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Original Article

Misconceptions as a barrier to understanding biological science lessons: A systematic review of pertinent studies

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Abstract

This systematic review explored the pervasive issue of misconceptions hindering understanding in biological science lessons, focusing on factors contributing to these misconceptions and ways to rectify them. The study employed a qualitative content analysis. Students often harbor misconceptions rooted in everyday experiences, language nuances, teacher methodologies, and textbooks. Biology, known for its complexity, abstract nature, and scientific terminology, poses particular challenges. Several studies conducted both abroad and in Ethiopia highlight high levels of misconceptions among students, particularly in topics such as cell biology, genetics, photosynthesis, and human anatomy. Existing research suggests that traditional teaching methods contribute to misconceptions, emphasizing the need for a constructivist approach, concept maps, clinical interviews, and inquiry-based learning. Ultimately, understanding and addressing misconceptions have implications vital for fostering meaningful learning experiences in biology education.

1 Introduction

Human beings can acquire knowledge and explore the vast horizons of the universe through logic and observation, a process that evolves into scientific knowledge (Tekkaya, 2002). Students bring diverse pre-existing ideas and explanations about the natural world to school. Misconceptions, defined as mental representations deviating from currently accepted scientific theories, can be categorized into alternative or experiential or intuitive or native conceptions and instructional misconceptions (Kesidou and Duit, 1993; Skelly and Hall, 1993; Nakiboglu, 2003). These misconceptions significantly impact students' learning, hindering their understanding of advanced concepts. Failure to address initial misconceptions may result in a lack of comprehension of new information or a surface-level understanding solely for test purposes, reverting to misconceptions outside the classroom (Özmen, 2004).

Children's misconceptions in science after formal education can be traced to three main sources: informal ideas derived from everyday experiences, incomplete or improper views

developed during classroom instruction, and erroneous concepts propagated by teachers and textbooks (Yip, 1998). It is widely acknowledged that students enter biology classes in Ethiopia with one or more of these misconceptions. Despite limited efforts to identify misconceptions in physical and life sciences like biology, physics, chemistry, and mathematics in Ethiopia (Engida, 2002). Thus, this review aims to offer an overview of misconceptions in biological science by exploring literature from both international and local sources.

1.1 Objectives

In this context, the review paper assesses the definitions of misconceptions, explores factors contributing to students' misconceptions, delves into common misconceptions in biology, discusses methods to correct misconceptions, and examines previous research on misconceptions, aiming to identify any existing research gaps. Therefore the study helps:

1. To identify sources of biology misconceptions that hinder students' learning.
2. To explore strategies of minimizing levels of misconceptions' in biology learning

2 Definitions of misconception

Misconception is defined by various authors in various ways. A misconception can be identified as something that people believe, but that are not actually correct. In broad terms, misconceptions correspond to the ideas that have personal perceptions and meanings in students' articulations that are defective (Bahar, 2003). In the literature, misconceptions are also indicated to as "alternative conception" (Dikmenli et al., 2009; Kurt, 2013; **kurt2013biology2**; Cinici, 2013), "misunderstanding" (Kılıç and Sağlam, 2009; Kirbaslar et al., 2009).

3 Factors Contributing to Students' Misconceptions

Misconceptions are developed by students from various resources. Misconceptions contrast with scientific concepts, and the most common factors as reported by different authors includes: influence from everyday life experiences (Abraham et al., 1992; Smith III et al., 1994; Kaltakci and Eryilmaz, 2010; Suniati et al., 2013; Widarti et al., 2016), teachers (Kaltakci and Eryilmaz, 2010; Gudyanga and Madambi, 2014; Satilmis, 2014; Erman, 2017), reference book or textbook (Devetak et al., 2007; Kaltakci and Eryilmaz, 2010; Gudyanga and Madambi, 2014; Widarti et al., 2016; Erman, 2017) and confusion of everyday language used as factors contribute to misconceptions (Osborne et al., 1983; Abraham et al., 1992; Tyson et al., 1999; Bahar, 2003; Boz, 2006; Suniati et al., 2013; Erman, 2017).

3.1 Everyday experiences

Students' interactions with the environment in their daily life experiences can lead to confusion (Smith III et al., 1994; Agnes et al., 2015). As students become acquainted with their surroundings and spend significant time outside of school, they develop personal explanations for the meanings of things in the world around them. These explanations

often diverge from scientific meanings. The understanding of science concepts by students is primarily influenced by their interactions with the surrounding environment and is intertwined with their daily life experiences (**arif2018**).

3.2 Language used

Students encounter challenges when scientific terminology is incorporated into everyday language. The use of scientific words in ordinary communication may contribute to students developing misconceptions (Osborne et al., 1983; Boz, 2006). The discrepancy between the technical language of science and its colloquial usage can create confusion and hinder students' accurate understanding of scientific concepts. Additionally, the potential for misconceptions arises when scientific terms are employed in a context that differs from their precise scientific meaning, adding a layer of complexity to students' comprehension. Therefore, bridging the gap between scientific language and everyday communication is crucial to minimizing misconceptions and promoting clearer understanding among students.

3.3 Teachers

Teachers propagate misconceptions because of their inability to communicate effectively with students (Gudyanga and Madambi, 2014). In some cases, teachers may be unaware of student's difficulties and fail to take appropriate methods in presenting specific ideas to students (Kaltakci and Eryilmaz, 2010). Furthermore, Satilmis (2014) stated that students had misconceptions due to ineffective teaching method especially when the teachers followed the traditional method. A teacher fails to present abstract concepts appropriately, either by visualization or analogy to help students understand the concepts (Treagust et al., 2003).

Teachers' misconceptions themselves can be a source of students' misconceptions (Gudyanga and Madambi, 2014). This suggests that there is a possibility of teachers transferring their misconceptions to students, given that they serve as the primary source of instruction. When teachers learn abstract concepts during their training without a clear understanding, they run the risk of disseminating these misconceptions to their students. Therefore, it is crucial for science teachers to possess a clear conceptual understanding of scientific concepts in each learning activity to avoid perpetuating misconceptions in the classroom.

3.4 Textbook

Textbooks, as tools employed in the teaching-learning process and as guides for both teachers and students, play a crucial role in the construction of conceptual understanding. However, they can also contribute to the occurrence of misconceptions (Devetak et al., 2007; Gudyanga and Madambi, 2014). The presence of unclear figures in textbooks is identified as one factor leading to misconceptions, particularly at the submicroscopic level (Devetak et al., 2007). Additionally, textbooks may not consistently offer complete or accurate information and explanations (Gudyanga and Madambi, 2014). Furthermore, the presentation of information in symbols within textbooks can pose challenges for student comprehension (Gabel, 1998; Widyatmoko and Shimizu, 2018). Addressing these issues in textbook design and content is essential to ensure that they effectively contribute to students' accurate understanding of scientific concepts.

4 Commonly observed misconceptions in biology

Many students have misconceptions about what science actually is and how it works. Biology is one of the courses in which students experience difficulty (Keleş and Kefeli, 2010). The content and complexity of biological notions, common ideas, deficiency of biological knowledge and additionally the hidden nature of many key processes cause biology to be an especially hard subject to teach and to learn (Sesli and Kara, 2012). Moreover, its abstract nature and scientific terminologies make biology confusing (Kumandaş, 2015).

During the past two decades, several studies have investigated students' understanding of biological concepts in different countries: Cell (Dreyfus and Jungwirth, 1988), photosynthesis (Bell, 1985, Haslam and Treagust, 1987, Waheed and Lucas, 1992), respiration (Sanders, 1993), genetics (Pashley, 1994, Lewis et al., 2000), ecology (Griffiths and Grant, 1985, Munson, 1994), classification (Trowbridge and Mintzes, 1988), the circulatory system (Yip, 1998), vertebrate and invertebrate (Braund, 1998) and energy (Boyes and Stanisstreet, 1991).

The above studies revealed that students "have misconception about different concepts of biology, and they leave secondary school with a distorted view of concepts, objects and events".

Research has shown that students have difficulty making the connection between molecular and cellular organization (Driver et al., 1994). Students seem to understand that both atoms and cells are made up of smaller parts including the nucleus. However, they struggle to conceptualize the foundational principal that all matter including cells is made of atoms. This misunderstanding seems to perpetuate beyond differentiation between cells and atoms in their understanding of the structure and function of macromolecules. According to the American Association for the Advancement of Science (1994), students should experience a progression of their understanding of cell structure and function as they move through the grade levels. As elementary students they should have an understanding that some parts of organisms must be seen through a magnifying glass and then as they enter the upper elementary grades, they should begin to form the concept of a cell as the basic unit of life. Finally, as they exit middle school students should have a clear understanding of basic cell function. By the end of the 12th grade, students should have knowledge and understanding of the nature and function of proteins and the specialization of organelles within the cells including the cell membrane.

However, Driver et al. (1994) show that students often confuse the concepts of molecules and cells. Often times, students have a very general concept of molecules and cells both of which contain a nucleus and are surrounded by other small things. This confusion seems to stay with children through the teenage years. Also, students at the high school level tend to think that larger macromolecules such as proteins and carbohydrates are made of cells rather than atoms. They did not understand the difference between cells and molecules. More confusion has been found in students' ability to differentiate the sizes of cells and atoms. Many students at the high school level believe that cells and molecules of protein are the same size. Driver et al. (1994) also found that students believe single-celled organisms contain intestines and lungs.

Moreover, a large number of prior studies reported that primary and secondary school students have many conceptual problems concerning cell biology and genetics (Lewis et al., 2000; Marbach-Ad and Stavy, 2000; Flores et al., 2003).

If higher education curriculum designers knew students' misconception, it might be helpful to prepare effective teaching strategies. Teachers can play an important role in teaching scientific concepts and from a constructivist perspective students should gain meaningful knowledge about biological concepts like cell biology and cell division. Biolog-

ically literate students should be able to use and apply basic biological concepts when considering biological problems or issues. Prior studies have shown that students experience difficulties in learning concepts related to the cell division process (Kindfield, 1994). Cell division constitutes the basis for genetics, reproduction, growth, development and molecular biology subjects in the biology curriculum. However, as a matter of fact, a majority of the students evaluated topics such as gene, DNA, chromosome and cell division as difficult to learn topics (Öztap et al., 2003).

Research on students' conceptual understandings on Cell division often indicates that even after being taught students use misconception different from the scientific concepts (Lewis et al., 2000; Yeşilyurt and Kara, 2007). Reasons for this misconception include students' inability to differentiate between doubling or replication, pairing or synapses and separating or disjunction, as well as determining whether or not these processes occur in mitosis, meiosis or both (Smith, 1991). Further misconception includes a lack of understanding of basic terms confusing chromatids with chromosomes or replicated chromosomes with un replicated chromosomes etc. (Kindfield, 1994). This is a concern for instructors because cell division processes are fundamental to the understanding of growth, development, reproduction and genetics (Chinnici et al., 2004; Cordero and Szweczak, 1994).

Studies conducted on problem-solving related to genetics revealed that students have some misconception regarding the stages of meiosis (Brown, 1990, Stewart and Dale, 1989). Accurate organizing of many concepts in cell biology is dependent on the degree of understanding cell division (Smith, 1999). As a matter of fact, a study related to genetics revealed that students possess misconception and inadequate knowledge about the behavior of chromosomes and transference of genetic material during cell division. It further suggested that such misconception led to conceptual problems in genetics (Kibuka-Sebitosi, 2007). Tekkaya and Yenilmez (2006) studied the misconception possessed by 9th grade students relating to cell division and the effect of the conceptual teaching regarding elimination of such conceptions. They hypothesize that conceptual teaching is an effective method for understanding the concepts related to cell division and for elimination of misconception.

Lewis et al. (2000) also studied the students' levels of understanding in regards to mitosis, meiosis and fertilization. The result of their study revealed that students possess inadequate knowledge and numerous misconceptions related to the physical relationships between the genetic material and the chromosomes and the relationships between the behavior of the chromosomes and continuity of the genetic information. Lewis et al. (2000) further emphasized the fact that the students mainly experience difficulties for explaining the relationships between the cell, nucleus, chromosome and gene concepts and the similarities and differences between mitosis and meiosis.

Clark and Mathis (2000) indicated that students experience difficulties particularly for discriminating chromatids, chromosomes and the homologous parts of the chromosomes during the cell division process. Atilboz (2004) studied the level of understanding and misconception of 9th grade students related to mitosis and meiosis. The result of the study showed that students experience difficulties in understanding fundamental concepts such as DNA, chromosome, chromatids, homologous chromosomes, haploid and diploid cells and the relationships between such concepts and possess some misconception.

Lewis et al. (2000) found that students in United Kingdom seemed to have a poor understanding of the processes by which genetic information is transferred and a lack of basic knowledge about other related concepts such as chromosomes, cell division and inheritance.

Saka et al. (2006) state that a science student has misconception particularly regarding

the concepts of gene and chromosome in accordance with their findings obtained from written responses and drawings. Krüger et al. (2006) studied the concepts of students regarding cell division and growth, and the study revealed that students generally focus on the increase occurring with number of the cells, as a result of cell division and disregard the growth occurring in the cells. They also indicated that such difficulties experienced during understanding such concepts might be overcome by learning activities that researchers have developed. Riemeier and Gropengießer (2008) analyzed the difficulties in learning as experienced by the 9th grade students regarding cell division and their conceptual understandings with in teaching experiments. They have shown that well planned teaching activities for the cell biology and cell divisions might enhance the conceptual development process and might contribute to the conceptual learning by the students. It is obvious from the literature that misconception related to cell division processes lead to a series of problems for the biology teaching. When attending their biology classes, students bring their perceptions, prejudices and former experiences in conflict with the scientific facts. This situation causes various problems to arise during their biology classes. Keeping knowledge or conceptual frames of the students in line with the scientific facts can only be possible with effective conceptual teaching.

Recently, several studies have also been conducted regarding biological science misconceptions. Putri et al. (2017) conducted a study on analysis of misconception of university students about biological evolution. The result of their study revealed that misconception found in high percentage. Their result also indicates that biology major students held wrong conceptions about evolution. Halim et al. (2018) conducted a study on Identifying and Remediating Student Misconceptions in Introductory Biology. The result of their study revealed that a greater number of misconceptions were identified pertaining to protein structure and function. They also reported that students used scientific terminology incorrectly. Some of the incorrect uses of terminology by the students include considering "Polypeptide bonds" as the same as "chains," interpreting "Protein unfolding," "misfolding," and "denaturing" as identical, and confusing "Alpha helix" with "double helix." Kapici and Akcay (2016) also reported that misconceptions about the particulate nature of matter are more common in middle school students compared to high school students. Yücel and Özkan (2015) found that most secondary school students had weak cognitive structure about Ecological concepts and they acquired superficial knowledge from their daily life and contained many misconceptions. On the other hand, Butler et al. (2015) also found that high level of misconception was reported in upper secondary school students and pre service teachers towards understanding of Ecological concepts.

Orbanic et al. (2016) also conducted a study on students' misconception about photosynthesis. The result of their study revealed that students who taught through traditional teaching method develop misconception towards photosynthesis as compared to students who taught through constructivist teaching method. Besides, Liu and Li (2013) also found that both the teachers and the students have misconception in photosynthesis and respiration.

AlHarbi et al. (2015) conducted a study on pre service teachers understanding of diffusion, osmosis and particle theory of matter concepts. The result of their study suggests that the pre-service science teachers in general experienced difficulty in understanding the principles of the particle theory of matter. However, they reported that the pre-service teachers' understanding of diffusion and osmosis was satisfactory.

Vitharana (2015) conducted a study on student misconception about plant transport. The analysis of student's responses reveals that students do not have a correct conceptual understanding of mechanisms responsible for plant transport especially osmosis, diffusion, active transport and transpiration.

Stevens et al. (2017) also found that students in higher institutions develop misconception in introductory microbiology courses particularly towards the topic antibiotic resis-

tance and host pathogen interaction concept inventory. Regarding to human anatomy and physiology, Taufiq et al. (2017) conducted a study on identification of pre service biology students' misconception in human anatomy and physiology course. The result of their study showed that majority (61.5%) of the students developed misconceptions in human anatomy and physiology courses. In detail, the finding of the study showed that participants develop misconception in skeletal system (57.81%), muscular system (52.34%), integumentary system (55.47%), nervous system (51.04%), endocrine system (54.69%), hemolymphatic system (66.02%), cardiovascular system (62.89%), respiratory system (68.75%), digestive system (70.31%), urinary system (70.7%) and reproductive system (71.88%). Misconceptions were mostly developed on reproductive system sub materials and less likely found in nervous system sub materials.

Aniyah et al. (2018) also reported that the overall level of grade 8 students' misconception on the transportation system of humans and plants in Indonesia is quite high that is on average about 60%. The location of misconception of each student is different. The highest misconception profiles were the absorption of water occurs diffusion and absorption of minerals occur osmosis (76.7%). Wahyono and Susetyarini (2021) conducted a study on Misconceptions of biology education students in Biochemistry Course during the COVID-19 pandemic. The result of their study revealed that 53% of the students experienced misconception in biochemistry course.

In Ethiopia, there were a few attempts to conduct a study on biological science misconception. Hailegebreil (2014) conducted a study on students' misconception about cell biology and cell division in Kelafo secondary school, Somali region Ethiopia. The result of his study showed that majority of the students had high level of misconception about cell biology and cell division and 16 types of common misconceptions about cell biology and cell division were identified and categorized into: definition of cell biology and cell division, structures and functions, types, energy and cell cycles. Moreover, the observed classes of cell biology and cell division lessons showed that all biology teachers did not implement effective instructional methods to remediate students' misconceptions.

Basha et al. (2014) also conducted a study on misconception of students about photosynthesis and cellular respiration in secondary schools of East Arsi, Ethiopia. The result of their study showed that high levels of misconceptions were observed (in more than 50% of students) in defining photosynthesis and concept of food making by green plants. They also reported that biology teachers' methods of instruction to teach photosynthesis and respiration and techniques used to remediate students' misconceptions were found to be ineffective and were not in line with the methods of teaching depicted in the textbook, syllabus and teacher's guide. Moreover, Dagnew and Mekonnen (2020) conducted a study on effect of using guided inquiry teaching method in improving grade eight students' misconception on the concept of photosynthesis in primary schools of Ethiopia. The result of their study revealed that those students who taught through inquiry-based teaching develop more conceptual understanding on the concept of photosynthesis than those students who taught through traditional teaching methods. Yenenesh et al. (2020) also found that primary school students taught through concept map method develop more conceptual understanding on the concept of photosynthesis than those students who taught through traditional teaching methods. Furthermore, Dagnew and Endris (2020) conducted a study on Model-based instruction to improve the concept of students on human anatomy in primary schools of Ethiopia, and showed that the model-based teaching approach improves students' conceptual understanding, participation and clear misconceptions compared to the students taught by traditional teaching approach.

After the recognition of misconceptions, the next step is correcting them (Allen, 2010). If teachers are to diagnose or become familiar with their students' views, they can apply some strategies accordingly (Çakır, 2008).

As reported by Devetak et al. (2007); Gudyanga and Madambi (2014), textbooks are one of the sources of misconceptions. To overcome this problem, there is a need to provide more concentration towards the curriculum developers and the textbook authors. The content should be arranged in such a manner which provides complete information and give examples which makes easy to understand the content. In addition to this, the content should be managed in such a manner which will help to make connection between new and previously existing concepts.

According to Treagust et al. (2003), teachers are less competent over the biology subject and fail to present abstract concepts appropriately. So, teachers should have adequate subject knowledge before entering into the classroom. The teachers should also have much mastery over the content and similarly should have the quality to simplify the content as per the learners understanding level.

Liu and Li (2013) also found that sound knowledge of the teacher is very necessary to minimize or eliminate misconceptions. As stated earlier, Biology is abstract by its nature and it makes difficulty in students biology learning, and for overcoming this obstacle, the teachers can use flow diagram or concept maps which will be helpful in showing the relationship between the two stages. It is also suggested that concept maps can be modified into activities which will make interesting and helpful to stop rote learning and enhance meaningful learning. Following prompting question can be used in constructing proper understanding the concepts.

Satilmis (2014) stated that students had misconceptions due to ineffective teaching method especially when the teachers followed the traditional method which does not provide any scope to understand the concept. Therefore, a constructivist teaching approach is useful to prevent and fix students' misconceptions. Constructivist theories support learning as a social improvement involving language, real world situations and cooperation among learners (Özer, 2004). Jean Piaget proposed that a constructivist education allows students to increase their ability to discover new ideas and construct new knowledge with regarding their personal interests and different level of intelligences (Özer, 2004). According to this theory, teachers should allow students to be in an effective learning environment in order to gain meaningful and persistent knowledge.

Mintzes et al. (2001) suggested that concept maps, Vein diagram, clinical interviews, portfolios and conceptual diagnostic tests can be used as a means to eliminate misconception in biological concepts. Michael (2002) concluded that providing opportunity for experiment in laboratory is a good way of eliminating misconceptions from the students. As reported by him 75% of the misconceptions can be eliminated by using this method in Biology teaching.

Perrone (2007) reported that children develop their concepts from their everyday life experiences and inquiry-based learning method which is useful as well as effective for addressing the misconceptions within the students.

5 Previous research on misconception and existing research gaps in Ethiopia

Exploring students' misconception in science started as research at late 1970s, and became more prominence at early 1980s (Taber, 2009). During this period, as briefly stated by Taber (2009), research groups based at the Universities of Waikato (New Zealand), Leeds (UK) and Surrey (UK) undertook extensive programs of research into children's ideas in science, and a range of seminal studies were published. These studies effectively initiated a research program into the nature of children's ideas; how they devel-

oped and how teachers should respond (Taber, 2009). The program was underpinned by a perspective on learning that is commonly referred to as constructivism. The interest in this area of research led to a number of books on children's ideas in science (Kind, 2004; Taber, 2009). In Ethiopia, it was the introduction of a new 'Master of Science Education (M. Ed)' post graduate program that exposed most post graduate students to the idea of students' misconceptions (Engida, 2002). However, as compared to studies conducted abroad, few studies were conducted in Ethiopia. Surprisingly, with regard to biological science misconceptions, only few studies were conducted i.e., Cell biology and cell division (Hailegebreil, 2014), photosynthesis and Cellular respiration (Basha et al., 2014), photosynthesis (Dagnew and Mekonnen, 2020 and Yenenesh et al., 2020), human anatomy (Dagnew and Endris, 2020) and human biology (Wodaj and Belay, 2021).

As reported by Peterson and Treagust (1989); Lee et al. (1993); Barker (1994), junior students have variety of misconceptions about the very basic biological concepts. However, few studies were conducted regarding to biological science misconception in junior secondary schools of Ethiopia. Furthermore, researchers suspected that those college, university students, and even teachers could have misconceptions about basic and advanced biological concepts from the very beginning which they have learnt in primary education before many years (Peterson and Treagust, 1989; Lee et al., 1993; Barker, 1994). However, no studies were conducted regarding biological science misconceptions at tertiary education levels of Ethiopia. Therefore, in attempt to bridging the above revealed gaps, there is a need to conduct research on biological Science misconceptions in primary, secondary and tertiary education levels of Ethiopia.

6 Conclusions

Misconceptions are deemed to occur when students' comprehension of a concept diverges from the scientific community's understanding. An examination of the literature underscores that everyday experiences, language usage, teachers, and textbooks play pivotal roles in contributing to students' misconceptions in biology lessons. Numerous studies conducted across different countries have delved into students' understanding of biological concepts. The identification of students' misconceptions holds paramount importance for effective teaching and learning in science. Various diagnostic tests, such as interviews, open-ended questions, multiple-choice questions, and multiple-tier tests, have been widely employed in science education research to measure and identify students' misconceptions. In order to enhance effective and meaningful learning, it is imperative to devise strategies for rectifying or preventing misconceptions based on their nature. While extensive research has been conducted internationally on biological science misconceptions, there is a noticeable dearth of research in the context of Ethiopia. Hence, there is an urgent need to undertake comprehensive research on biological science misconceptions at the primary, secondary, and tertiary levels of education in Ethiopia to address the identified gaps. Such endeavours are crucial for advancing science education and ensuring that teaching practices align with students' understanding, fostering a more accurate and comprehensive grasp of biological concepts.

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Data Availability

Data can be made available on the behavior of the request

Declaration of interests' statement

The author declare no competing interests.

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