ORIGINAL ARTICLE

Pre-Service Science Teachers' Conceptual Integration Understandings in Explaining the Subject of Metabolism with the Concepts of Physics and Chemistry

Mustafa Hamalosmanoğlu

Erciyes University, Kayseri, Turkey

***Abstract**: This study focuses on exploring pre-service science teachers' conceptual integration understandings in explaining the subject of metabolism with the concepts of physics and chemistry. Action research was employed in this study. Nine pre-service science teachers taking the General Biology II course participated. Participants were taught metabolism considering conceptual integration. Data were collected via paper-and-pencil questionnaire administered before and after the intervention. The results showed that the pre-service science teachers could not understand physics and chemistry concepts at a sufficient level while explaining metabolism. Although the activities and practices were executed for conceptual integration in the action plan, only three participants achieved complete conceptual understanding for better conceptual integration at the end of the course in the first question. Thus, future studies could design interventions to be effective in conceptual integration. Further research could also design experimental investigations to examine how conceptual integration is necessary for establishing the relationship between science and other fields.*

Science Insights Education Frontiers 2024; 24(2):3927-3949
DOI: 10.15354/sief.24.or636

How to Cite: Hamalosmanoğlu, M. (2024). Pre-service science teachers' conceptual integration understandings in explaining the subject of metabolism with the concepts of physics and chemistry. Science Insights Education Frontiers, 24(2):3927-3949.

***Keywords**: Action Research, Conceptual Integration, Metabolism, Pre-Service Science Teacher, Science Education*

***About the Author**: Mustafa Hamalosmanoğlu, Associate Professor, Department of Science Education, Erciyes University, Kayseri,Turkey, E-mail: hamalosmanoglu@erciyes.edu.tr, ORCID: https://orcid.org/0000-0002-1126-0268*

***Correspondence to**: Prof. Mustafa Hamalosmanoğlu at Erciyes University in Turkey.*

***Conflict of Interests**: None*

***Funding**: No funding sources declared.*

***AI Declaration**: The author affirms that artificial intelligence did not contribute to the process of preparing the work.*

Introduction

INTERDISCIPLINARY learning is a curriculum approach that enhances and enriches learning by meaningfully combining multiple disciplines or subject areas (Cone, et al., 1998). Klein (1990) and Newell (1998) suggested four major steps for interdisciplinary education; determining the problem, determining the disciplines to be integrated, drawing an integrating framework plan by determining the concepts of each discipline, and integrating with the current information in the disciplines. Students can benefit in many ways from the application of interdisciplinary education. They may, for instance, have an increased sensitivity to ethical issues, have a better ability to synthesize or integrate, broaden their perspectives or horizons, become more creative, original, demonstrate unconventional methods of thinking, have more humility, increase their listening skills, or have an increased level of sensitivity to prejudice (Newell, et al. 1990, pp.70-71). Interdisciplinary education enables teachers to identify areas of learning. Moreover, students actively use the concepts of different disciplines in their learning processes (Lederman & Niess, 1997). Many education systems expend high levels of time, effort, and resources to educate qualified individuals equipped with 21st-century skills. These skills are mainly problem-solving, critical thinking, entrepreneurship, creativity, innovation, communication, co-operation, information, and technological literacy (Koenig, 2011). To acquire these skills, individuals need to think multidimensionally and relate multiple disciplines to one another (Daugherty, 2013). This approach positively contributes to the improvement of individuals' 21st-century skills and the meaningful learning of concepts (Crowther, 2012; diSessa, 1993; Taber, 2008). Thus, this study was guided by the interdisciplinary approach and aims to explore pre-service science teachers (PSTs)' conceptual integration (CI) of physics and chemistry concepts in explaining metabolism. The metabolism unit is among the most crucial biology units, and it is necessary to utilize the concepts taught within various physics and chemistry units to meaningfully learn it (Yip, 1998). For these reasons, this unit was chosen.

In the literature, CI is defined as the ability to establish relationships between concepts by using the prerequisite knowledge of a discipline while learning information regarding another (Taber, 2003a; Toomey & Garafalo, 2003). For instance, external respiration can be defined in biology as the exchange of carbon dioxide in the blood and oxygen with the air using the lung. A plausible explanation of the same phenomenon by an individual utilizing CI might be as follows: An individual, while inhaling, expands their chest cavity volume by tightening their diaphragm and opening their ribs. In this way, the oxygen fills the lungs in the chest cavity, which has a lower pressure than the atmospheric pressure, and mixes with the blood. Carbon

dioxide also passes from the blood to the lung. After the transition, the exhaling individual reduces the volume of their chest cavity by loosening their diaphragm and narrowing their ribs. Hence, the chest cavity, which has a higher pressure than the atmospheric pressure, compresses the lungs inside and sends the air filled with carbon dioxide into the atmosphere (Reece et al., 2015). Therefore, the individual in question will have utilized both the concept of pressure learned in physics and Boyle's law learned in chemistry. However, Taber (2003b) has stated that learners do not tend to bring relevant physics concepts to mind when learning about chemistry. Similarly, students may not bring relevant physics and chemistry concepts to mind when learning about biology. For meaningful learning to occur in the area of biology, the use of chemistry and physics concepts could be crucial. In fact, learning biology using the symbolic and microscopic language of chemistry could be very important to give students 21st-century skills. Although CI is essential, students consider it to be an unreasonable demand to use the concepts of other fields in the learning of science (Taber, 1998). Therefore, this study is crucial as it explains that the concepts of chemistry and physics should be used in the learning of biology.

Previously conducted studies have indicated that the CI of the disciplines reduced students' misconceptions (Çıray, 2010; Ganaras, et al., 2008; Taber, 2003b) and improved their scientific thinking (Taber, 2003a; Taber, 2008b). For instance, Çıray (2010) reported that interdisciplinary analogy-based teaching was effective in improving junior high school students' academic achievements and simultaneously reduced their misconceptions. Thus, it is necessary to acknowledge how to facilitate sufficient conceptual integration across different teaching disciplines (Authors, 2016).

The interdisciplinary approach suggests that students' 21st-century skills will increase through the integration of concepts in different disciplines (Xie, et al., 2015). Although the interdisciplinary approach has been started to be integrated into curricula at different levels of education, the concepts of different disciplines have been taught without being linked to one another (Akpınar & Ergin, 2004). One of the main reasons for this circumstance is the teachers who have difficulty using the interdisciplinary approach (Stinson, et al., 2009). For instance, Dervisoglu and Soran (2003) have discovered that most biology teachers are not equipped with knowledge regarding interdisciplinary teaching. Authors of a previously conducted study (2018) have stated that science teachers and PSTs had insufficient knowledge regarding CI, as they had not previously received training for an interdisciplinary approach. Consequently, CI is essential for the achievement of meaningful learning, the development of scientific thinking, the reduction of misconceptions, and the acquisition of science literacy and 21st-century skills. Therefore, teachers have great responsibilities for enabling students to

use CI effectively. In this respect, further studies should be conducted to investigate pre-service teachers' subject-matter knowledge about CI (Caudill, et al., 2010; Godrick & Hartman 2000).

Previously conducted studies found in the literature have mainly focused on the CI of students at secondary and university levels or integrating the concepts across two disciplines (Salah & Dumon, 2011, 2014; Taber, 2008; Toomey & Garafalo, 2003). Moreover, investigations have concluded that the integration of biology, physics, and chemistry concepts is at an insufficient level (Authors, 2018). This study consequently investigated how PSTs integrate physics and chemistry concepts in their teaching of the concept of the metabolism. The following research questions guided the study:

- Can PSTs use the physics and chemistry concepts while explaining the concepts in the metabolism unit? How?
- Does the instruction considering conceptual integration contribute to PSTs to explain the concepts in the metabolism unit by using the concepts in physics and chemistry? How?

Methodology

Research Design

This study employed the action research method. In action research, the researcher identifies one or more problems and prepares an action plan regarding them. Similarly, they gain an understanding on whether or not the aforementioned action plan was effective in resolving the aforementioned problem(s). Hence, the researchers attempt to conclude the study by finding an appropriate solution to the problem (Creswell, 2009). In this study, the initial extent of the CI in PSTs during the teaching of the metabolism was determined. Afterwards, an action plan was designed and implemented to help participants achieve the desired CI level.

Study Group

The study group was determined using purposeful criterion sampling in which one or more criteria are used in the determination of participants (Merriam, 2009). In this study being conducted on PSTs, taking the "General Biology-II" course for the first time was the criteria set in determining the participants. Therefore, the participants consisted of sophomore PSTs at a public university in Turkey. Nine students who volunteered to participate in the study were selected. The participants consisted of eight women and one man. All names depicted throughout the study are pseudonyms. The study was conducted in accordance with ethical rules, and the participants filled

out an informed consent form regarding their participation. The PSTs had graduated from four-year teacher education programs. They were required to take many courses regarding biology, chemistry, physics, mathematics, teaching as a profession, and general culture, and to complete the program in a total of 148 credits of coursework.

Data Collection Tool(s)

Data was collected via a paper-and-pencil questionnaire. In the questionnaire, the participants were asked questions regarding how they could integrate physics and chemistry into some concepts related to metabolism. The questionnaire included six questions concerning the topic "metabolism", in which students could integrate physics and chemistry. The questions were prepared based on the content of related literature texts (Bozcuk, 2004; Keeten, et al., 1999; Reece, et al., 2015). The contents of the questions were as follows; "The concept of energy and its types", "The importance of energy to living things", "The differences in the chemical structures of oil", "The differences in the mechanisms of moving of living things", "The importance of energy conservation for living things", "How living things produce their energies.". The questions were examined by two experts of science education to ensure the validity of their content.

The Data Collection Process

The data of the study was collected via paper-and-pencil questionnaires administered to nine PSTs before and after the application of the intervention (**Figure 1**). The PSTs were given 50 minutes to complete the questionnaire. The PSTs' answers to the questionnaire before the intervention were analyzed, and the extent to which PSTs integrated physics and chemistry concepts in their explanations of the concept of the metabolism was determined. Following the intervention, the students were given the questionnaire once again to determine whether the PSTs integrated physics and chemistry concepts at a sufficient level in the process of explaining the metabolism.

Action Plan

The intervention consisted of a three-week action plan in which the PSTs were taught the topic of metabolism, with consideration being paid to CI. The class assembled for six 50-minute periods per week. Metabolism was taught considering concepts such as energy, photosynthesis, heat, temperature, chemical reaction, light, and mass and using various activities such as videos, experiments, and portfolios for three weeks by the first

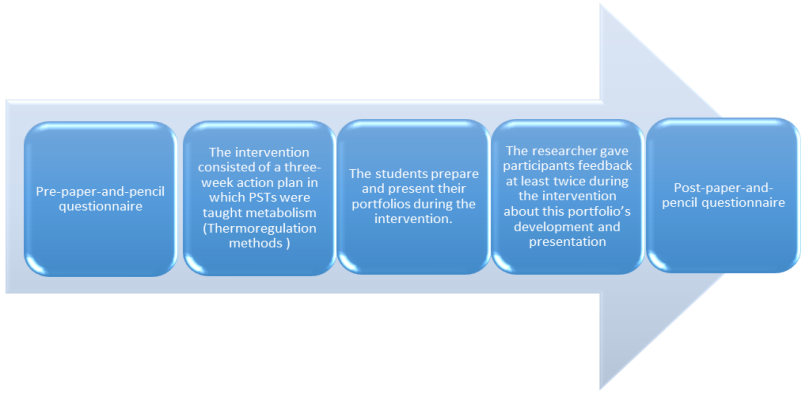


Figure 1. Data Collection Process.

Table 1. Biology Course Based on Conceptual Integration.

Question No	Biology Lesson for Previous Years	Biology Lesson Based on Conceptual Integration	
		Physics	**Chemistry**
1	• Living things need energy. • Chemical energy (focus on ATP) • Explaining the transport of energy through only the ATP	Energy is the ability to do work.	• Energy can be obtained through chemical changes. • One of the most important energy sources is found in atomic nuclei.
		Potential, kinetic, heat, light, electricity, nuclear, and sound energy etc.	Potential, kinetic, and chemical energy etc.
		Explaining the energy transfer using the concept of heat energy in addition to ATP	Explaining the energy transfer using the concept of chemical energy in addition to ATP
2	• Living things obtain energy from food. • Foods that provide energy are carbohydrates, fats, and proteins.	Living things use light energy. Thus, they heat the water with sunlight and generate electricity with solar panels.	Symbolic display of reactions using ATP as energy source $6CO_{2(g)} + 6H_2O_{(aq)} \rightarrow C_6H_{12}O_{6(s)} + 6O_{2(g)}$
3	• Olive oil and Sunflower oil are obtained from plants, while butter is obtained from animals. • Vegetable oils are liquid at room temperature, while butter is an emulsion. • Vegetable oils are unsaturated, and butter is saturated fats.	-	The differences between the chemical formulas of these oils have been examined. Symbolic level was used to explain the differences.
4	• Animals actively make relocation movements. • They make these movements using their muscles and skeletons. • Movement in plants is in the form of tropism (orientation) and nastic.	• Explaining the physical strength, suction pressure, the pushing and pulling forces that muscles create with contraction and relaxation in animals. • Explaining the movement of plants by factors such as light, temperature and pressure	-
6	• ATP is an organic compound involved in energy conversions in all living cells. • ATP is a special nucleotide containing the adenine base, ribose sugar and three groups of phosphates.	-	Explain the structure of the ATP using microscopic and symbolic levels in chemistry

researcher. During the activities, the relevant topic or concept was explained using not only the concepts of biology, but also the concepts of chemistry and physics.

Table 1 depicts CI in the current biology course for each question the fifth, as well as the content of the biology course conducted in the previous years without using CI. For the fifth question, the first researcher explained in previous years during biology lessons why our body remained at the same temperature with the following definition:

"Body temperature is kept constant by homeostasis. People are warm-blooded creatures. The body temperature of warm-blooded creatures is always constant. Energy is constantly produced and expended in the human body. Meanwhile, the heat released allows the body to warm up. There is a center that controls body temperature. At the same time, the skin provides insulation to maintain body temperature. Excess heat is given by evaporation. In this way, the human body always remains at the same temperature."

However, in the study, the first researcher used thermoregulation methods to achieve CI. Thus, he explained the concepts of convection, conduction, and electromagnetic radiation in physics, and evaporation in chemistry at an in-depth level. Thus, the students realized that enzymes cannot catalyze reactions by denaturing at extreme temperatures and that the body is cooled by thermoregulation methods such as evaporation and convection. Additionally, the students understood that the system had to fulfill its functions in order to live in accordance with the laws of thermodynamics. Thus, they realized that the heat energy to be given to the system while the work is being done and the heat energy released from the system should be equal. As a result, they realized that physics and chemistry lessons should be integrated with biology concepts to understand the thermoregulation methods. The students were required to prepare and present their portfolios after the first administration. Their portfolios included the subject topic, concept maps, puzzles, essays, stories, etc. The researcher gave participants feedback at least twice during the intervention about the aforementioned portfolio's development and presentation. Moreover, this researcher gave participants feedback regarding their portfolios after the intervention until the second administration was conducted.

Data Analysis

Content analysis, an unobtrusive technique used to analyze unstructured data in terms of meanings, symbolic qualities, and expressive contents (Krippendorff, 2013), was employed in this study. Newell (2001) stated that

better integration will ensure complete understanding. Thus, while assessing the PSTs' answers to the questionnaire, the following criteria were used:

- Complete Conceptual Understanding (CCU): The participant should provide a complete conceptual understanding for better conceptual integration
- Partial Conceptual Understanding (PCU): The participant should provide a partial conceptual understanding for weak conceptual integration.
- No Conceptual Understanding (NCU): The participant should not provide any conceptual understanding for conceptual integration.

For instance, the following answer to the question "Explain one of the sources of energy used by living things with their reasons" was regarded as NCU as it was answered only through the utilization of only biology concepts: One of the energy sources utilized by living beings is light. Light is a renewable source of energy. It is the source of life. All living beings on earth continue their lives in the presence of light. Plants perform photosynthesis by using the energy in sunlight and thus produce food. Moreover, the following answer to the same question was rated as CCU: One of the sources of energy used by living beings is light. Plants perform photosynthesis by using the energy of the light from the sun, the carbon dioxide (CO_2) in the atmosphere, and minerals from the soil and water (H_2O). As a result of this process, glucose ($C_6H_{12}O_6$) and oxygen (O_2) are produced. This expression is shown at the symbolic level as depicted below.

$$6CO_{2(g)} + 6H_2O_{(aq)} \xrightarrow[\text{Chlorophyll}]{\text{Light Energy}} C_6H_{12}O_{6(s)} + 6O_{2(g)}$$

On the other hand, as indicated above, all wavelengths of light energy are not utilized in photosynthesis. Plants absorb the light in the wavelength range of 380-700 nm to perform photosynthesis. This light energy from the sun is generated during the transformation of hydrogen molecules into helium atoms. Here, light energy at this wavelength range is used in photosynthesis since the chlorophyll molecule can only absorb light energy at this wavelength.

The answer depicted above successfully demonstrated that the PST utilized physics and chemistry concepts such as the symbolic and microscopic language of chemistry, chemical reactions, and the wave theory of light to explain why light is a source of energy. Finally, the answers including biology and chemistry concepts or biology and physics concepts, but only to some extent, were categorized as PCU. Two researchers read both the questionnaire responses and the portfolios separately. They later got together and reached an agreement on different codes. Finally, the third researcher checked the codes. After the three researchers agreed on the codes,

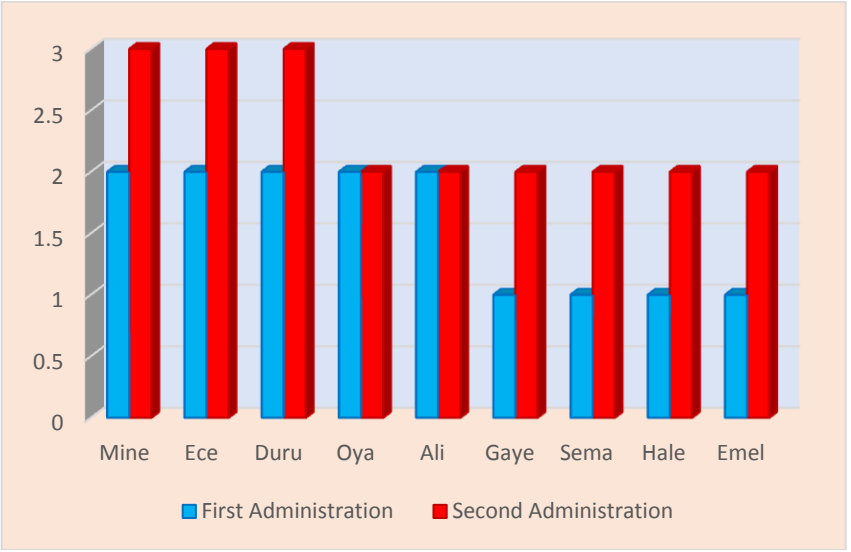


Figure 2. The Changes in Participants' Conceptual Integration for Question 1.

another science educator checked them and brought the analysis to its conclusion. The coding conformity percentages were calculated according to Miles and Huberman's (2015) formula resulting in a value higher than 80% indicates that the research is reliable (Miles & Huberman, 2015). The coding conformity percentage was found as 82%. Internal validity was thusly achieved. The analysis of the portfolios was carried out according to the three categories mentioned above. The evidence was gathered from participants' portfolios for all three categories. To increase the internal validity of the study, the participants' thoughts were depicted in the form of an excerpt. Additionally, the codes generated as a result of data analysis were submitted to be controlled by an expert.

Result and Discussion

Changes in Participants' Conceptual Integration for the Question of "Energy and its types"

The integration categories of the participants based on their responses to the questions of "What do you think energy is?", "What types of energy are there?", and "Explain one of the types with examples" during the first and second administrations were depicted in **Figure 2**.

As can be seen in **Figure 2**, five PSTs were able to partially utilize CI during the first administration while the others could not fulfill the CI

criteria. On the other hand, it was observed that three PSTs could fulfill the requirements for complete CI, while six participants demonstrated partial CI in the second administration. Furthermore, examples from some participants' portfolios were presented to support both the first and second administrations' data.

Ece, who scored partial CI in the first administration, stated that "*...It can be measured with some tools in many ways. The units can be joules, calories, etc.*" Ece also wrote similar statements in her summary of the topic in the portfolio she prepared after the first administration, and defined heat energy as "*It is the energy transferred from high-temperature area to low-temperature area". Moreover, she explained the calorie, as the unit of heat energy, as* "*...it can be used as a unit of heat".* In the second administration, Ece completed the CI by writing the following expression*: "...energy is the capacity to make any change in something. There are many different forms of it such as chemical energy, potential energy, kinetic energy, heat, nuclear energy, etc. While some can be measured by a device, there are special formulas for some to be calculated. Heat can be measured by a calorimeter. It is also calculated by the formula Q = m.c.dt. The unit of energy is calories or joules.*" Ece rewrote her previous summary following the instruction and feedback given by the first researcher and reached complete conceptual understanding (CCU). Ece's sentences in her summary supporting her CCU were as follows:

"As the most general definition of energy, it is the capacity to do work. It is the ability to move matter against opposing forces such as gravity and friction. In other words, energy is the ability to rearrange a community of matter .... Energy forms include kinetic energy, potential energy, electrical energy, light energy, chemical energy, heat, and nuclear energy. ... Heat can be transferred from the high-temperature area to the low-temperature area. Its unit is calories (cal). The heat cannot be measured directly. It is calculated by measurements made with a calorimeter. Meanwhile 1 cal = 4186 j. It can be calculated by the following equation (Q = m.c.dt, Q)".

Duru, one of the participants who made scored partial CI in the first administration, stated that: "*...There is internal and external energy. Kinetic energy and potential energy. The unit is Joule.*" In the second administration, Duru made complete the CI by stating "*...the energy is the ability to do work. We can measure the transformation of energy into each other. For example, if a substance loses kinetic energy and gains potential energy, we can measure the transition between them. Units are kg(m/s)2 and mgh*." Emel could not make the CI in the first administration and she stated as "*Energy is not one thing. The whole of the universe, life, which people need and is occurring naturally or artificially, is energy*". Emel was coded partial the CI for the second administration: She wrote as "*It is necessary to apply force to*

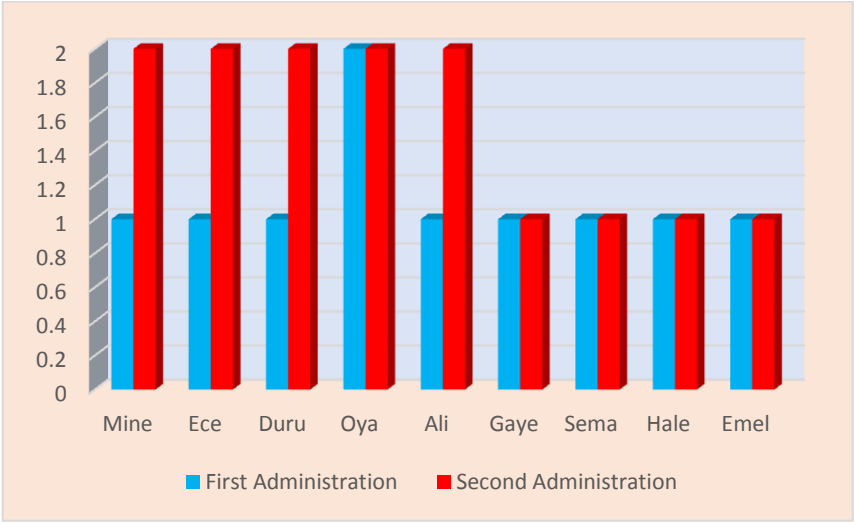


Figure 3. The Changes in Participants' Conceptual Integration for Question 2.

do work. The unit of energy is calorie or joule. Energy can be measured with coefficients in respiration and formulas."

Changes in Participants' Conceptual Integration for the Question of "The Importance of Energy for Living Beings"

The integration categories of the participants in relation to their responses to the question of "Explain one of the sources of energy used by living things with their reasons" during the first and second administrations were depicted in **Figure 3**.

As can be seen in **Figure 3**, one participant made partial the CI while the other eight PSTs could not make any the CI in this question. In the second administration, five PSTs made partial the CI while four participants could not make any the CI.

Mine, one of the PSTs who were unable to fulfill the requirements for CI, stated that: "*Living things continue their lives by producing ATP*." In the second administration, she made partial the CI with the following explanations: "*There are varieties of energy sources that can be used by living things such as solar, wind, and geothermal energy. People use chemical energy to carry out their vital activities such as eating, drinking, and running by taking it from the nutrients (there is chemical energy available at any time stored in nutrients)*" Oya, who made partial the CI in the first administration, stated, "*…The primary energy source is the sun. In*

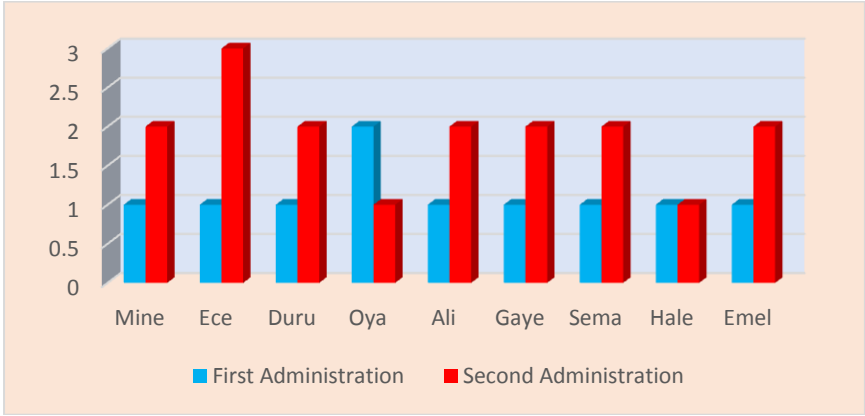


Figure 4. The Changes in the Participants' Conceptual Integration for Question 3.

fact, it would not be wrong if it was called fission and fusion reactions." In the second administration, Oya achieved partial CI with the following explanations: "*Living things can only get energy for their body from food. The food contains solar energy. Living things can use the existing energy for various things. For example, they can benefit from natural gas in cooking.*" Gaye, who was unable to reach the CI threshold in the first administration, stated that "*We take energy from the food we eat.*" In the second administration, she could not make the CI again with the following explanations: "*...Living things get energy from food*."

Changes in Participants' Conceptual Integration for the Question of "Differences in Structures of Oils in Terms of Chemistry"

The integration categories of the participants in relation to their responses to the question of "Although olive oil, sunflower oil and butter consist of the same monomers, what can be the reason(s) for their structural differences? Please explain." during the first and second administrations were depicted in **Figure 4**.

As can be seen in **Figure 4**, one participant reached partial CI while the other eight PSTs could not reach the required CI threshold in the first administration. In the second administration, however, it was determined that only one participant could achieve complete CI. In contrast, six PSTs reached partial CI, and two PSTs could not achieve CI at all. Moreover, Oya, who achieved partial CI in the first administration, could not achieve CI in the second administration.

Ece, one of the participants who was unable to reach the CI threshold in the first administration, stated, "*Monomers have different forms of attachments*." In the second administration, Ece achieved complete CI by answering the question with the following: "*These oils are examples of saturated and unsaturated fats…. Unsaturated fatty acids are double bound fatty acids and unsaturated with hydrogen. The reasons why these kinds of fats are different are as follows: First, the oils show cis-trans isomer because of their double-bonded alkene structure. Cis and trans have different structures. Because their position in the molecule is different. Second, in fatty acids, even if one hydrogen has a different position in the molecule, that fatty acid differs from the other acids. Therefore, their melting and boiling points differ, as well. Saturated fatty acids are types of fats whose structures are fully saturated with hydrogen. Again, the reason why these oils are different is that the molecular structures of fatty acids are different.*" Ali, who was among the participants who were unable to reach the CI threshold in the first administration, stated: "*They may be composed of the same monomers, but if they are different in their arrangement and attachment, they are not the same*." In the second administration, Ali fulfilled the requirements for partial CI by explaining that: "*… They differ in terms of their structures because the bonding forms and positions of the atoms are different. As known, unsaturated fats contain double bonds. The location of the double bond, i.e., pi bond, may be different*." Hale, one of the participants who was unable to reach the CI threshold in the first administration, stated: "*While olive oil and sunflower oil are vegetable oils, butter is an animal fat. Monomers of animal fats are saturated fatty acids while vegetable oils contain unsaturated fatty acids*." In the second administration, Hale answered the 3rd question with the following: "*The monomers of olive oil, sunflower oil, and butter are the same, but olive oil and sunflower oils are vegetable oils and butter is animal fat. More generally, olive, and sunflower oils are unsaturated fats, and butter is saturated fat*." Hence, she was unable to achieve CI again. Oya, who was able to achieve partial CI in the first administration, wrote that "*Monomers can have forming bonds, bond angles, sigma and pi numbers, etc.*" In the second administration, Oya could not provide any conceptual integration in the following explanation: "*The reason for the different substances is that they bind in different ways and numbers, just like in enzymes and DNA.*"

Changes in Participants' Conceptual Integration for the Question of "Differences in Movement Mechanisms of Living Things"

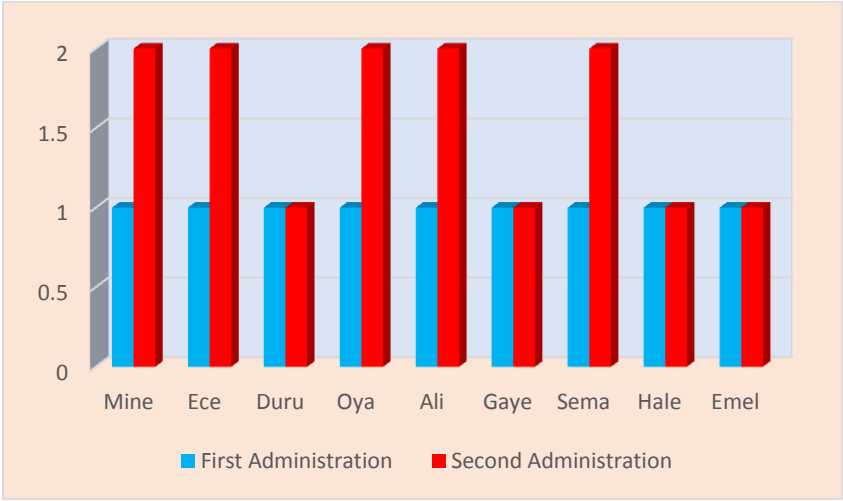


Figure 5. The Changes in Participants' Conceptual Integration for Question 4.

The integration categories of the participants in relation to their responses to the question of "Explain the fundamental difference in the movement mechanisms of animals and plants." during the first and second administrations were depicted in **Figure 5**.

As can be seen in **Figure 5**, no participant was able to reach the CI threshold for this question in the first administration. In the second administration, however, five participants achieved partial CI while four PSTs could not achieve any degree of CI as was in the first administration.

Oya, who was unable to demonstrate CI during the first administration, stated: "*...When animals are actively moving, plants move where they are. They make various passive movements.*" She could not answer this question in the portfolio she prepared before the implementation of the course. On the other hand, Oya achieved partial CI in the second administration by stating: "*Muscles cause the movement of an animal while hormones and the stimulation of these hormones or turgor pressure cause the movement of a plant. The growth is also considered as the movement, that is,* " In the portfolio she prepared at the end of the term, it was demonstrated that she had a similar opinion that could be categorized as PCI. Her sentences were as follows: "*Every living thing moves, passively or actively... Animals move with their muscles. These muscles are the filaments of actin and myosin. We can explain the movements of the muscles with the sliding filament model. ... The movements of plants are tropism and nastic movement. Hormones such as auxin and gibberellin are effective in the tropism while sudden changes in turgor pressure are effective in nastic movement.*" Emel could not reach the CI threshold in the first administration,

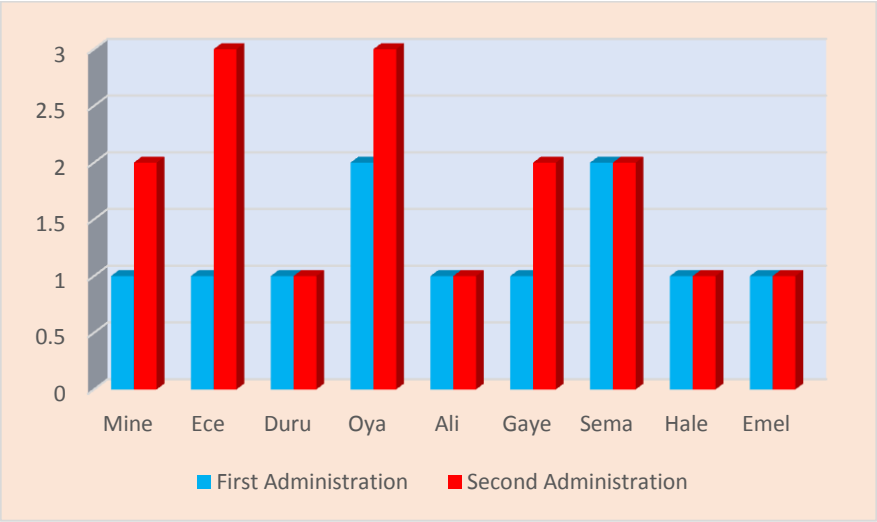


Figure 6. The Changes in Participants' Conceptual Integration for Question 5.

wrote the following statements: "*All living things are in motion, but some cannot move. While animals carry out their movements in an active way, the plants move with nastic movement and tropism, turning movements. This turning movement is slow and long-term*." Emel was similarly unable to achieve a sufficient level of CI in the second administration by stating: "*...Animals are living things with the skeletal system and nervous system; so, they can move actively. Plants do not have a nervous system to direct them, and they cannot move actively because they need nutrients in the soil. They can only do turning movements.*"

Changes in Participants' Conceptual Integration for the Question of "The Importance of Energy Conservation for Living Beings"

The integration categories of the participants in relation to their responses to the question 5, "What is the main reason for our body to stay at the same temperature? Please explain." during the first and second administrations were depicted in **Figure 6**.

As can be seen in **Figure 6**, two PSTs were able to demonstrate partial CICI while the other seven could not utilize integration for this question during the first administration. In the second administration, however, two participants demonstrated complete CI while three PSTs reached the partial CI threshold and four PSTs could demonstrate CI.

Ece, who was unable to demonstrate CI during the first administration, stated her answer as: "*Water and some enzymes in our bodies keep the body temperature constant.*" When the summaries, concept maps, question preparation assignments, and puzzles in her portfolio, which she prepared before the implementation in the course, were examined, no answer was found regarding the explanation of this problem. In the second administration, Ece fulfilled the requirements of complete CI by explaining that: "*This is due to thermoregulation. In other words, heat regulation in Turkish. The role of our skin in this event is important. If our body temperature increases during the ATP production and with heat-releasing reactions, we will remove the excess heat from our body and bring it to its previous temperature thanks to the evaporation of water on our skin by sweating.*" Ece was included in the CCU category with the portfolio she prepared at the end of the term. The answer in her summary indicated that Ece was in the CCU category. Ece's response in the summary that qualified for CCU was as follows: "*...In warm-blooded living organisms, the neural reflex mechanisms that affect heat generation (thermogenesis) and its distribution (thermolysis) ensure that the temperature remains constant. On the skins of these living things, there are special receptors sensitive to temperature changes… When the body temperature increases, capillary vessels expand, sweating increases, and respiration accelerates. These events enhance evaporation… Heat insulation reduces or completely stops heat transfer between two environments of different temperatures. Skin is also an insulating layer for the body… When exposed to cold, the skin aims to reduce heat loss, the veins shrink, sweating decreases or stops, and respiration slows down. Thus, the skin tries to keep the body temperature constant.*" Oya was categorized as partial CI in the first administration, and she wrote that "*There are three main centers in our body that produce heat. While obtaining energy from nutrients, heat is released and distributed through the blood to everywhere in accordance with the laws of thermodynamics.*" In the second administration, Oya was able to achieve complete CI by stating: "*Our bodies work in a wonderful way with physics, biology, and chemistry. The exothermic reactions occur in the mitochondria to form ATP. The chemical bond energy in the nutrients is converted to ATP. The excess heat is transported to other places through the blood. The skin serves as insulation or gives off excess heat to the air with evaporation. Thermoregulation is applied regularly.*" Gaye was unable to meet the requirements of CI in the first administration and she wrote that: "*I think it might be because of the heat exchange.*" In the second administration, Gaye was categorized as partial CI due to her response, stating that: "*Humans are warm-blooded. The body adjusts the heat balance through thermoregulation. By sweating, the excessive heat in the body is removed through evaporation.*" Sema, one of the participants who scored partial CI in the first administration,

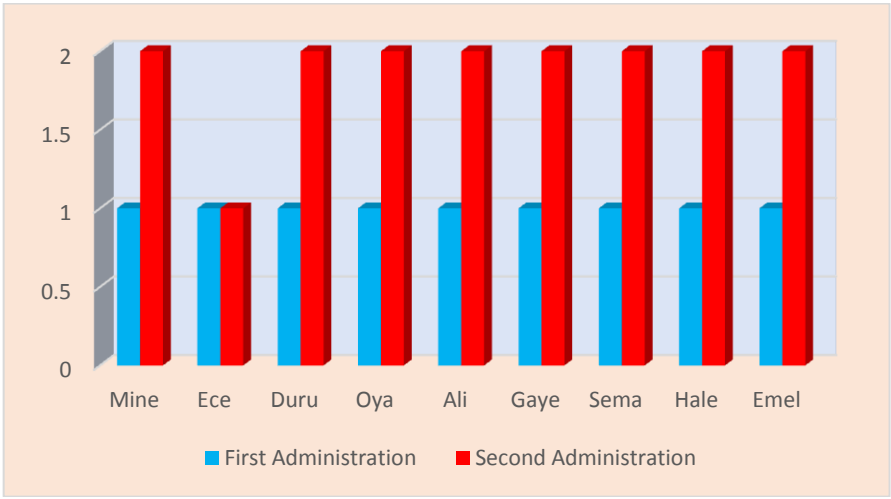


Figure 7. The Changes in Participants' Conceptual Integration for Question 6.

wrote that: "*We sweat when our body temperature rises. Because the water comes out and the temperature of our skin vaporizes this water and allows our body to cool down.*" In the second administration, Sema was categorized as partial CI again as she stated that: "*Our body can adjust itself according to temperature, that is, through thermoregulation. The body discharges to water by sweating at high temperatures, so it lowers the temperature. Since we are warm-blooded, we are always at the same temperature.*" Ali, one of the participants who was unable to achieve CI during the first administration, wrote the following statements: "*Our body maintains the temperature balance by performing adaptations to different temperatures.*" In the second administration, Ali was, again, unable to demonstrate conceptual integration by writing these statements: "*Mammals are warm-blooded creatures. Normally, our body takes a defensive position against external temperature changes with its features such as sweating and piloerection.*"

Changes in Participants' Conceptual Integration for the Question of "Energy Production of Living Things"

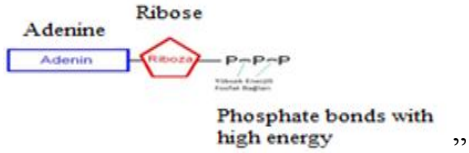
The integration categories of the participants in relation to their responses to the question 6, "What is Adenosine Tri Phosphate (ATP)? How is it produced? Please explain." during the first and second administrations were depicted in **Figure 7**.

As can be seen in **Figure 7**, none of the participants were able to achieve CI for this question in the first administration. In the second

administration, however, eight PSTs achieved partial CI while one PST was unable to meet the CI threshold, as was in the first administration.

Mine, one of the participants who were unable to meet the CI threshold in the first administration, explained that: "*ATP is responsible for the energy production of living things. It is produced in mitochondria. Production occurs when the organism needs energy. The structure of ATP is*

and she made a mistake in the figure she drew in terms of the structure of the ATP. In other words, she utilized the structure of Adenosine monophosphate (AMP) as ATP. In the second administration, Mine achieved partial CI by stating: "*ATP is the way to transfer energy in living things. Each cell produces its own ATP. When energy is needed, the ATP molecule is hydrolyzed, and the energy needs of the living are met. The production of ATP is called Phosphorylation. It is exergonic. The structure of ATP is*



,,

Ece was categorized as NCI in the first administration, she stated that: "ATP is the energy that our body both produces and uses. It is produced continuously. I do not know exactly where and how it is produced.". In the second administration, Ece was, again, unable to achieve CI by stating that: "*ATP is the energy molecule that can be used by living cells. It can be produced in mitochondria, chloroplasts, or cytoplasm. It is used in the metabolic activities of the cell. It is generated through cellular respiration. ATP is produced by the mixed chain of the chemiosmotic hypothesis.*"

Discussion

This study aimed to investigate how PSTs integrate physics and chemistry concepts in their teachings of the metabolism. The results demonstrated that the PSTs could not understand the physics and chemistry concepts required for conceptual integration to be performed in the context of metabolism at a sufficient level before the intervention. For instance, they had difficulty explaining the energy sources used by living beings and their reasons for using these sources through the CI. It was concluded that five participants suffered from this difficulty and were unable to fulfill the criteria required

for CI at the end of the action plan. Researchers also highlighted that the conceptual integration demonstrated by the PSTs were unsatisfactory in their science educations (Salah & Dumon, 2011; 2014; Taber, 2003b, 2008). Although the activities and practices were executed for CI in the action plan, only three participants achieved complete conceptual understanding for better CI at the end of the course in the first question. Moreover, one participant in question three and two participants in question five were able to achieve complete CI. On the other hand, there were no participants in question two, four, and six who achieved complete conceptual understanding. There are many reasons for why the participants' conceptual integration did not demonstrably improve following the action plan. First of these is the fact that the participants have been unaccustomed to the different activities requested of them as part of the action plan, such as portfolios. Although PSTs voluntarily participated in the study, they have often expressed that these portfolios took a considerable amount of non-class time for them to be completed. They consequently did not have time to do anything else during this period. Second, although the first researcher gave too much feedback to the portfolios outside of the lesson, they may not have been able to change their perception in such a short time. Therefore, educational researchers should consider that participants should not spend too much time on activities to achieve complete conceptual understanding for CI. Moreover, practitioners should act with an understanding of participants' emotional states and prepare them for practice accordingly.

PSTs who were unable to sufficiently demonstrate CI will not be able to help their students achieve meaningful learning when they become teachers in the future. As stated in the literature, meaningful learning must be realized effectively by using CI throughout science education (Duit & Treagust, 2003).Students of these PSTs will simultaneously be unable to develop scientific thinking (Taber, 2003a), relate science to their daily lives (Authors, 2018), reduce their own misconceptions in science subjects (Ganaras, et al., 2008), and be individuals who are science literate (Lederman & Niess, 1998) and have 21st-century skills (Koenig, 2011). Additionally, a PST who is unable to reach a complete conceptual understanding for conceptual integration with regards to the topic of the metabolism at a sufficient level will not be able to understand energy transformations. For instance, a PST who cannot comprehend that light is in different wavelengths will not fully understand the conversion of light energy into chemical energy. In other words, they will consequently be unable to utilize the concept of photosynthesis in their daily lives. Therefore, if they were to grow a plant in a flowerpot at home, they would not be able to decide where to position this plant at home. Another example of this difficulty is that a PST who cannot achieve CI can face difficulties when using oils. More specifically, it should be known that there is a difference

among olive oil, butter, and sunflower oil in terms of a balanced diet. However, a PST who cannot understand this difference will not distinguish between oils by acting as a science-illiterate individual and will decide on using the oil only in terms of its price and taste. On the other hand, an individual capable of achieving CI will be able to determine which oil can be used for a balanced diet by knowing that the mentioned oils are composed of different fatty acids. Like previous studies (Salah & Dumon, 2014; Taber, 2008), this study also demonstrated that complete conceptual understanding for the CI was not achieved at a sufficient level. This is alarming since it has been acknowledged that CI plays an essential role in meaningful learning (Duit & Treagust, 2003), the development of scientific thinking, and the reduction of misconceptions in science (Ganaras, et al., 2008). As a result of this study in which the teaching based on the CI was implemented, it was concluded that PSTs could fulfill the criteria set for CI despite their insufficient level while explaining the concepts of metabolism by relating them to the physics and chemistry concepts. As evidence for this circumstance, it can be shown that seven PSTs raised their CI level by one step (From NCU to PCU or from PCU to CCU) in the first question. Similarly, four PSTs in the second, six in the third, five in the fourth, four in the fifth, and eight in the sixth question increased their conceptual understanding level one step. Furthermore, one PST in the third question and one PST in the fifth question raised their conceptual understanding level from NCU to CCU. To the best of the researchers' knowledge, there is no study in the literature devoted to investigating the effect of the implementation of instructional strategies on students' CI. There are many studies emphasizing the importance of interdisciplinary education (Lattuca et al. 2004; Repko, 2006). These studies have emphasized that interdisciplinary education is crucial for students to obtain 21st-century skills. Therefore, this study additionally aimed to help students acquire 21st-century skills and emphasized the necessity of gaining a full conceptual understanding of CI.

Conclusion

In this study, the subject of the metabolism was studied to explore PSTs' conceptual understandings of CI. Further research could focus on different science subjects across different disciplines. The findings of this study demonstrated that PSTs were unable to understand physics and chemistry concepts at a sufficient level while explaining the concepts of metabolism. Future studies could design interventions to be effectively improving CI. In this study, CI was studied in terms of scientific disciplines. A high degree of CI must be acquired to establish the relationship between science and other fields such as mathematics, engineering, technology, history, geography, and art. Thus, further research could design experimental studies to investigate

how the CI is necessary for establishing the relationship between science and other fields.

References

Bozcuk, S. (2004). Bitki Fizyolojisi (Plant Physiology). Hatipoglu Publishing.

Caudill, L., Hill, A., Hoke, K., & Lipan, O. (2010). Impact of interdisciplinary undergraduate research in mathematics and biology on the development of a new course integrating five STEM disciplines. *CBE-Life Sciences Education*, 9(3):212-216. https://doi.org/10.1187/cbe.10-03-0020

Cone, T. P., Werner, P., Cone, S. L., & Woods, A. M. (1998). Interdisciplinary Teaching Through Physical Education. Champaign, IL: Human Kinetics.

Creswell, J. W. (2009). Research Design, Qualitative, Quantitative, and Mixed Methods Approaches (3rd ed.). SAGE Publications.

Crowther, G. (2012). Using science songs to enhance learning: an interdisciplinary approach. *Life Sciences Education*, 11(1):26-30. https://doi.org/10.1187/cbe.11-08-0068

Daugherty, M. K. (2013). The prospect of an 'A' in STEM education. *The Journal of STEM Education*, 14(2):10-15.

Dervisoglu, S., & Soran, H. (2003). Evaluation of interdisciplinary teaching approach in high school biology education. *Hacettepe University Journal of Education*, 25:48-57.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, 10(2&3): 105-225. https://doi.org/10.1080/07370008.1985.9649008

Duit, R., & Treagust, D. F. (2003). Conceptual change: a powerful framework for improving science teaching and learning. *International Journal of Science Education*, 25(6):671-688. https://doi.org/10.1080/09500690305016

Ganaras, K., Dumon, A., & Larcher, C. (2008). Conceptual integration of chemical equilibrium by prospective physical sciences teachers. *Chemistry Education Research and Practice*, 9:240-249. https://doi.org/10.1039/B3RP90031B

Godrick, E., & Hartman, S. (2000). Integrating introductory biology and general chemistry laboratories. *Journal of College Science Teaching*, 29(3):184-186.

Keeten, W. T., Gould, J. L., & Gould, C. G. (1999). Genel Biyoloji (General Biology), (Translated to Turkish by Demirsoy, A. & Türkan, İ.). Palme Publishing.

Klein, J. T. (1990). Interdisciplinarity: History, Theory, and Practice. Wayne State University Press.

Koenig, J. A. (2011). Assessing 21st Century Skills: Summary of a Workshop. DC: National Research Council.

Krippendorff, K. (2013). Content Analysis: An Introduction to Its Methodology. SAGE Publications.

Lattuca, L. R., Voigt, L. J., & Fath, K. Q. (2004). Does interdisciplinarity promote learning? Theoretical support and researchable questions. *The Review of Higher Education*, 28(1):23-48.

Lederman, N. G., & Niess, M. L. (1997). Integrated, interdisciplinary, or thematic instruction? Is this a question or is it questionable semantics? *School Science and Mathematics*, 97(2):57-58. https://doi.org/10.1111/j.1949-8594.1997.tb17342.x

Lederman, N.G., & Niess, M.L. (1998). Survival of the fittest. *School Science and Mathematics*, 98(4):169-172. https://doi.org/10.1111/j.1949-8594.1998.tb17412.x

Merriam, S. B. (2009). Qualitative Research (2nd ed.). San Francisco: Jossey-Bass.

Newell, W. (1998). Professionalizing Interdisciplinarity. In W. Newell (Ed.), Interdisciplinarity: Essays from the Literature. (pp. 529-563). College Board.

Newell, W. H. (2001). A theory of interdisciplinary studies. *Issues in Integrative Studies*, 19:1-25.

Newell, W. H., Doty, W. G., & Klein, J. T. (1990). Interdisciplinary curriculum development. *Issues in Interdisciplinary Studies*, 8: 69-86.

Reece, J. B, Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., & Jackson, R. B. (2013). Campbell Biyoloji (Campbell Biology). (Translated to Turkish by Gündüz, E. & Türkan, İ.). Palme Publishing.

Repko, A. F. (2006). Disciplining interdisciplinarity: The case for textbooks. Issues in Integrative Studies, 24: 112-142.

Salah, H., & Dumon, A. (2011). Conceptual integration of hybridization by Algerian students intending to teach physical sciences. *Chemistry Education Research and Practice*, 12(4):443-453. https://doi.org/10.1039/C1RP90049H

Salah, H., & Dumon, A. (2014). Conceptual integration of covalent bond models by Algerian students. *Chemistry Education Research and Practice*, 15(4):675-688. https://doi.org/10.1039/C4RP00041B

Stinson, K., Harkness, S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration: models and characterizations. *School Science and Mathematics*, 109(3):153-161. https://doi.org/10.1111/j.1949-8594.2009.tb17951.x

Taber, K. S. (1998). The sharing-out of nuclear attraction: Or I can't think about physics in chemistry. *International Journal of Science Education*, 20(8):1001-1014. https://doi.org/10.1080/0950069980200807

Taber, K. S. (2003a). Theme issue: Teaching chemistry and physics editor's introduction: facilitating science learning in the inter-disciplinary matrix - some perspectives on teaching chemistry and physics. *Chemistry Education Research & Practice*, 4:103-114. https://doi.org/10.1039/B3RP90009F

Taber, K. S. (2003b). Understanding ionization energy: Physical, chemical and alternative conceptions. *Chemistry Education Research & Practice*, 4:149-169. https://doi.org/10.1039/B3RP90010J

Taber, K.S. (2008). Conceptual resources for learning science: issues of transience and grain-size in cognition and cognitive structure. *International Journal of Science Education*, 30(8):1027-1053. https://doi.org/10.1080/09500690701485082

Taber, K. S. (2008b). Exploring conceptual integration in student thinking: Evidence from a case study. International Journal of Science Education, 30(14):1915-1943. https://doi.org/10.1080/09500690701589404

Toomey, R., & Garafalo, F. (2003). Linking physics with chemistry-opportunities in a constructivist classroom. *Chemistry Education Research & Practice*, 4:189-204. https://doi.org/10.1039/B2RP90044K

Xie, Y., Fang, M., & Shauman, K. (2015). STEM education. *Annual review of sociology*, 41:331-357. https://doi.org/10.1146/annurev-soc-071312-145659

Yip, D. Y. (1998). Identification of misconceptions in novice biology teachers and remedial strategies for improving biology learning. *International Journal of Science Education*, 20(4):461-477. https://doi.org/10.1080/0950069980200406

Received: May 07, 2024
Revised: June 10, 2024
Accepted: June 18, 2024