

Genetic Misconceptions Among African/ Asian Secondary School Students: A Systematic Literature Review

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Abstract

Students usually misconstrue genetics concepts taught in secondary schools. Unfortunately, without understanding these scientific concepts, making informed decisions on health, reproduction, and general moral stance in genetics may be challenging. This systematic review of literature on genetic misconceptions among secondary school students in Asia and Africa provides a synthesis of research studies in Asia and Africa to unveil the common genetic misconceptions among the students and the factors that contribute to these misconceptions. Four databases were searched (Web of Science [WOS], Scopus, ProQuest, and EBSCOhost). Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, it was unveiled that some misconceptions upheld by African and Asian students include misconception of the molecular nature of genes, the gender dependency of the transfer of baldness, baldness is a consequence of ageing, becoming an albino by wearing second-hand clothes, cells from same species have the same genetic composition, genetic mutations are race dependent, daughter cells have more genetic information than parent cells, and many more. Some factors that facilitate these misconceptions include textbooks, teaching methods, television and video representation of biological concepts, the elders' and community sayings, religion, and students' presumptions. These misconceptions can be mitigated through teaching strategies and early detection of students' alternative conceptions. This study recommends practical-based instructional strategies such as visiting molecular genetics laboratories for exposure to real-life laboratory-based molecular genetics. It is also crucial that 3D visual aids are used in teaching such abstract topics.

Keywords: Genetic misconception, students' genetic misconceptions, systematic review, Asian genetics misconceptions, African genetics misconceptions

Introduction

Genetics, the study of how traits are transferred from parents to offspring or from generation to generation, can be regarded as the cornerstone of life. Nevertheless, it is one of the most widely misunderstood concepts in education (Etobro & Banjoko, 2017). Many research studies (Hayssen, 2020; Kılıç, 2019; Duda, 2020; Etobro & Banjoko, 2017; Perrone, 2007) have investigated students' misconceptions about genetics, most of which are quantitative studies. However, there does not seem to be a synthesis of research findings on students' misconceptions about genetics. This paper systematically reviews empirical studies on Genetic Misconceptions among African and Asian secondary school students. Beyond theoretical knowledge, understanding and conceptualising biological terms is fundamentally essential for science students. The tangible application of biological knowledge in everyday life creates a reality centred on students' ability to grasp and internalise concepts fully. Wahyono and Susetyarini (2021) argue that

misconceptions about biology are a dilemma grappled with when teaching biology in the classroom. According to Modell et al. (2005, p. 20), 'misconception is defined as an individual's discernment of occurrences happening in the mundane world that is inconsistent with the scientific elucidation of the phenomena'. To Aydin and Balim (2009), misconception means the definition of concepts in a way that differs from the scientists' perspective. We could, therefore, argue that a misconception is any meaning or interpretation given to a concept by individuals or groups of people that does not align with the scientist's explanation. Misconception and alternative conception are used interchangeably. In some articles, misconceptions and alternative conceptions refer to the same thing (Wisch, Farrell, Siegel & Freyermuth, 2018; Leonard, Andrews & Kalinowski, 2014). Duda (2016) points out that these two concepts can be used synonymously. In contrast to the previous view, authors like Reinoso, Delgado-Iglesias, and

Fernández (2019) explain that alternative conceptions precede students' misconceptions. Essentially, they assert that an alternative conception leads to students' misconceptions. We agree with Wisch et al. (2018) that learners' alternative conceptions of genetics and genetic misconceptions can be used interchangeably. As confirmed by Sesli and Kara (2012), the consequence of conceptual challenges faced by students is to revert to an alternative understanding. Reinoso et al. (2019) assert that misconceptions or alternative conceptions usually emanate from learning errors due to the abstract nature of a subject or topic. Duda et al. (2020) argue that most misconceptions result from errors in prior knowledge of these abstract concepts. Sometimes, misconceptions in biology may be due to visceral thoughts or 'through the use of analogies that oversimplify the scientific concept being studied' (Duda et al., 2020) during teaching and learning. The misconceptions in learning must be known (Kiliç, 2019) to be corrected adequately. Etobro and Banjoko (2017) also emphasise the role of media in projecting biological misconceptions. In their studies, Osman, BouJaoude, and Hamdan (2017) note that Lebanese students hold several misconceptions about the molecular nature of DNA, as recorded by Ben-nun and Yarden (2009) in their study. Lebanese students struggle to understand the role difference between genes and alleles. Biology teachers need to detect these misconceptions and correct them in learners to avoid genetic illiteracy (Osman et al., 2017). Since misconception is cognitively ingrained in children, it can be a deterrent to effective learning (Perrone, 2007). However, Reinoso et al. (2019) contend that misconceptions in young people are difficult to change after being acquired and established in their minds.

Genetics and its applications are becoming ubiquitous, infiltrating various aspects of modern life, from healthcare to agriculture and technology. Regrettably, this advancement has also given rise to numerous ethical dilemmas. Therefore, it is not just crucial but urgent that students develop a comprehensive understanding of genetic principles. The benefits of genetic literacy extend beyond personal decision-making, empowering students to make well-informed decisions in their daily lives (Maghfiroh et al., 2023). Moreover, given the significance of genetics in biological sciences, addressing the students' misconceptions is important in improving science education. For example, many genetics-related concepts (e.g., heredity, DNA, genetic disorders) are foundational in science education, and misconceptions can persist into higher education. Its understanding is also central to national

scientific literacy, making understanding genetics-related concepts integrated into the secondary school curricula of many secondary-level programs imperative (Etobro & Banjoko, 2017). Over the past few decades, numerous studies have shown that students often hold misconceptions and struggle to grasp the deeper complexities of genetics. This raises serious concerns about the effectiveness of genetics education in adequately preparing them for the future. It is clear that there is an urgent need for improved genetics education to address these misconceptions, and it is a responsibility we all share.

This study sought to integrate and synthesise the existing literature on genetic misconceptions among high school students in African and Asian countries. Hayssen (2020) in his article argues that cultural beliefs, religious perspectives, and indigenous knowledge contribute to specific misconceptions about genetics. Lvova (2024) asserts that African and Asian countries are entrenched with various cultural and religious beliefs that have infiltrated their understanding of science. This twisted perception fosters scientific misconceptions and disapproval of some scientific explanations, as expressed in genetics (Matazu & Isma'il, 2024). However, understanding these misconceptions can help bridge the gap between scientific concepts and local beliefs. This systematic review, therefore, seeks to answer these two research questions: (i) What are the common misconceptions about genetics among high school students in African and Asian countries? (ii) What factors contribute to the misconceptions about genetics among high school students in African and Asian regions? The study addresses the argument of Wanyama et al. (2022) that systematic reviews enhance the integration of various empirical studies in a particular field. Hence, the identification of empirical studies on genetic misconceptions in these two continents and the comparative description of the findings are central to the current study. Apart from harnessing the findings in empirical research, the systematic review brings a comprehensive report of research from different authors in the same field of enquiry (Harden & Thomas, 2005). A replicable, systematic documentation and reporting process is pivotal to systematic review, thus ensuring minimal bias in the selection and inclusion of articles in a study

Background

Genetics is key to understanding and applying biological concepts such as heredity (Adelana et al., 2021). Genetics is the study of hereditary (Perge & Igaz, 2019, p.3). According to Táriba (2023) and Suzuki (2022), it is regarded as one of the fast-growing branches of biological science that deals

with the study of genes. Bolondi et al. (2017, p. 5) described genes as “the indivisible unit of inheritance subject to mutations and genetic recombination”. Human existence and propagation hinge on understanding and making crucial decisions regarding all aspects of human existence, including heredity. Genetics is critical these days as we battle with questions that pertain to our very existence, such as genetic diseases, genetic testing, genetic engineering, race, and ancestry. A deep understanding of genetics will also ensure clarity in explaining the biases that are fundamentally excusable through genetic essentialism, as recorded by Donovan (2021). In the study by Zounon et al. (2012), the people of Benin Republic held a series of misconceptions about the fact that sickle cell disease is an inherited disease and does not automatically lead to illness. For example, they believed that sickle cell disease is also attributed to affliction by evil spirits (Rahimy et al., 2003), a misconception about the disease and its origin.

There are various branches of genetics. These are identified as molecular genetics, which is the study of the structure and function of DNA (Tariba, 2023); genetics genealogy, which deals with the use of DNA to trace ancestry (Nikolova, 2018), classical or Mendelian genetics, dealing with the transmission of traits (Tariba, 2023), population genetics is the study of changes in the genetic structure of a population (Tariba, 2023), and quantitative genetics (study of polygenic traits) (Tariba, 2023, p. 3).

Culture plays a huge role in postulating misconceptions (Hayssen, 2020; Matazu & Isma'il, 2024). For example, in places where indigenous knowledge crosses paths with scientific explanations, it is most likely that the widely accepted will be the indigenous knowledge that cannot be scientifically substantiated. Conceptual misrepresentations are evident in biology, influencing how the acceptance of explanations consequently impacts their application in life (Matazu & Isma'il, 2024)

Methodology

This article reviews empirical studies on Genetic misconceptions among high school students in African and Asian countries. African and Asian countries are rich in culture and religion. They hold culture in high esteem and have the tradition of handing down Indigenous knowledge to their progeny (Akolade et al., 2020). According to Matazu and Isma'il (2024), these two are fundamental to misrepresenting scientific knowledge. This is to synthesise the empirical studies from the continents

into a single comprehensive document. The study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol (Page et al., 2021). This guideline identifies empirical studies, describes their characteristics, summarizes findings, and makes recommendations for future research (Mamad et al., 2024).

The search is conducted on the Web of Science (WOS), Scopus databases, ProQuest, and EBSCOhost due to their scope of covering educational research on both continents.

The search procedure

Both line-by-line and single-line strategies were applied. In the line-by-line method, each search term or concept is placed in each line on the search engine. In contrast, the single-line method uses Boolean operators (AND, OR) to connect the terms within each concept, and parentheses are used to group concepts together. For example, in this study, the concepts used are misconceptions, genetic misconceptions, biology misconceptions, high school, secondary school, Africa, Asia, and qualitative research.

In the line-by-line method, misconceptions, such as high school, Africa, and Asia, are placed in individual lines, and the filter is applied. Four thousand articles were retrieved, and they were checked based on the criterion, using the Boolean operators, of misconceptions OR genetic misconceptions OR biology misconceptions AND high school OR secondary school AND Africa AND Asia AND qualitative research OR qualitative study OR qualitative method, which has an initial yield of 4,851 entries.

Inclusion Criteria

The focus of a study is dictated by the inclusion and exclusion criteria set by the researcher. Patino & Ferreira (2018) emphasise that inclusion/exclusion criteria are ‘key features of the target population that the investigators will use to answer their research question’. Since this study is based on studies conducted on genetic misconceptions in high schools in Africa and Asia, the inclusive criteria are focused on only empirical studies conducted in Africa/Asia on genetic misconceptions in high schools. The studies must be published in peer-reviewed journals to ensure their quality. Studies conducted before 1990 are excluded since 1990 marked the start of a transformative period in genomics and biotechnology, significantly impacting everyday life and possibly raising ethical issues.

Table 1: Database search table

	Search terms	Search options	Result
EBSCOhost	'misconceptions' AND 'genetic misconceptions' OR 'biology misconceptions' AND 'high school' OR 'secondary school'	Limiters - Academic (Peer-Reviewed) Journals; Published Date: 19900101- 20240931; Education Level: High Schools; Publication Type: Academic Journal; Document Type: journal articles Expanders - Apply equivalent subjects Narrowed by journals: See the attached appendix Search modes - Proximity	2104
ProQuest	'misconceptions' AND 'genetic misconceptions' OR 'biology misconceptions' AND 'high school' OR 'secondary school'		1814
Scopus	'misconceptions' AND 'genetic misconceptions' OR 'biology misconceptions' AND 'high school' OR 'secondary school'	Limiters - Academic (Peer-Reviewed) Journals; Published Date: 19900101- 20240931; Education Level: High Schools; Publication Type: Academic Journal; Document Type: journal articles 1990-2024	180
WOS	misconceptions (Abstract) and genetic misconceptions (Abstract) or biology misconceptions (Abstract) and 'high school' (Abstract) or 'secondary school' (Abstract)	1990-01-01 to 2024-09-16	753

Exclusion Criteria:

Exclusion criteria are applied during the study selection process in a systematic review to identify which studies will be excluded. The current study excluded studies outside the two aforementioned continents, books, magazines, and umbrella reviews such as systematic reviews.

Study design

The study design for this paper follows the systematic review design, where the PRISMA chart ensures the systematic flow of the reviewed papers and enhances the transparency of the process.

The PRISMA diagram

The PRISMA diagram (Fig. 1) visually describes the various steps taken during the systematic review process to establish the credibility, transparency, and value of reports in this study. The PRISMA diagram visually represents the current study's literature selection and screening process. (Liberati et al., 2009). The source identification, screening of the sources to ensure they are relevant, establishing the sources' eligibility, ensuring that they meet the inclusion and exclusion criteria, and separating the studies included in the review.

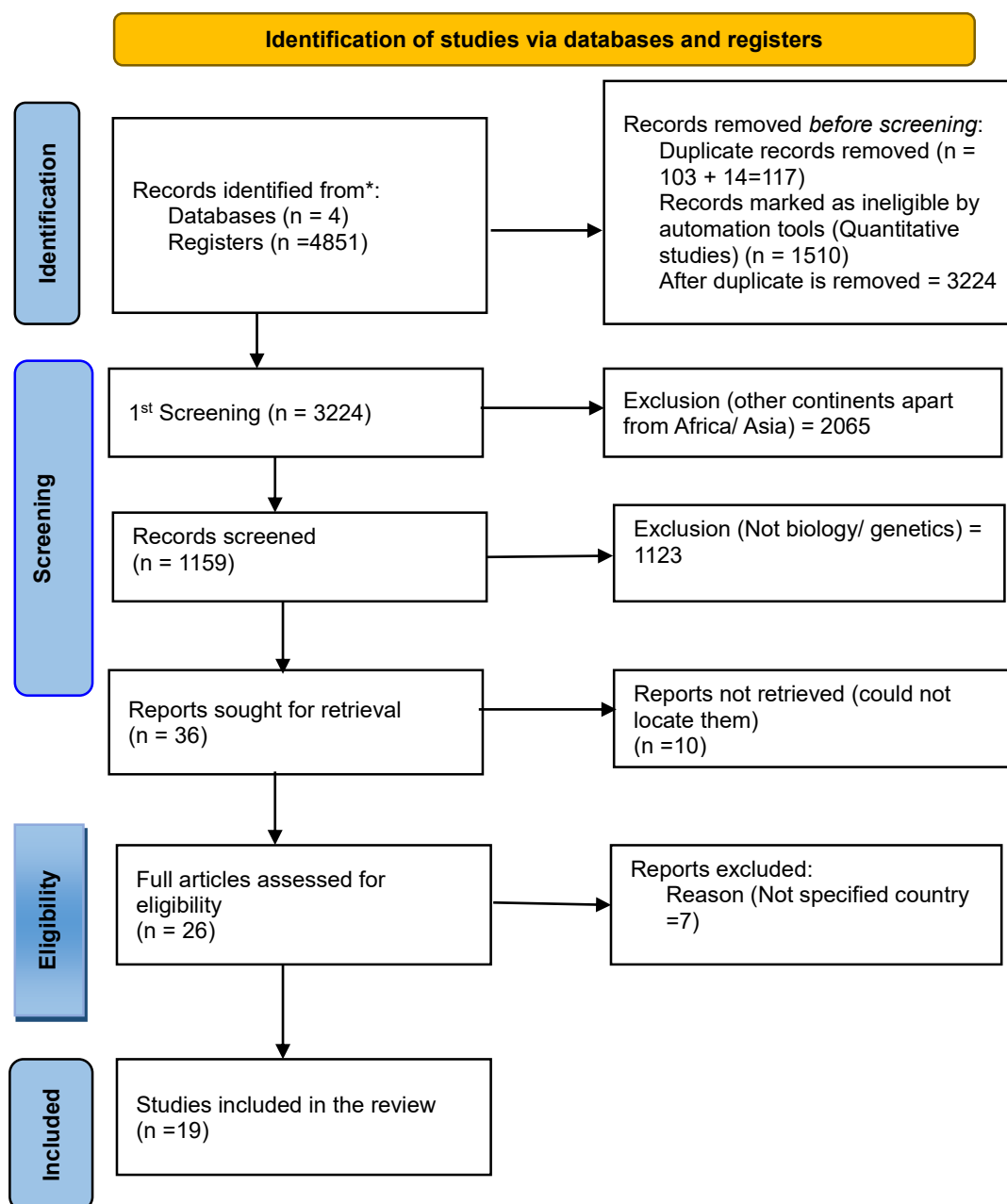


Figure 1: The PRISMA diagram for this study.

Findings

Common misconceptions about genetics among high school students in African and Asian countries.

The subsequent paragraphs will discuss common misconceptions about genetics among high school students in Asia and Africa.

Asian countries

Twelve articles from Asia met the study's criteria. These are from studies conducted in Israel (2), Turkey (4), Singapore (2), Pakistan (1), Indonesia (1), India (1), and the last cuts across the Asia/Africa continents (1) (See Appendix 1).

This review study found that students in Asian countries held different thoughts contrary to the scientific explanation of genetic evolution. For instance, students in Pakistan believe in special creation as opposed to the natural selection theory that evolution upholds. Special creation is the belief that some creations are created and do not undergo natural selection and the evolutionary theory, while others do. This notion is also propagated by the Pakistani curriculum, which interlaces evolutionary theory and creationism.

Ageiotos and Puig (2021) state that Asian students believed that 'black people' could control genetic

mutations based on their will, which does not align with scientific explanations. Scientifically, this notion is inaccurate. However, culturally, students link Sickle Cell Disease (SCD) predominantly with African-Americans or blacks. Even though many African-Americans have never resided in Africa because of their skin colour, they believe that they are automatically susceptible to the disease, meaning that SCD is linked to the black race.

Israeli students are conversant with biological concepts and their application. According to Ben-nun and Yarden (2009), their misconception is about the molecular nature of various genetic materials, such as DNA, RNA, and genes. Even though the students can use the concepts while explaining biological processes, there is a misapprehension of the molecular nature of these concepts. The students understand classic genetics but have contrasting conceptions concerning the concepts. For example, this is evident in their expectation to see the DNA strand in a test tube with their naked eyes. Even after it was treated by polymerase chain reaction (PCR), the students discussed their inability to see the DNA with unaided eyes.

Vital note-taking is when teachers who teach biology in schools hold several misconceptions about crucial genetic matters pertinent to day-to-day life. For example, preservice teachers in Turkey (Acarli, 2016) find it difficult to differentiate between Genetically Modified Organisms (GMOs) and growth hormones, such as auxins, abscisic acid (ABA), gibberellins, etc, used in enhancing growth in plants. The teachers, in essence, do not appreciate or understand that genetic modification deals with altering the DNA of a particular organism to bring a particular desired characteristic, which is different from the use of hormones. Using hormones to enhance plant growth has nothing to do with the alteration of the genetic configuration of organisms.

Biology students in India believed that every cell from an individual carries the same genetic material, thus failing to take into consideration the differences between the somatic cells (body cells) and the sex cells (gamete cells) of an individual (Chattopadhyay, 2005). Some students also believe that only cells from the same part of the body have the same genetic information. For example, cells from an individual's cheek will have the same genetic information as the cells from the other side of the same individual's cheek. However, when it comes to comparing the genetic information of the same individual's cheek to their nerve, then it is believed that they are different. Some assume that sex cells are diploid like somatic cells, which is an outrightly misconception. Chattopadhyay, 2005) also recorded that the

mechanism of sexual reproduction in plants and animals is viewed as the same by the students. This means that students, when explaining sexual reproduction in plants, fail to identify the concept of pollination- either self or cross-pollination, which is central to plants' sexual reproduction. Another one is that the students assume that plants only reproduce sexually when the environmental conditions are favourable, while in an unfavourable situation, plants tend to reproduce asexually. However, this is a misconception because the choice of the type of reproduction in plants is not dependent on the favourability of the environmental conditions. It is also a misconception that they believed that asexual reproduction is limited to lower plants.

According to Osman et al. (2017), Lebanese students have a misconception about cell division, genetic inheritance, and trait transmission, especially concerning albinism. Amidst these misconceptions is the fact that they believed that the reason why women give birth to a person with albinism is because of the wrong medication they took during their pregnancy. Some of the students also believed that Albinism is a result of the lack of calcium in pregnant women's diets. Concerning the transmission of traits such as height, some students believe that the type of food the parents, especially the fathers, eat influences their genes, which are consequently passed to their children.

The qualitative study conducted by Cinici (2013) reveals that Turkish students assume that the metamorphosis of a butterfly, where eggs develop into larvae, and the larva (caterpillar) turns into a pupa (chrysalis) and then transforms into a butterfly, is another form of mini-evolution. They (students) fail to differentiate between the process of growth in butterflies and the principles of evolution. Some students also believed that caterpillars and butterflies are two different species of organisms.

Meanwhile, in Indonesia, students assume that environmental factors do not play any role in gene trait expression. They believe that traits are solely dictated by genes. According to Gusmalini and Wulandari (2020), students are also confused about the replication process. Due to the oversimplification of this concept, they assume that replication is only referred to when DNA multiplies itself into more DNA replicas, failing to acknowledge that RNA also replicates itself, and that is also a replication process. Some also confuse the process of protein synthesis with the replication process.

Kara and Yesilyurt (2007) report on their experimental research that Turkish students misconstrue the location of genes. They assume that genes are only located on the gametes and are not

found in the somatic cells. They also believe, as reported by the authors, that genes are made up of amino acids instead of nucleotides and that DNA is found only in specific parts of the body, such as the blood. The same study revealed that students believed that chromosomes are made up of other chromosomes and that genetic composition and information are the same in all living organisms.

According to the study conducted by Sesli and Kara (2012), schoolchildren in Turkey nurture the misconception that genetic variation depends on the number of chromosomes in cells. Most of their misconceptions are about the process of mitosis and meiosis. They believe daughter cells have more chromosomes or genetic information than parent cells. They also believed that all the cells of an individual species have the same genetic information. Another misconception by Turkish students is that meiosis can occur in both somatic and reproductive cells of the body and that the genetic composition of the egg cells from the same person is the same. In plant genetics, schoolchildren in Turkey believe that plant cells do not undergo cell division because they are not animals.

According to Seoh et al. (2016), a misconception by students in Singapore is that they express disbelief that humans have ancestors dating back millions of years. They believe that traits like the ability to think cannot be passed down through natural selection, indicating a misunderstanding of how natural selection operates in the evolution of cognitive traits.

African countries

Five articles were included in the analysis of the African continent. Two of these articles are from South Africa, one from Swaziland, one from Nigeria and the last one is shared with the Asian, which was discussed in previous paragraphs (See Appendix 1 for all entries).

It was recorded by Kibuka-Sebitosi (2007) that South African students are confused about differentiating genes from chromosomes. Students in the context view genes and chromosomes as the same concept, therefore misconstruing how genetic information is passed down to the offspring. For example, when asked questions on how heritable traits are passed on, some students mentioned that genetic traits are passed from parents to offspring through chromosomes. Some students also said that the transfer of traits is through the blood, while others said it is through hormones. Students also hold misconceptions about understanding inheritable traits, juxtaposing traditional beliefs and scientific reasoning. Some students believe that God determines whether a trait will be passed on to the offspring. Mthethwa-Kunene

et al. (2015) based their study on teachers' PCK. However, in their interviews with the teachers of the students in Grades 11 and 12 in Swaziland, they note the same mix-up of the key genetics discovered by Kibuka-Sebitosi (2007). They sometimes used these terms interchangeably, indicating a significant misconception. The teachers did not intentionally explore these misconceptions. However, they could pick them up as they teach their students. Some students also hold a misconception about Albinism in which they attribute this genetic trait to the consequence of traditional consultation with witch doctors during pregnancies or the use of second-hand clothes bought from flea markets (Kibuka-Sebitosi, 2007). Some believe that people with albinism are products of adultery (Kibuka-Sebitosi, 2007). In the study of Kibuka-Sebitosi (2007), students believed that the combination of old age and too much thinking causes baldness. Others believed that the trait is gender-dependent, which means that only boys can be bald and not girls (Kibuka-Sebitosi, 2007). Mpeta et al. (2015) argue that teachers may harbour misconceptions about evolution and the likelihood of teaching those misconceptions to their students. In their study, some students experience tension between their Christian beliefs of creationism and the concept of evolution, which can lead to their rejecting evolutionary theory. Genetic evolution has recently been added to the South African curriculum. Therefore, teachers are still grappling with the best strategies to teach the topic.

According to Ojo (2024), students have a misconception about how traits are transmitted and how genes are expressed. The study indicated that over 57% of Nigerian secondary school respondents had misconceptions about the transmission of traits in living organisms.

Mpeta et al. (2015) explained that some teachers use inappropriate methods for teaching evolution, failing to incorporate students' views and accommodate differences of opinion. This can result in students developing a distorted view of evolution and rejecting it outright.

Factors contributing to misconceptions

Students come into the classroom with several preconceived ideas. Chen et al. (2020) state that some of these ideas are commonly believed by society but are in contrast with scientific discovery. These preconceived ideas, often called misconceptions, are informed by various factors. The reviewed articles indicate various factors that have shaped the students' alternative conceptions or misconceptions in Asian and African schools. Such factors include challenges with instructional materials used in classes,

understanding abstract concepts, instructional strategies, teachers' underlying beliefs, communal sayings from elders in the community, and religion. It is known that some topics in biology, especially evolutionary genetics, are in contrast with all the religions that believe in creation and a deity. According to Ashgar et al. (2010), in Pakistan schools, the textbooks are written so that the creation story and evolution theory are presented alongside. Religion and evolution have been seen as contradictory to each other since the inception of Darwin's theory of evolution, Obirek (2017) contested. Religiously inclined teachers find it challenging to teach this topic, while students brought up in religious homes are caught up in this dichotomy (Seoh et al., 2016). A study by Abrie (2010) indicates that South African preservice teachers who were in the study were uncomfortable with teaching evolution, even though they held positive opinions about it. One of the reasons is that the theory has never been included in the country's curriculum before now. Instead, education has always embraced creationism theory, which is assumed to sit at the opposite extreme of Darwin's theory versus the creationism continuum.

The challenges of understanding abstract biology concepts contribute to students' misconceptions in the two continents. Biology comprises of many abstract concepts that students find challenging to comprehend. Visual aids can enhance students' understanding of the concepts in this case. For example, Gusmalini and Wulandari (2020) reported that Indonesian students developed misconceptions about the replication process due to the complexity of the term and misconstrued the role of genes and chromosomes due to the abstract nature of the concepts. From the review, the concepts often misconstrued by students include mitosis and meiosis, DNA and RNA (Mthethwa-Kunene et al., 2015). According to Ben-Nun et al. (2009), students contend with the cognitive mental models of genetic concepts, in which they tend to view the concepts as a "concrete physical copy of reality", failing to understand that the concepts are at molecular states and forms. This confusion harboured by the students leads to misconceptions and misrepresentations of the concepts (Sesli & Kara, 2012). The lack of ability to engage in formal operational thinking is seen to promote students' misconceptions. Topics such as the study of cell division and reproduction at a molecular level are abstract to students, as reported by Gusmalini and Wulandari (2020). Therefore, these topics and concepts must be taught in a way that will promote students' understanding.

Often, instructional strategies employed by teachers could lead students to acquire fragmented knowledge (Chattopadhyay, 2009). This incomplete knowledge acquisition hinders students' adequate understanding of these concepts. According to Chattopadhyay (2009), sometimes, the concepts are not linked with other concepts within the aspect of Biology, and as such, students fail to grasp the whole picture of what they are learning. Moreover, some of these strategies lead to rote learning, especially when not linked to real-life situations. Therefore, teachers must be equipped to employ strategies that can promote these formal operations that foster abstract thinking to engender understanding, argued Sesli and Kara (2012). However, this may be challenging for some teachers who do not have such skills.

Textbook representations of some concepts, such as DNA, genes, chromosomes, etc., have been noted as an important factor that fosters misconceptions (Ben-Nun & Yarden, 2009; Chattopadhyay, 2005; Livni-Alcasid, Haskel-Ittah & Yarden, 2018). According to Chattopadhyay (2009), instructional materials are reported to only provide shallow explanations that barely cover the complexities that the genetic topics represent. Ben-Nun & Yarden's (2009) findings also support Chattopadhyay's (2009) view that the pictorial representations provided in the textbooks are misleading and could provoke misconceptions. In addition, Ben-Nun and Yarden (2009) also mentioned that television and video presentations fail to acknowledge the molecular nature of genetic structures like DNA, thereby causing misconceptions among students.

Culture is one of the factors identified by the reviewed papers that form the foundation of some misconceptions. For example, Ageitos and Puig's (2021) study reveals that students believe that certain diseases are genetically passed to offspring by racially black people. They also hold the misconception that black people can control genetic mutation whenever they want to. These notions were propagated by the common beliefs in certain places in Asia and Africa. Communal sayings from elders in the community and teaching from teachers with misconceptions also foster students' misconceptions. For instance, students alluded to the fact that they heard from elders in their community that killing Albinos would result in giving birth to Albino children or buying second-hand clothes could make a woman pregnant with an Albino child or children. Acarli's (2016) study of Turkish preservice teachers reported that teachers' misconceptions of the mix-up of GMOs and the use of growth hormones, as well as the misconceptions about the sameness of the DNA of a virus and bacteria, could be critical in propagating

misconceptions. Sadly, ill-informed teachers will pass on their misconceptions to their students when they become teachers.

All these factors engender genetic misconceptions in students and must be addressed carefully to disallow scientific and naturalistic conflict.

Discussion of the findings

Understanding genetics and its accompanying concepts has challenged many students globally (Ageitos & Puig, 2021; Sesli & Kara, 2012; Ben-Nun et al., 2009). Genetic misconceptions in Asia and Africa are similar. This is in the sense that abstract topics such as cell growth and division, meiosis and reproduction, DNA replication, and distinguishing genes from chromosomes are reported to be difficult for the students to comprehend. It was argued by Ben-Nun et al. (2008) that the point at which misconception sets in for most students is at the molecular level of comprehension. With this lack of understanding, students become confused since their conceptions and convictions are at variance with the scientific facts. Most reviewed papers in the current study that relate to genetic evolution indicate that governmental, cultural, religious, and the most common narrative prevalent in the community or environment strongly influence the enforcement and propagation of scientific misconceptions. According to Mpeta et al. (2018), students' worldviews may contradict scientific facts if that is the thought that dominates their milieu. It is, therefore, necessary to educate society concerning the scientific facts.

For one of the reviewed articles from South Africa, misconceptions from the students are centred on differentiating between genes and chromosomes. Sometimes, students think these two concepts are the same or interchange them. In Kibuka's (2007) article, students link inheritance to blood, not genes (p. 58). Students' misconception stems from their thoughts, what they read or the narratives that are going on in the community (Kibuka, 2007). This corroborates Mpeta et al.'s (2018) findings that the thinking of the people in a community fuels students' misconceptions. For instance, in Kibuka's (2007) scenario given to the student, the students believe that albinism is due to the previous consultation of the mother of the child with a traditional ritualist or the repercussion of the parents' bad behaviour. The students interviewed in the study are in Grades 11 and 12 and are preparing to enter the university. The assumption is that these students should be able to understand these concepts and how albinism relates to inheritance. The implication is that we will have graduates who will maltreat and mishandle an albino, assuming that they are who they are as a result of their

parents' bad behaviour. Other students relate the trait to religious factors. In contrast, Mpeta et al. (2015) and Asghar et al. (2010) agree that religion did not influence the acceptability of the scientific explanation of evolution. However, in the article by Asghar et al. (2010), the authors still believe that the acceptance of the scientific explanation of evolution was only based on the government and does not represent the viewpoint of the majority of the community in the context of the study. Ageitos and Puig (2021) also report that misconceptions are propagated by cultural beliefs when they understand from students that certain races can control genetic mutation.

In the reviewed article, misconceptions could also emanate from what teachers teach (Kiribuka, 2007) and the teachers' inability to detect the students' alternative conceptions (Mthethwa-Kunene et al., 2015). Misconceptions are also propagated by various teaching strategies adopted by the teachers (see Ben-Nun & Yarden, 2009). Ben-Nun and Yarden (2009) propose that correcting these misconceptions can be achieved by instigating cognitive conflict through practical or hands-on activities.

However, one solution to this confusion is exposing students to real-life learning where they can experience biology as biology professionals experience it (Ben-nun & Yarden, 2009). In their conclusion, Ageitos and Puig (2021) suggest that providing students with support that will change their prior conceptions will help dismantle their wrongly preconceived ideas. Sesli and Kara (2012, p. 221) further affirmed that misconceptions can be reduced to the barest minimum "if teaching-learning environments include more visual-based activities towards identified alternative understanding". According to Menendez, Donovan, Mathiapparanam, Klapper, Yoo, Rosengren and Alibali (2024), visual representations could foster students' genetic conceptual understanding at the molecular level.

Conclusion

Genetic misconceptions in schools need to be addressed. To address these misconceptions, it is important to know the causal agents and how to limit the propagation of misconceptions. Genetics is central to most medical professions. However, when misconceptions are not doused in secondary schools, they may be carried along into higher institutions where the possibility of detection becomes slimmer. The misconceptions also impact the genetic literacy of students and their constructive participation in public debate. This systematic review of articles from Asian and African countries has highlighted some factors that cause genetic misconceptions in schools,

which include the teachers' misconceptions passed down to the students, their inability to detect the students' alternative conceptions and oversimplification of concepts, which ultimately leads to misconceptions. This study also reveals that Asian and African students' misconceptions emanate from their assumptions and the beliefs of the community where they reside.

Hence, we recommend more practical instructional strategies such as visiting molecular genetics-based laboratories and exposure to real-life laboratory-based molecular genetics. In doing so, the students' misconceptions about the molecular nature of genetic concepts will be curtailed. We also recommend that teachers explore their students' misconceptions about any topic they teach to enhance a strategic approach to teaching such students. Visual representation of abstract topics such as genetic concepts is also an excellent tool in promoting students' understanding of such abstract concepts. Further studies may include comparative studies on the influence of students' educational level on their genetic misconceptions. It will also be valuable to explore the effect of teachers' misconceptions on students' understanding of the genetics concept.

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Appendix 1

Studies included in the review

Title (19 entries)	Continent	country	Topic	Study aim	Data collection method	Identified misconception	Factors
Acarli, D. S. (2016). Determining Prospective Biology Teachers' Cognitive Structure In Terms Of "Biotechnology". <i>Journal of Baltic Science Education</i> , 15(4), 494-505.	Asia	Turkey	Genetics	To determine prospective biology teachers' conceptual framework of biotechnology	Qualitative research approach	The use of growth hormones such as auxin is the same as producing genetically modified organisms (GMOs). Taking the DNA or virus and bacterial as the same in structure and roles	Not specified
Ageitos, N., & Puig, B. (2021). Argumentation as a tool to explain the evolutionary links between human diseases: a case study. <i>Journal of Biological Education</i> , 55(2), 188-195.	Africa/Asia	Africa/Asia	Genetic evolution	To explore the role of debating in helping students understand the evolutionary connections between human diseases and to foster the learning of genetics and evolution,	Qualitative research approach	Sickle Cell Disease only affects the Black race 'Black people' can influence genetic mutations at will	Students' personal presumption



Asghar, A., Wiles, J. R., & Alters, B. (2010). The origin and evolution of life in Pakistani high school biology. <i>Journal of Biological Education</i> , 44(2), 65–71.	Asia	Pakistan	Evolution	It seeks to reconcile science and religion, which is evident in Pakistan's school curriculum.	Qualitative	Special creation is the same as evolution theory	Religion
Ben-Nun, M. S., & Yarden, A. (2009). Learning molecular genetics in teacher-led outreach laboratories: Educational research. <i>Journal of Biological Education</i> , 44(1), 19-25.	Asia	Israel	Molecular genetics	Aim at the use of Teacher-Led Outreach Laboratories to foster students' understanding of molecular genetics concepts.	Mixed method approach	Apprehension of the molecular nature of Misjudging DNA size and its molecular nature for something that can be seen under a light microscope	Textbook representation of DNA Teaching strategy TV and video representations
Chattopadhyay, A. (2005). Understanding of genetic information in higher secondary students in northeast India and the implications for genetics education. <i>Cell biology education</i> , 4(1), 97-104.	Asia	India	Genetics	To investigate the understanding of secondary students in northeast India on basic genetics concepts.	Mixed method approach	Cells from every individual carry the same genetic material and information. - Only cells of the same type or from the same body part contain the same genetic information. For example, cheek	Instructional materials used in classes are often not deep enough to cover the complexities of genetic phenomena, Instructional strategies that give room to fragmented or



						<p>to cheek and not cheek to arm.</p> <ul style="list-style-type: none"> - Inability to differentiate between somatic cells and sex cells. -Sequels to the previous point: sex cells are diploid - The same mechanism of sexual reproduction applies to both plants and animals - Sexual or asexual reproduction in plants is dependent on the favourability of the condition - only lower plants undergo asexual reproduction. 	incomplete knowledge and encourages rote learning.
Cinici, A. (2013). From caterpillar to butterfly: A window for looking into students' ideas about life cycle and life forms of	Asia	Turkey	Genetics	to explore students' understanding of metamorphosis	Qualitative research approach	- The transformation from a caterpillar to a	Not specified



insects. <i>Journal of Biological Education</i> , 47(2), 84-95.						butterfly is evolution. - Caterpillars and butterflies are different species of insect	
Gusmalini, A., & Wulandari, S. (2020, October). Identification of misconceptions and causes of student misconceptions on genetics concept with CRI method. In <i>Journal of Physics: conference series</i> (Vol. 1655, No. 1, p. 012053). IOP Publishing.	Asia	Indonesia	Genetics	To identify students' misconceptions about genetics and the causes	Quantitative research approach	- Only the genes and chromosomes determine the nature of living things without considering other environmental factors. - Relates replication only to means multiplying DNA into more DNA, not considering the occurrence of RNA replication - The replication process is the same as the protein synthesis process.	- Complexity of the terms - The broadness of the scope of genetics as a topic - The abstract nature of the concept
Kara, Y., & Yesilyurt, S. (2007, December). Assessing the effects of tutorial and edutainment software programs on students'	Asia	Turkey	Genetics	To investigate the use of software programs on students'	Experimental research design	- Genes are found anywhere and everywhere (which is vague)	Not specified



achievements, misconceptions and attitudes towards biology. In <i>Asia-Pacific Forum on Science learning and teaching</i> (Vol. 8, No. 2, pp. 1-22). The Education University of Hong Kong, Department of Science and Environmental Studies.				achievements, misconceptions, and attitudes towards genetics.		<ul style="list-style-type: none"> - Genes are only found in reproductive cells. -Genes are made up of amino acids -DNA is only found in specific parts of the body, for example, blood - Chromosomes are made up of other chromosomes Genetic information is the same in all living organisms. -All body cells from one individual do not contain the same genetic information 	
Kibuka-Sebitosi, E. (2007). Understanding genetics and inheritance in rural schools. <i>Journal of biological education</i> , 41(2), 56-61.	Africa	South Africa	Genetics	The primary aim of the study was to investigate biology learners' understanding of concepts related to genetics and inheritance and	Both qualitative and quantitative methods	<ul style="list-style-type: none"> - Killing an Albino can lead to giving birth to an Albino - The transfer of traits to offspring is 	Sayings from the elders and the community



				to identify and address misconceptions that learners held about genetics and inheritance.		<p>through chromosomes.</p> <ul style="list-style-type: none"> - Transfer of traits is through the blood, -Transfer of genetic inheritances is through hormones - Baldness is gender dependent - Baldness is as a result of old age and too much thinking - Wearing second-hand clothes makes on turn to Albino 	
Livni-Alcasid, G. A., Haskel-Ittah, M., & Yarden, A. (2018). As symbol as that: Inconsistencies in symbol systems of alleles in textbooks, and students' justifications for them. <i>Education Sciences</i> , 8(3), 110.	Asia	Israel	Textbook-Gene	to explore the use of symbol systems for alleles in genetics education and to understand the justifications for changes in these systems	Qualitative approach	Students often misinterpret scientific representations, leading to confusion.	Textbook
Mpetta, M., De Villiers, J. J. R., & Fraser, W. J. (2015). Secondary school learners'	Africa	South Africa	Evolution	to explore and understand the beliefs of	Mixed method	The creationism and rejection	Teachers beliefs Religion



response to the teaching of evolution in Limpopo Province, South Africa. <i>Journal of Biological Education</i> , 49(2), 150-164.				secondary school learners regarding evolution, how these understandings impact their learning and acceptance of the concept of evolution		evolutionary theory a distorted view of evolution	
Mthethwa-Kunene, E., Onwu, G. O., & de Villiers, R. (2015). Exploring biology teachers' pedagogical content knowledge in the teaching of genetics in Swaziland science classrooms. <i>International Journal of Science Education</i> , 37(7), 1140-1165.	Africa	Swaziland	Genetics	The study's primary aim was to investigate Pedagogical Content Knowledge and identify students' preconceptions demonstrated during genetics lessons.	Qualitative approach	Confusion of the role of key genetics terms such as 'chromosomes' and 'genes', 'genes' and 'alleles'	Not specified
Ojo, A. T. (2024). Examination of Secondary School Students' Conceptual Understanding, Perceptions, and Misconceptions about Genetics Concepts. <i>Pedagogical Research</i> , 9(1).	Africa	Nigeria	Genetics	To investigate the extent of students' comprehension of genetic concepts	Mixed methods	Transmission and expression of character	
Osman, E., BouJaoude, S., & Hamdan, H. (2017). An investigation of Lebanese G7-12 students'	Asia	Lebanon	Genetics	To identify Lebanese students' misconceptions	Mixed methods	Students believed that Albinism resulted from the	From previous teachers, From family Media



misconceptions and difficulties in genetics and their genetics literacy. <i>International Journal of Science and Mathematics Education</i> , 15(7), 1257-1280.				while teaching genetics in the classroom.		lack of calcium in pregnant women's diets. The type of food a parent eats informs their genes, which are consequently passed to the child.	Personal visceral thoughts
Safitri, D., Zubaidah, S., Gofur, A., & Rahayu Lestari, S. (2024). Academic Level and Gender-based Mapping of High School Student's Genetic Literacy: A Cross Sectional Study in Indonesia. <i>Uniciencia</i> , 38(1), 147-171.	Asia	Indonesia	Genetics	To assess the level of genetic literacy among students in Indonesia.	Quantitative/observational method	Genetic traits are entirely predetermined by the genes themselves, neglecting the role of factors like diet, lifestyle, or external exposures in gene expression and phenotypic variation.	Superficial explanations of concepts in Instructional strategies al materials like textbooks.
Seoh, K. H. R., Subramaniam, R., & Hoh, Y. K. (2016). How humans evolved according to grade 12 students in Singapore. <i>Journal of Research in Science Teaching</i> , 53(2), 291-323.	Asia	Singapore	Evolution	To understand the perceptions of grade 12 students in Singapore regarding human phylogeny, with a particular focus on their perceptions of	Qualitative Method	Belief in creationism Disagreement on the influence of natural selection on the evolution of cognitive traits	Not specified



				the chimpanzee-human last common ancestor			
Sesli, E., & Kara, Y. (2012). Development and application of a two-tier multiple-choice diagnostic test for high school students' understanding of cell division and reproduction. <i>Journal of Biological Education</i> , 46(4), 214-225.	Asia	Turkey	Cell division and hereditary	To develop and apply a two-tier multiple-choice diagnostic test to assess high school students' understanding of cell division and reproduction concepts	Qualitative	Daughter cells have more chromosomes or genetic information than parent cells. The cells of the same species have the same genetic information. The cells formed through the same type of cell division would have the same genetic information. Meiosis can occur in both the somatic and reproductive cells of the body.	Not specified

