a moderately high level of scientific concepts. However, the levels of inaccurate preconceptions and synthetic models were higher while the level of scientific concepts was lower compared to the scientific profile. The prescientific profile included 25.4 % of the students.

The inaccurate preconceptions profile had similarities to the non-scientific profile; students in this profile had a low amount of accurate scientific knowledge as well, and the profile was characterised by a high level of inaccurate preconceptions, average level of synthetic responses and low level of scientific concepts. However, the level of inaccurate preconceptions was higher while that of synthetic models was lower compared to the non-scientific profile. The inaccurate preconceptions profile included 10.3 % of all students.

In the fragmented profile, the students had an average level of inaccurate preconceptions, synthetic responses and scientific concepts. This finding showed fragmented understanding in various sub-concepts of photosynthesis and respiration. Of the study's population, 30.1 % belonged to the fragmented profile. Students in the synthetic profile had a high level of synthetic responses compared with the inaccurate preconceptions and scientific concepts. The synthetic profile included 11.1 % of the students. The synthetic profile was different from the fragmented profile because students in the former had high amounts of answers in which the inaccurate preconceptions and scientific concepts were integral in explaining the same sub-concepts of photosynthesis or respiration. Students in fragmented profile had inaccurate preconceptions and scientific conceptions in different test items.

Cross-tabulation was used to analyse the distribution of latent profiles in different counties of Lithuania. When latent profiles were cross-tabulated with counties, there was no significant relationship, Chi2 (40) = 46.38, *p* = .226.

#### 3.2. Students' profiles in relation to their grade level, academic achievement in biology and sophistication of epistemic beliefs

Table 2 shows the distribution of students' most likely profile membership by grade level. Fragmented and synthetic profiles were equally frequent in all grade levels. Inaccurate preconception and non-scientific profiles were typical for lower grade levels whereas prescientific and scientific profiles were most frequent among 11th graders. Only <1 % of 7th graders belonged to the scientific profile. The three-step approach revealed that the scientific profile was more likely to have older students in it than all the other profiles, except the synthetic profile (odds ratios >1.31, SEs < 0.18, *ps* < .004). Based on the distribution of most likely class memberships, it appears that this relation may be especially driven by fewer 7th graders in the scientific profile than would be expected. No other statistically significant differences were observed between the profiles in students' grade levels.

Table 3 presents students' biology grades by most likely profile membership. The three-step approach revealed substantial differences in biology grades between the profiles. The scientific profile had significantly higher biological grades than all the other profiles (odds ratios >1.50, SEs < 0.18, *ps* < .005). The prescientific profile had significantly higher biological grades than the inaccurate preconceptions (odds ratios >2.35, SEs < 0.26, *p* < .001), non-scientific (odds ratios >2.35, SEs < 0.22, *p* < .001) and fragmented (odds ratios >1.52, SEs < 0.12, *ps* < .001) profiles. The synthetic profile had significantly higher biological grades than the inaccurate preconceptions (odds ratios >2.00, SEs < 0.27, *p* < .001) and non-scientific (odds ratios >1.99, SEs < 0.25, *p* < .001) profiles. The fragmented profile had significantly higher biological grades than the inaccurate preconceptions (odds ratios >1.55, SEs < 0.16, *p* = .001) and non-

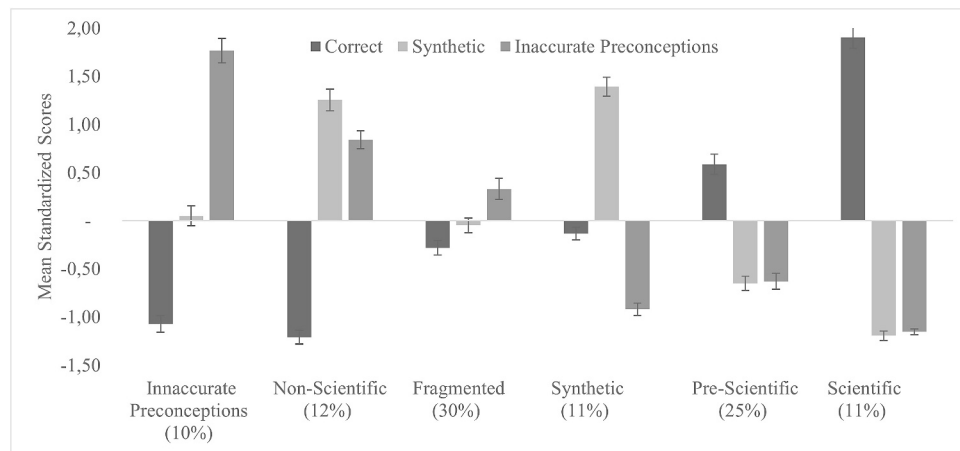


Fig. 1. Mean standardised scores of correct scientific concepts, synthetic models and inaccurate preconceptions by latent profiles. Error bars represent ±1 S.E. The values do not sum to 100 % because of rounding.

Table 2 Percentages of profiles at each grade level.

Profile	7th grade %	8th grade %	9th grade %	10th grade %	11th grade %
Inaccurate preconceptions	29.3	24.8	28.4	22.4	19.8
Non-scientific	13.8	14.4	10.5	10.6	5.9
Fragmented	29.3	28.0	28.7	32.6	31.0
Synthetic	12.1	12.0	11.5	13.3	11.8
Prescientific	14.9	12.0	14.7	13.7	21.4
Scientific	0.6	8.8	6.2	7.3	10.2

Table 3 Biology grades in the latest school year report.

Profile	N	Mean	Std. deviation	Std. error	95 % confidence interval	
					Lower bound	Upper bound
Inaccurate preconceptions	134	7.09	1.474	0.127	6.84	7.34
Non-scientific	159	7.09	1.314	0.104	6.88	7.29
Fragmented	395	7.82	1.286	0.065	7.70	7.95
Synthetic	145	8.18	1.383	0.115	7.95	8.41
Prescientific	333	8.42	1.131	0.062	8.30	8.54
Scientific	141	8.87	1.016	0.086	8.30	9.03
Total	1307	7.96	1.378	0.038	7.89	8.04

Table 4 Epistemic beliefs of students by most likely profile membership.

Profile	N	Mean	Std. deviation	Std. error	95 % confidence interval	
					Lower bound	Upper bound
Inaccurate preconceptions	136	3.46	0.50	0.13	3.38	3.55
Non-scientific	160	3.50	0.56	0.13	3.41	3.58
Fragmented	395	3.60	0.50	0.07	3.55	3.65
Synthetic	145	3.72	0.50	0.12	3.64	3.80
Prescientific	333	3.68	0.46	0.08	3.63	3.73
Scientific	141	3.83	0.49	0.13	3.74	3.90
Total	1310	3.63	0.51	0.04	3.60	3.66

scientific (odds ratios >1.54, SEs < 0.13,  $p < .001$ ) profiles.

Table 4 presents students' epistemic beliefs by most likely profile membership. The three-step approach revealed substantial differences in epistemic beliefs between the profiles. The scientific profile had significantly higher epistemic beliefs score than prescientific (odds ratios >1.39, SEs < 0.13,  $p = .003$ ), fragmented (odds ratios >1.34, SEs < 0.10,  $p < .001$ ), non-scientific (odds ratios >1.60, SEs < 0.17,  $p < .001$ ) and inaccurate preconceptions (odds ratios >1.69, SEs < 0.18,  $p < .001$ ) profiles. The prescientific profile had significantly higher epistemic beliefs score than the inaccurate preconceptions (odds ratios = 1.39, SEs = 0.13,  $p = .003$ ) and non-scientific (odds ratio = 1.32, SE = 0.12,  $p = .009$ ) profiles. The synthetic profile had significantly higher epistemic beliefs score than the inaccurate preconceptions (odds ratio = 1.51, SE = 0.16,  $p = .002$ ) and non-scientific (odds ratio = 1.42, SE = 0.15,  $p = .005$ ) profiles.

Finally, according to the results of the general linear model with county as random factor, there was no significant interaction effect of latent profiles and counties on epistemic beliefs,  $F(39) = 1.20, p = .19$ , or biology grades  $F(39) = 1.09, p = .329$ . These results suggest that the relation between profile memberships, epistemic beliefs and biology grades was not due to regional differences.

#### 4. Discussion

The purpose of this study was to provide a better understanding of the different learner profiles among 7th–11th-grade students regarding their conceptual understanding of the biological topics of photosynthesis and respiration. These learner profiles were validated using the grade level, biology grades and discipline-specific epistemic beliefs of the students. Based on the conceptual understanding survey, six unique latent profiles were identified, all of which had individual characteristics according to the level of scientific concepts, synthetic models and inaccurate preconceptions. Our findings of the latent profiles are somewhat similar to previous studies in the field of physics education (Edelsbrunner et al., 2018; Schneider & Hardy, 2013). Scientific and prescientific profiles were the profiles with high scientific understanding and few synthetic conceptions and inaccurate preconceptions. These two profiles consisted of a little more than one-third of the study population. In contrast, the so-called non-scientific and inaccurate preconception profiles were characterised by substantial amounts of inaccurate preconceptions and synthetic models. These two learning profiles consisted of little more than one-fifth of the participants, indicating that some of the participants in the present study had a relatively poor level of conceptual understanding regarding photosynthesis and respiration.

In addition, there were two somewhat dissonant subgroups of

participants: fragmented and synthetic profiles. The fragmented profile was the most common profile and included students with almost average scores in all three categories: scientific, synthetic and inaccurate preconceptions (Edelsbrunner et al., 2018; Schneider & Hardy, 2013). Among the students belonging to the fragmented profile, certain sub-concepts within the complex content areas of photosynthesis and respiration were better understood, while other sub-concepts were poorly understood. This finding refers to the lack of coherence of knowledge of different sub-topics of the domain described in the Model of Domain Learning (Alexander, 2003). Previous studies among school students have shown that fragmentation and integration of knowledge are the two key steps related to conceptual change (Schneider & Hardy, 2013).

Students belonging to the synthetic profile (called the 'intermediate profile' in Edelsbrunner et al., 2018) had several synthetic models but only a few scientifically correct ideas or inaccurate preconceptions. The synthetic profile may indicate the coexistence of scientific conceptions and inaccurate preconceptions regarding certain sub-concepts among the students belonging to this profile (Potvin & Cyr, 2017; Shtulman & Legare, 2020; Vosniadou et al., 2018). According to Vosniadou and Brewer (1992), synthetic models act as natural, intermediate steps in the change from inaccurate preconceptions to scientific understanding. Hence, we hypothesised that students belonging to either the synthetic or fragmented profile might be in a transition phase towards a more sophisticated understanding regarding the themes of photosynthesis and respiration.

The results of this study also showed that the profiles appear to exhibit hypothesised patterns of relations with external variables. The sophistication of the students' epistemic beliefs and their profiles of conceptual understanding of photosynthesis and respiration were related to each other. The two profiles with the highest scientific knowledge and lowest inaccurate preconceptions or synthetic models also had the highest epistemic beliefs scores, while the profile with high inaccurate preconceptions and low scientific knowledge had the lowest epistemic beliefs scores. These results are in line with previous studies, in which the sophistication of students' epistemic beliefs was shown to relate to their level of understanding and learning regarding scientific topics (Sinatra et al., 2014; Windschitl & Andre, 1998). For students who understand the self-correcting, dynamic and evolving nature of scientific knowledge and can judge the trustworthiness of the knowledge source, it is possible to change their conceptions based on scientific findings when necessary (Ferguson, 2015; Lin & Tsai, 2017). However, in our study, the students belonging to the synthetic profile also had relatively high scores for epistemic beliefs. This study did not investigate the causality between conceptual understanding and epistemic cognition, yet these results might strengthen the hypothesis that students in the synthetic profile are on their way towards a more scientific conceptual understanding. The recent meta-analysis showed that epistemic cognition interventions had a statistically significant, medium-level effect on academic achievement (Cartiff et al., 2020). Thus, it could be hypothesised that epistemic cognition interventions might impact knowledge accuracy and coherence. However, the quality and causality of the interrelation of discipline-specific epistemic cognition and conceptual understanding require further studies.

The results of validating students' latent profiles by (teacher-rated) academic achievement in biology supported our hypothesis. The students' academic achievement and conceptual understanding of photosynthesis and respiration were clearly related. There were two profiles with the highest scientific knowledge and lowest inaccurate preconceptions or synthetic models that received the highest grades in the biology subject, whereas the profile with high inaccurate preconceptions and low scientific knowledge received the lowest grades. These results were consistent with previous studies in mathematics education that showed the relation of academic achievement with conceptual understanding (Zakaria et al., 2010; Zulnaidi & Zakaria, 2010). According to Szu et al. (2011), course grades significantly correlate with

conceptual understanding: high-achieving students, as measured by course grades, score higher on measures of conceptual understanding tasks. In our study, the students belonging to the synthetic profile also had relatively high grades in the biology subject; only the students belonging to the scientific profile had higher grades. These findings might contribute to strengthening the hypothesis that students in the synthetic profile are approaching a more scientifically correct conceptual understanding.

Lastly, the results of validating students' latent profiles by grade level also supported our hypothesis. Our results uncovered clear individual differences in students' conceptual knowledge, even within grade levels; all latent profiles, including the inaccurate preconceptions profile, could be found in all grade levels. This outcome aligns with previous studies in various fields reporting that students in all age groups have similar inaccurate preconceptions (Kurnaz, 2012; Uzun et al., 2013). However, the scientific profile, which includes students with the smallest number of inaccurate preconceptions and synthetic models, was more common among higher-grade students compared with lower-grade students. This result is in alignment with studies in biology (Tarakçi et al., 1999), mathematics (Ayieko et al., 2022), chemistry (Abraham et al., 1994) and physics (Tural, 2015) stating that students' conceptual understanding improves over the schooling years. We hypothesise that teaching at schools is not fully effective because, even if students improve their understanding of various concepts by grade, inaccurate preconceptions are still present, even in the highest grades. Therefore, various teaching interventions should be tested to improve teaching effectiveness.

#### 4.1. Pedagogical implications

The present study has shown that there may be significant variance among students in terms of their level and quality of understanding of central biological topics, even within the same classroom. Teachers should be aware of this and allocate time to obtain an understanding of the students' level and quality of prior knowledge. Pedagogical decisions should be made accordingly so that the instruction better matches the needs of different learners. In our study, the most common single profile was the fragmented one. Hence, teachers should pay particular attention to helping learners integrate correct fragments of information into a full, systemic understanding as well as encourage them to critically evaluate and compare their existing conceptions with scientific explanations (Linn, 2006).

A central characteristic of learning biology is that it requires a certain type of understanding of how different levels of organisation, such as molecules, cells, organisms, populations and ecosystems, are interrelated. This is referred to as systemic understanding (Momsen et al., 2022; Verhoeff et al., 2018). Many of today's pressing ecological challenges, such as climate change and biodiversity loss, are complex systems that require an understanding of basic biological concepts and processes, such as photosynthesis and respiration (Janssen et al., 2014). However, school instruction has faced criticism, such as the tendency to break down biological processes into isolated facts rather than considering them as interconnected systems (Plate, 2010). Photosynthesis and cellular respiration are typically presented as separate concepts in biology classrooms and learning materials, resulting in a more surface-level comprehension (Brown & Schwartz, 2009). Previous studies have also shown that preservice teachers themselves may encounter challenges in grasping these topics and are likely to struggle in creating learning environments that would lead to a systemic understanding in their classrooms (Södervik et al., 2014).

The results of the present study support the view that, to improve the understanding of science, students need to reconstruct both their conceptual understanding and epistemic cognitive processes (Sinatra & Chinn, 2011). Thus, promoting the sophistication of students' scientific epistemic beliefs is of the utmost importance in science classrooms. Teachers should address the topic of the nature of knowledge while taking into account important aspects of discipline-specific epistemic

beliefs for students to understand the nature, foundation and principles underlying scientific research and the empirical grounds for acceptance (Bråten et al., 2009). According to previous studies, even short interventions may be beneficial in supporting epistemic change (Cartiff et al., 2020). Instruction should work towards building both the conceptual understanding and epistemic competence of students by supporting them in evaluating the source and worthiness of evidence (Hofer, 2018; Murphy & Alexander, 2016).

#### 4.2. Limitations

This study has been constrained by certain factors that need to be considered when the results are interpreted and generalised. As highlighted in the theoretical introduction, conceptual change is a long-lasting process that occurs through many phases. However, this study was cross-sectional and unable to uncover the developmental dynamics of conceptual learning. It only provided a description of different conceptual profiles that students had at a certain phase of learning. Thus, longitudinal studies that could analyse transitions between profiles are needed in the future.

The ratio of different age groups in the study population was not balanced. The sample was not completely random because a large number of schools nominated in the original sample did not agree to participate and were replaced by other schools. Although the conceptual understanding test used was designed to measure conceptual understanding, a multiple-choice test always carries the possibility of guessing or relying on superficial recognition rather than indicating deep conceptual understanding. Therefore, the test may not completely capture nuances in understanding. In this sample of young students, the research instrument of epistemic beliefs did not fully follow the theoretical assumptions based on the original model of Hofer and Pintrich (1997). It was, however, in line with other studies that have found inconsistent results with regard to epistemic beliefs measures and have not been able to identify the four dimensions in Hofer and Pintrich's (1997) theoretical framework (e.g. Bråten et al., 2009). As an example, in Bråten et al. (2009), the simplicity subscale did not yield consistent results across all student samples. Therefore, we opted to exclude it. Finally, to capture the complex nature of these biological concepts, it would be important to apply qualitative methods and a longitudinal research design.

#### 5. Conclusion and future studies

The main contribution of this study is that it uncovered distinct

patterns in students' knowledge, ranging from inaccurate pre-conceptions to scientific knowledge, which may represent potential stages of learning. These findings can open new ways to organize teaching that will help students to develop a correct understanding of complex phenomena such as photosynthesis and respiration. The major finding is that, between the scientific and non-scientific understanding of photosynthesis and respiration, several different conceptual profiles exist. Even though the results are based on cross-sectional results, these findings increase our understanding of the various steps from misconceptions to scientific understanding. In the future, longitudinal studies are necessary to investigate how students' conceptual profiles, together with related factors, develop over time and school years. Other designs (longitudinal) and methods (interviews, think alouds) should be used to capture nuances in understanding in further studies. In addition, the crucial next steps should include designing and testing teaching interventions and providing opportunities for students to develop their conceptual understanding.

#### Statements on ethics

Appropriate permission and ethical approval were obtained for the study.

#### Funding sources

There was no special funding provided in order to conduct this study.

#### CRediT authorship contribution statement

**Vesta Vančugovienė:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Ilona Södervik:** Conceptualization, Data curation, Methodology, Supervision, Writing – review & editing. **Erno Lehtinen:** Conceptualization, Formal analysis, Methodology, Project administration, Supervision, Writing – review & editing. **Jake McMullen:** Formal analysis, Methodology, Software, Visualization, Writing – review & editing.

#### Declaration of competing interest

The authors declare no conflicts of interest.

#### Appendix 1. 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 takes 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 takes 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.

. (continued).

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?**

. (continued).

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.

. (continued).



C Carbon dioxide + water + energy → glucose + oxygen

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.*

. (continued).

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 stomates during photosynthesis.
- 4 \_\_\_\_\_

**13. 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 strats 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 \_\_\_\_\_

. (continued).

**Appendix 2. Epistemic beliefs test**

Please answer the following questions according to your current ideas. There are no right or wrong answers.	1 = disagree 2 = somewhat disagree 3 = neither agree nor disagree 4 = somewhat agree 5 = agree				
Biology knowledge is continuously changing	1	2	3	4	5
Biology research problems often do not have one clear and precise solution	1	2	3	4	5
Certainty in biology knowledge is rare.	1	2	3	4	5
Critical thinking is important when assessing the accuracy of biology information.	1	2	3	4	5
Facts originating from biology research do not change over time.	1	2	3	4	5
In order to gain deep understanding on biology phenomena one must form his/her own understanding of the content.	1	2	3	4	5
In order to trust news on biology research findings it is important to find out to which original research data are they based on.	1	2	3	4	5
Knowledge originating from biology research may be proven as false any time.	1	2	3	4	5
Media sometimes reports on biology information that contrasts scientific knowledge.	1	2	3	4	5
Research data on biology research is preliminary in nature.	1	2	3	4	5
To find out whether what I read about biology is trustworthy, I try to compare knowledge from multiple sources	1	2	3	4	5
When acquiring new information on biology questions, I try to assess its reliability by comparing it to things I have previously learned.	1	2	3	4	5
When I read about issues related to biology, I try to form my own understanding of the content	1	2	3	4	5
When reading information related to biology, I pay attention to the reliability of the information source.	1	2	3	4	5
When reading news related to biology topics, I assess the logics of its contents.	1	2	3	4	5
Within biology research, knowledge is complex	1	2	3	4	5
Within biology research, there are connections among many topics	1	2	3	4	5

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