Interdisciplinary Journal of Environmental and Science Education
2022, 18(4), e2287
ISSN 2633-6537 (Online)
https://www.ijese.com

Research Article

A Gender-based Investigation of Indian Senior Secondary Students' Misconceptions about Plant Reproduction through Concept Inventory

Anirban Roy [1*], Animesh Kumar Mohapatra [1]

[1] Department of Education in Science and Mathematics, Regional Institute of Education (NCERT) Bhubaneswar, Odisha 751022, INDIA
***Corresponding Author:** anirbanroy247@gmail.com

Citation: Roy, A., & Mohapatra, A. K. (2022). A Gender-based Investigation of Indian Senior Secondary Students' Misconceptions about Plant Reproduction through Concept Inventory. *Interdisciplinary Journal of Environmental and Science Education, 18*(4), e2287. https://doi.org/10.21601/ijese/12089

ARTICLE INFO

Received: 11 Mar. 2022

Accepted: 11 May. 2022

ABSTRACT

The central objective of this study was to unveil the misconceptions and their sources through the responses of Indian senior secondary (n=102; 54 boys and 48 girls) students about plant reproduction. A concept inventory with correct and incorrect statements was designed to elicit the misconceptions among class XII students. A semi-structured interview of selected students followed this exercise to report the sources of misconceptions from students' perspectives. Descriptive statistics like mean and percentages determined the extent of misconceptions through frequencies of incorrect responses–overall, 40.392% of students bore misconceptions in this sub-concept with statements like "no difference between vegetative propagation and vegetative reproduction" getting a higher frequency of incorrect responses. Gender-based differences were investigated through inferential statistics like Chi-square and Kruskal-Wallis tests, more misconceptions were observed in boys than girls in plant reproduction. Qualitative analysis of the interview responses revealed the ambiguities in everyday classroom transactions and textbook explanations as to the major sources behind misconceptions. The study concluded with suggestive measures–and possible pedagogical tools–to help teachers identify and eradicate student misconceptions.

Keywords: concept inventory, gender, misconceptions, plant reproduction, senior secondary students

INTRODUCTION

Lamichhane et al. (2018) have described a misconception as "the old, the bad, and the ugly" of prior knowledge, ideas, or conceptions that learners have. Misconceptions in extant knowledge of the students regulate the reception of new information heaping to a bigger pile of faulty learning (Unal et al., 2010). The birth of a misconception is when learners justify their correct or incorrect responses with reasoning based on information that is different from the real notions of a concept (Bruning et al., 2011; Nilson, 2010). Researchers like Potvin & Cyr (2017) and Stern et al. (2018) have argued that misconceptions do prevail in many highly educated adults who seem to rely on the "models, beliefs and theories" that they developed as preschoolers. Such deeply-rooted misconceptions create 'cognitive conflicts' while students acquire new knowledge (Wartono et al., 2018). Students are emotionally and intellectually attached to misconceptions (Oberoi, 2017), and therefore, these ideas encumber a healthy learning process when students tend to reject them with hesitancy (Chen et al., 2020). Teachers' familiarity with misconceptions is crucial for effective classroom transactions since students cannot self-rectify their misconceptions (Mulungye et al., 2016; Sadler et al., 2013). Students can bear misconceptions in any discipline; however, it is more investigated in sciences (Kumandas et al., 2019). Among all science subjects, students' inability to collate the real biological world with academic ideas makes biology an easy catch to develop misconceptions (Coley & Tanner, 2015).

Biology (or biological sciences) is a natural science subject that primarily deals with the study of life and living beings including their structures, forms, and physiology (Kareem, 2018). Biology provides a premise for the students to be aware of the existence and influence of immediate and distant natural elements in their everyday lives (Taiwo & Emeke, 2014; Yalim, 2021). Certain topics in biology are perceived as boring, abstract, and difficult to understand by many students (Akinbadewa & Sofowora, 2020) with low scholastic achievement in this subject (Hasibuan & Djulia, 2016). Biology misconceptions are extensively studied across various topics (Halim et al., 2018; Karakaya et al., 2020; Karpudewan et al., 2017). From the academic purview, life process(es) is one of the contents in biology which includes the topic of reproduction (Deshmukh, 2015). Perrone (2007) found that students have misconceptions about specific concepts in reproduction and heredity. Reproduction–as a concept–can be categorized into broad classes of plant and animal reproduction where the former is a part of plant sciences (vis-à-vis botany) and the latter is a part of animal sciences (vis-à-vis zoology). Usually, plant sciences are tagged as boring and onerous by students (Kubiatko et al., 2021) and misconceptions are either retained or reinforced with boredom (Kennedy & Lodge, 2016). Aspects of boredom influence the perceived sense of difficulties for a given subject (Macklem, 2015) and misconceptions can easily grow out of learning difficulties. Etobro and Fabinu (2017) surveyed 400 senior secondary students to measure their perception of (level of) difficulty of biology topics where they noted 50.3% of students flagged plant reproduction (or, plant reproductive system) 'difficult'. In a similar vein, Maskour et al. (2016) found that more than two out of five students faced problems in topics related to plant reproduction. For instance, students considered inbreeding (and/or self-fertilization) as the favored reproductive mode for the plants due to their immobility- this misconception has arisen out of the learning difficulties involved with this sub-concept.

Despite covering all the topics of plant reproduction in earlier classes, 30.94% and 28.70% of university students vented their 'difficulty' in learning double fertilization in angiosperms and sexual-asexual reproduction of plants respectively (Maskour et al., 2019). Certain misconceptions like 'pollens are like seeds' and 'asexual reproduction in plants is equivalent to cell multiplication' were reported in a study on conceptual difficulties of high school students in biology (Flores et al., 2003). From the stance of prospective biology teachers, 11.1% of respondents find plant reproduction a 'difficult' topic in plant physiology (Susanti et al., 2010). Chattopadhyay (2005) figured that the students' notion of plant reproduction is driven by their knowledge of animal reproduction- misconceptions discovered in this study were 'plants can not move to have sexual reproduction with another plant' and 'plants can not produce sperm and ovum'. Misconceptions in pollination and seed dispersal mechanisms in plants were detected in the majority of grade 5 to 12 students (Lampert et al., 2019). Reproductive physiology of lower organisms like fungi and bacteria are usually clubbed under plant reproduction for school-level education in India. Along the similar line, research indicated that confusion among students about fungal reproduction through spore-based mechanisms (Green et al., 2019). Similar topics of bacterial reproduction also recorded misconceptions like confusions in stages of sexual reproduction in high school students (Novitasari et al., 2019). Contrarily, animal reproduction (mainly focusing on human reproduction) was traced with moderate difficulties in the three-tier test to sort student misconceptions (Hasyim et al., 2018). Misconceptions in animal reproduction usually originate due to their tendency of over-generalization in the course of their conceptual change (Murat et al., 2011), which can be viewed as misconceptions not arising out of learning difficulties.

The association between learning and gender has been an invested topic in the field of educational studies. Gender–an inherent variable–influences learning differences through multiple and (case) specific parameters. Awan et al. (2012) summarized the gender-based attributes linking that to the academic achievement in sciences. Kristyasari et al. (2018) spotted differences in science literacy skills (like recognizing the scientific question, detecting evidence, etc.) among high-school boys and girls. Such differences were also conveyed through the study of Yamtinah et al. (2017), where boys displayed better observational skills than girls. In a recent study, it was found that the scientific interest in girls got more precise from lower to higher classes–grade 4 girls had higher generic scientific interest while grade 8 girls had a higher interest in biological sciences (Jia et al., 2020). More girls had difficulties and misconceptions than boys in inorganic chemistry (Adesoji & Babatunde, 2008). Likewise, misconceptions occurred differently in boys and girls in a study by Cahyanto et al. (2019)–evidently, such studies are specific to the academic content in question (Moodley & Gaigher, 2019). In that purview, the present study investigates the gender-based differences in misconceptions of senior-secondary students on the topic of plant reproduction.

From the perspective of past research, only three studies were reported from Turkey on misconceptions in reproduction and reproductive systems in the time frame of 14 years (Kumandas et al., 2019), which can be extrapolated as a research gap in the literature on student misconceptions in reproduction due to lest plant reproduction. Considering the need to globally normalize the educational perimeters, this study will be a novel addition to extant educational literature such that academic practitioners learn this uninvestigated domain of "learning biological sciences". This study is also significant in using students' narratives to identify the sources of misconceptions, thus, validating its implications as a student-centric approach to address misconceptions.

RELEVANCE & OBJECTIVES OF THE STUDY

The constructivist paradigm in teaching-learning practices reinforced the role of learners as active members attaining new knowledge based on their experiences (Selcuk & Mehmet, 2020). Teachers are only 'guides' in the constructivist approach whose role is to facilitate the knowledge construction–being aware of learners' previous knowledge, rationalizing their ideas, and providing regular feedback (Vaishali & Misra, 2020).

The exchange of dialogues between teachers and students is such that students accommodate new information of the external world, fitting with the existing experiences while teachers assist this process (Bhattacharjee, 2015; Rillo et al., 2020). Such being the situation, it is likely that misconceptions in the prior learning experiences impede the reception and processing of new concepts in students. Students' competence to relate concepts from lower to higher classes are disturbed by misconceptions (Ramadhani et al., 2020); this study is opportune in terms of similar pursuit where the gender-based inquiry of misconceptions in plant reproduction is carried out in the senior-most batch of school-level education.

Revealing the misconceptions in an important subset of the school-level biological topics, the findings from this study can be employed by teachers around the globe to help students build scientifically-acceptable knowledge of the said topic. In other words, internationally, teachers and curriculum designers can use this paper as a resource to enable the students to travel from their misconceptions to the constructed understanding of plant reproduction. Furthermore, the gender-based analysis will help to identify and serve the vulnerable group with more misconceptions. in this way, teachers can better their focus to eliminate the misconceptions. Since the sources of misconceptions are tiered through the student perceptions, this study determined what changes are needed in the students' external environment to improve their learning. Post knowing the level of misconceptions, this exercise with selected students can help the global audience to muster their priorities to the specific sources of misconceptions to serve the students in the right direction.

With that in mind, the central objective of this study revolves around exploring the misconceptions in the concept of plant reproduction among Indian senior secondary students (of class XII) and further investigating the potential sources of misconceptions through their perspectives.

The research questions (sub-objectives) of this study can be summarized as:

1. What are the misconceptions about plant reproduction among senior secondary students?
2. Are there any differences in the (quantitative) level of misconceptions for senior secondary boys and girls?
3. From the perspectives of senior secondary boys and girls who marked more than or equal to 4 incorrect responses, what are their possible sources of the misconceptions.

RESEARCH METHODOLOGY

Sample and Sampling Technique(s)

There exists a linear quantitative relationship between the age of the students and the magnitude of the prior knowledge/ideas since the older the student is, the more are the life experiences and higher is the accretion of ideas (Sewell, 2002). In that perspective, the present study dealt with the senior secondary students of class XII–the ultimate grade of school–level education. The study's sample population was 102–54 boys and 48 girls–students of biology stream of a CBSE-affiliated English medium urban school in Bhubaneswar (Khurdha District) of Odisha State, India.

All the biology stream students of class XII (three sections) were taken as one-group, randomized subjects with no pre-test. For confidentiality reasons, the school and participating students will be anonymous in the study. The mean age of the students was 17.5 years (range 17-18 years). The regular biology teachers were consulted to get an idea of students' academic intellect such that the sample participants are homogenous. None of the 108 students had learning disabilities and their mean academic scores ranged from average to high in biology. The arbitrary distribution of the students excluded the possibility of the extraneous variables and a single group was exposed to the investigatory treatment. The absence of any pre-test rejected the chances of any interaction effect of the pre-test and treatment of the participants with the concept inventories (Adesoji & Babatunde, 2008). To circumvent the difference among boys and girls, all the statistical analyses were done in percentages. The study was conducted in July 2017 and reproduction being the first unit of the class XII biology textbook, was finished in April 2017.

Research Design & Hypotheses

For this study, a close-ended concept inventory was developed for a quantitative survey to explore the misconceptions. Biological concept inventories were effective to identify the misconceptions in students and teachers in the US (Klymkowsky et al., 2010; Queloz et al., 2017) and can also be used to assess essential educational needsby probing the gap between a student's misconceptions and the authentic conceptual understanding (Kaufman et al., 2002). Following the work of Adesoji and Babatunde (2008), the design for the given study employed the schema of ATE, where,

A: arbitrariness among the sample population,

T: treatment of the students with the concept inventories,

E: examination of the student responses followed by an interview.

In this design, the element of A is concerned with the selection of the participants for this study–as aforementioned, the randomized selection of students as one test group (without any pre-test) is an essential aspect to legit the study. The consistent distribution of a nearly identical number of boys and girls is requisite for the gender-based analysis of misconceptions. The element of T fell under the methodological section of this study- it is the part where the students were surveyed to collect their responses using the research tool. The element of E referred to the statistical interpretation of the student responses to comment on the level and gender-based prevalence of misconceptions–it was followed by interviewing the selected students to unveil the sources of their misconceptions through their perceptions.

The interview question was a one-liner: why did you choose the option you chose. Technically, it was not a two-tier diagnostic test tool as all the students were not subjected to the interview; only those who reported more than 4 wrong answers were questioned to know why they marked the wrong option. Taber (2011) remarked on the efficacy of interviews in deciphering students' notions about misconceptions and their sources, so, the final part of this study interviewed a certain group of students with a similar intention.

The investigators articulated three hypotheses circling the research questions:

1. **H_1:** There is a significant relationship between the misconceptions derived from the correct and incorrect statements.
2. **H_2:** There is a significant relationship between the misconceptions of boys and girls.

3. **H_3:** There is a significant relationship between the source(s) of misconceptions and the incorrect responses of boys and girls (student genders).

The Research Tool

The research tool was a close-ended concept inventory–they are usually developed by scrutinizing students' thoughts and their explanations of scientific situations. It serves as a diagnostic tool for recognizing misconceptions and logical inconsistencies and offers data that aid direct curricular reforms (Queloz et al., 2017). According to Garvin-Doxas et al. (2007) and Libarkin (2008), concept inventories are designed for formative assessments and the wordings must be coherent with students' understanding levels. A sample of the research tool is added throughout the paper by using various tables.

Development of the research tool

The concept inventory comprised of 10 statements in two sections, the first section contained five correct statements and the second section contained five incorrect statements (vis-à-vis, distracters) on plant reproduction. The choice of these statements was based on the contents of their academic chapters of reproduction in organisms, sexual reproduction in flowering plants of the present class. Additionally, their previous class's biology textbooks (classes X and XI) were checked to borrow from learned concepts. The sub-concepts in plant reproduction were tried to be covere–like, basics of asexual and sexual reproduction, seed formation and fruits, reproduction in lower taxonomic groups, and horticultural applications of reproduction.

The statements in the tool were in an amiable "student language" style, closer to the pupils' thinking (Queloz et al., 2017). The entire concept inventory can be completed in a period (i.e., 30 minutes) and there were three potential options (3-point scale) to choose: 'agree', 'disagree', and 'don't know'. The initial section of the concept inventory was devoted to gathering the demographic profile (name, age, and gender) of the respondents which helped the investigators to pursue the comparative analysis of the data. The tool bore an option of consent and the testing took place in students' natural settings with an assurance of anonymity concerning the publication of the results.

Scoring of the research tool

Student responses to each statement in the inventory were scored dichotomously (1 for absolutely correct response and 0 otherwise). For a correct (true) statement, choice 'agree' was given 'one' mark while 'disagree' and 'don't know' were awarded 'zero'. For an incorrect (alternatively, distractor/false) statement, choice 'disagree' was awarded 'one' mark while 'agree' and 'don't know' choices were awarded 'zero'. Therefore, for this study, any statement(s) that are awarded with a 'zero' mark for a given student will be counted as a misconception of that student. There was no provision of 'partially correct' responses to ensure a stringent scoring method for a tool that is intended to disseminate student misconceptions (Kalas et al., 2013).

Reliability index of the research tool

Taber's (2018) research on Cronbach's alpha reliability index has revealed that researchers should carefully consider whether seeking a high value of internal consistency for their diagnostic instruments is desirable in light of their research aims or not. Quansah (2017) documented several pieces of literature about alpha as an index of reliability where the author has highlighted multiple dimensions that decide the alpha value and how a higher alpha value does not ensure homogeneity in the tool items. For example, alpha is affected by the number of items in the tool–fewer number of items (less than 10) would yield a small alpha value. In a similar line, Green and Thompson (2005) opined that alpha cannot be construed as an index for the internal consistency of a tool (or test). Considering the aforementioned studies and the fact that our results are binary (dichotomous data–1 or 0) for this tool, a derivative of Cronbach's alpha was used to determine the internal consistency of the tool- Kuder-Richardson 20 (KR 20) coefficient (Capik & Gozum, 2015; Quaigrain & Arhin, 2017). It was calculated using the following formula–

$$KR\ 20 = \frac{k}{k-1} \cdot \left(1 - \sum \frac{pq}{\sigma_y^2}\right),$$

where $\sum pq$ is the summation of each (test) item of the proportion of students passing that item (p) times the proportion of people not passing that item, k is the number of test items, and σ_y^2 is the variance of the total scores of all the people taking the test (Rubio, 2005). The value of KR 20 ranges between 0 to 1 where values above 0.9 are considered excellent and values below 0.6 are undesirable concerning the reliability (internal consistency) of the tool (Gómez-Rodríguez et al., 2020).

The reliability of the concept inventory was calculated after the collection of data from the students and it was found that the tool was highly reliable. The obtained KR 20 value was 0.932 which is at the higher end in the scale of 0-1 of KR 20 values (El-Uri & Malas, 2013; Gómez-Rodríguez et al., 2020).

Validity index of the research tool

Since the study did not involve any pre-tests with the student population to ascribe a quantitative number for the tool validity, two types of validity were explored for the concept inventory- face validity and content validity.

First, face validity (Trochim, 2005) ensured that the tool can be used as a measure of students' understanding of the concept of plant reproduction. The investigators self-questioned to determine the face validity of the concept inventory, "do the statements listed in the inventory suffice the necessary content for measuring the 'latent' misconceptions among the students?" The search for the answer to this question included an exhaustive review of textbooks, syllabi, surveys with the subject teachers to conclude face validity for the tool (Zeilik & Morris-Dueer, 2005). Withal, five pre-service teacher educators, enrolled in M.Ed. degree with a specialization in biology pedagogy was consulted. They rated the 10 statements of the inventory according to the criteria of clarity (language and wordings), precision (unambiguous expressions of statements), and apprehension (a clear understanding of meanings through the statements). It was followed by the calculation of the Fliess' Kappa index (estimation of the index of inter-observer

Table 1. Inter-rater agreement of the five experts regarding the criteria of clarity, precision, and apprehension for the concept inventory items

No	Test item	Clarity	Precision	Apprehension
1	No difference between vegetative propagation & vegetative reproduction.	1	1	1
2	Tomato is a fruit.	0.8	1	0.8
3	It is not possible to make a graft if the scion is not put over the stock.	0.8	1	0.2
4	Plumule grows up and radicle grows down.	1	1	1
5	Fungi is found everywhere because it reproduces via spores.	0.2	1	1
6	Only fungi can reproduce via spores.	0.8	1	1
7	Zygote and embryo are same.	0.2	1	1
8	Cross pollination is less advanced than self pollination.	1	1	0.8
9	Banana does not have seeds, so it is not a fruit.	1	1	1
10	Binary fission and budding are same.	1	1	1

Table 2. Inter-rater agreement for the 10 randomly chosen, freshly passed class XII students regarding the comprehensibility for the concept inventory items

No	Test item	Comprehensibility (%)
1	No difference between vegetative propagation & vegetative reproduction.	88.7
2	Tomato is a fruit.	86.2
3	It is not possible to make a graft if the scion is not put over the stock.	82.5
4	Plumule grows up and radicle grows down.	82.8
5	Fungi is found everywhere because it reproduces via spores.	81.3
6	Only fungi can reproduce via spores.	80
7	Zygote and embryo are same.	80.1
8	Cross pollination is less advanced than self pollination.	90.9
9	Banana does not have seeds, so it is not a fruit.	93.5
10	Binary fission and budding are same.	91.6

agreement) and the acceptable range spanned between 0.41 and 0.60 (Osorio & Jaimes, 2019). And lastly, the face validity was based on comprehensibility levels where outcomes closest to 80% comprehensibility were considered as satisfactory. For this calculation, 10 freshly passed XII students from the same school (from the academic session 2016-17) were randomly selected to inspect the tool through comprehensibility criteria as mentioned in Osorio and Jaimes (2019). All these results were compiled to decide the face validity of the concept inventory.

Second, content validity was performed by five experts (three textbook developers and two bioscience pedagogy faculties) for an overall remark on its level of difficulty and permissible time. This was done following the Lawshe index, as cited in Osorio and Jaimes (2019) and Tristán-López (2008) and–each item was categorized as essential, useful but not essential, and not necessary (for the tool). All the experts (n=5) were individually consulted for examining the tool and they were instructed to submit their consolidated results to the investigators. Content validity ratio (CVR) was calculated in compliance with the methods mentioned in Tristán-López (2008) and any item whose CVR was less than 0.99 was decided to be rejected (Lawshe, 1975):

$$CVR = \frac{n_e - \frac{N}{2}}{\frac{N}{2}},$$

where n_e=number of experts who marked the "essential" category and N=total number of experts.

The content validity index (CVI) of the tool can be obtained through the average of the CVRs of the accepted items.

The given tool was found to have 'high' face validity based on the aforementioned parameters- the first parameter was a detailed review of the textbook, relevant curricular items, and discussions with subject teachers which yielded a high face validity of the tool qualitatively. The second parameter of face validity was further assessed through five M.Ed. enrolled pre-service teacher educators (raters) for its clarity, precision, and apprehension (**Table 1**).

The Fliess' kappa index of inter-rater agreement (since there were more than two raters) was determined for each of the criteria: clarity (0.417), precision (1), and apprehension (0.556). It was under the acceptable (0.41 to 0.60) and very good range (0.61<) of Fliess' kappa index as per González et al. (2016). Lastly, the third parameter of face validity was evaluated through the level of comprehensibility as reported by the 10 students who recently passed class XII board exams back then (**Table 2**).

The comprehensibility was determined according to Osorio and Jaimes (2019), where three classes were created according to the following percentages: equal to or greater than 85% (5 items)=high comprehensibility; 80-84.9% (5 items)=medium comprehensibility; and less than 80% (0 items)=low comprehensibility (**Table 2**). The Fliess' kappa index of inter-rater agreement was calculated to be 0.422, which belonged to the range of acceptability. Given all the results reported above, it can be deduced that the research tool of this study bears face validity.

The content of each item in the tool was validated by five experts to corroborate its ability in conveying the content to the participants. The CVR was calculated across the categories of essential, useful but not essential, and not necessary through the formula mentioned above. The values obtained confirmed that the content is valid for the tool since none of the CVRs were below 0.99 (**Table 3**). The overall validity index

Table 3. Content validity ratio and content validity index of items and tools according to the five experts

No	Statement	Essential	Useful; non-essential	Non-essential	CVR
1	No difference between vegetative propagation & vegetative reproduction.	5	0	0	1.00
2	Tomato is a fruit.	5	0	0	1.00
3	It is not possible to make a graft if the scion is not put over the stock.	5	0	0	1.00
4	Plumule grows up and radicle grows down.	5	0	0	1.00
5	Fungi is found everywhere because it reproduces via spores.	5	0	0	1.00
6	Only fungi can reproduce via spores.	5	0	0	1.00
7	Zygote and embryo are same.	5	0	0	1.00
8	Cross pollination is less advanced than self pollination.	5	0	0	1.00
9	Banana does not have seeds, so it is not a fruit.	5	0	0	1.00
10	Binary fission and budding are same.	5	0	0	1.00
CVI					1.00

of the 10 items was 1–an ideally acceptable value for the index since all the experts found the content of the item 'essential' for the tool.

All the results, therefore, supported the 'good' reliability (internal consistency) and validity of the research tool (concept inventory) for this study.

Data collection

The date and time of the study were fixed in consultation with the Principal of the School. The students of class XII were randomly assorted to alternative desks in the test venue (the auditorium of the school). The investigators and their regular subject teachers were present to clarify any doubts and avoid events of cheating. The students were informed of the time duration (30 minutes; a period) and assured that this was not any kind of assessment where they might be graded.

In the second tier of the study, students for the interview were identified based on their responses. Since the first investigator (author) worked as an Intern in the given school, the students were quite acquainted with him and therefore, did not show any reluctance to appear for the interview. This personal familiarity of the participants with the first investigator (author) did not cause any anxiety among the former to write their names in the concept inventory in the first place. The questions in the interview were meant to investigate the reason behind the students' responses and aimed at inspecting the source from which students gathered the misconception.

Data analysis

The responses of the students were analyzed in two subsections, namely, a comprehensive analysis involving all the students succeeded by a gender-based analysis. An item (statement) is considered to be answered correctly only when there is a single tick mark corresponding to any of the three options associated with the concerned item. Thus, an item was not considered for analysis if there were more than one tick against the options in that item. An incorrect response (based on the scoring) for an item would infer that the participant bears a misconception for the given idea (Ainiyah et al., 2018). Descriptive (mean and percentages) and Inferential (Kruskal Wallis and Chi-square) analyses were used to provide answers to research questions. The degree of misconceptions was calculated through (percentage) frequencies of incorrect responses–maximum and minimum levels were determined by combining all the statements in the concept inventory.

Owing to the non-normal distribution of data (based on histogram visualization), Kruskal-Wallis tests were performed to interpret statistically significant differences between the categorical variables in question ($\alpha<0.05$). Chi-square tests for independence were conducted for both the comprehensive and gender-based analyses wherein the investigators tested the significant relationships between the corresponding variables in question. All the analyses were done with the help of PAST 4.0 software with a probability level of 0.05 was used for retaining or rejecting the hypotheses.

RESULTS

Comprehensive Analysis

The comprehensive responses of the students to the correct and incorrect statements of the concept inventory are shown in **Table 4** and **Table 5**, respectively. The correct response to the correct statements is 'agree' (**Table 4**), while the correct response to the incorrect statements is 'disagree' (**Table 5**).

The results revealed the level of misconceptions in plant reproduction prevailing among senior secondary students. There was no significant difference in the distribution of the students' correct responses between the two categories of statements (Kruskal-Wallis, $\chi^2(df=1)=0.884$, p-value=0.346, $\alpha\leq0.05$). We hypothesized that there was no significant relationship between the misconceptions of correct statements and incorrect statements. In that view, we have tested the hypothesis using the Chi-square test and found that the null hypothesis is rejected since $\chi^2_{observed}>\chi^2_{critical}$ ($\chi^2_{observed}$

Table 4. Distribution of students based on their responses to the correct statements

No	Statement(s)	Agree (%)	Disagree (%)	Do not know (%)
1	No difference between vegetative propagation & vegetative reproduction.	21.569	78.431	0.000
2	Tomato is a fruit.	47.059	51.961	0.980
3	It is not possible to make a graft if the scion is not put over the stock.	63.725	25.490	10.784
4	Plumule grows up and radicle grows down.	71.569	18.627	9.804
5	Fungi is found everywhere because it reproduces via spores.	51.961	43.137	4.902

Table 5. Distribution of students based on their responses to the incorrect statements

No	Statement(s)	Agree (%)	Disagree (%)	Do not know (%)
6	Only fungi can reproduce via spores.	36.275	54.902	8.824
7	Zygote and embryo are same.	52.941	40.196	6.863
8	Cross pollination is less advanced than self pollination.	37.255	52.941	9.804
9	Banana does not have seeds, so it is not a fruit.	2.941	96.078	0.980
10	Binary fission and budding are same.	2.941	96.078	0.980

Table 6. Relationship between gender and misconceptions for correct statements

No	Statement(s)	NoS	NoB	% boys	NoG	% girls	$\chi^2_{observed}$	df
1	No difference between vegetative propagation & vegetative reproduction.	80	44	55.000	36	45.000	1.403	1
2	Tomato is a fruit.	54	42	77.778	12	22.222	6.080*	1
3	It is not possible to make a graft if the scion is not put over the stock.	37	25	67.568	12	32.432	0.585	1
4	Plumule grows up and radicle grows down.	29	20	68.966	9	31.034	0.692	1
5	Fungi is found everywhere because it reproduces via spores.	49	22	44.898	27	55.102	5.664*	1
Total		249	153		96		14.425**	4#

Note. NoS: Total number of students with misconceptions; NoB: Number of boys; NoG: Number of girls; $\chi^2_{critical}$=3.84, df=1; *Significant at $\alpha \leq 0.05$; $\chi^2_{critical}$=9.49, df=4; **Significant at $\alpha \leq 0.05$; #This is not the summation of all the degrees of freedom in the table and it is calculated by df=(number of columns-1)*(number of rows-1)

Table 7. Relationship between gender and misconceptions for incorrect statements

No	Statement(s)	NoS	NoB	% boys	NoG	% girls	$\chi^2_{observed}$	df
6	Only fungi can reproduce via spores.	46	23	50.000	23	50.000	0.141	1
7	Zygote and embryo are same.	61	29	47.541	32	52.459	0.667	1
8	Cross pollination is less advanced than self pollination.	48	31	64.583	17	35.417	2.692	1
9	Banana does not have seeds, so it is not a fruit.	4	2	50.000	2	50.000	0.012	1
10	Binary fission and budding are same.	4	1	25.000	3	75.000	1.237	1
Total		249	163	86		77		4.748**

Note. NoS: Total number of students with misconceptions; NoB: Number of boys; NoG: Number of girls; $\chi^2_{critical}$=3.84, df=1; *Significant at $\alpha \leq 0.05$; $\chi^2_{critical}$=9.49, df=4; **Significant at $\alpha \leq 0.05$; #This is not the summation of all the degrees of freedom in the table and it is calculated by df=(number of columns-1)*(number of rows-1)

(df=4)=55.009, $\chi^2_{critical}$(df=4)=9.49, α=0.05) and we conclude that there was a significant relationship between the misconceptions of the correct and the incorrect statements.

The percentage of misconceptions is more with the correct statements as compared to the incorrect statements (**Table 4** and **Table 5**), implying that students can identify the latter as an erroneous concept more precisely. 78.431% of students denied that vegetative reproduction and vegetative propagation are the same (statement 1), which reflected the maximal level of misconceptions for all the statements in this study. More than half of the participating population (52.941%) considered that tomato is not a fruit (statement 2) while 48.039% of students held misconceptions about the concept of fungal reproduction (statement 5). On the other hand, the distracters provided slightly different results wherein the frequencies of incorrect responses were less. In statement 6, maximum mistakes (for distractors) were observed–52.941% of students nodded to the fact that zygote and embryo are the same, with 6.863% of students choosing the 'don't know' option. Statement 8 about pollination is poorly answered as 47.059% of respondents agreed that cross-pollination is less advanced than self-pollination. The statements answered the most accurately are 9 and 10, which asked banana is not a fruit since it has seeds and if binary fission and budding are the same (96.078% correct responses) respectively.

The comprehensive analysis, therefore, revealed that there were varying levels of misconceptions with respect to the statements in the concept of plant reproduction among senior secondary students. Overall, 40.392% of students displayed to bear misconceptions with 48.824% students with misconceptions in correct statements and 31.961% students with misconceptions in incorrect statements (first research question).

Gender-Based Analysis

The results of the present study showed that the boys are more frequently involved in the various misconceptions, in light of correct statements, except the 5th statement (**Table 6**). Moreover, apart from statements 2 and 5, the investigators observed that $\chi^2_{observed}<\chi^2_{critical}$, implying that there was no significant relationship in the misconceptions of the senior secondary boys and girls for the given set of the correct statements. But looking at the overall result, it can be concluded that there is a significant relationship between the misconceptions of the boys and girls since $\chi^2_{critical}<\chi^2_{observed}$ (for statements 1 to 5; correct statements).

Quite diverging from the result for correct statements, the responses of students depicted that boys and girls are more or less equally involved in the misconceptions concerning the distracters (**Table 7**). Rather, in this case, more girl students displayed to own misconceptions in statements 7 and 10, though the numerical difference between the boys and girls is quite marginal. There is no significant relationship in the misconceptions of the boys and girls since $\chi^2_{observed}<\chi^2_{critical}$ in all

Table 8. Relationship between source of misconception and student gender

No	SoM	NoR	BR	% BR	GR	% GR	$\chi^2_{observed}$	df
1	Text_Concepts	44	34	24.113	10	7.092	0.861	1
2	Class_Trans	46	31	21.986	15	10.638	0.278	1
3	Everyday_Exp	26	18	12.766	8	5.674	0.036	1
4	Vernacular_Conf	25	17	12.057	8	5.674	0.104	1
		141	100		41		1.278	3

Note. SoM: Source(s) of misconceptions; NoR: Total number of responses; BR: Boys' responses; GR: Girls' responses; $\chi^2_{critical}$=3.84, df=1, *Significant at $\alpha \leq 0.05$; $\chi^2_{critical}$=7.81, df=3, **Significant at $\alpha \leq 0.05$

the cases. Hence, we failed to reject the null hypothesis for the incorrect (distractor/false) statements.

In general, the overall gender-wise comparison of misconceptions in plant reproduction disclosed that girls have lower misconceptions than boys, except for a few concepts that dealt with fungal reproduction (second research question). The presence of significant relationships between the misconceptions are subjected to the kind of statements used in the tool where the overall $\chi^2_{observed}$ (columns=2 (boys and girls), rows=10 (all the statements)) equaled to 19.173 (df=9) and the investigators could conclude that there is a significant relationship between the misconceptions of boys and girls ($\chi^2_{critical} < \chi^2_{observed}$).

Qualitative Analysis of the Interviews

The investigators interviewed those students who reported more than four incorrect responses (that involved choosing the 'wrong' and 'don't know' options) out of the 10 statements. Upon analysis of the responses, 25 respondents (eight girls and 17 boys) were identified who belonged to the given category. Furthermore, the frequency of the number of incorrect responses chosen was more for 5(16) followed by 6(4), 7(3), and 8(2), where the number in the parentheses represented the number of students who chose the incorrect options. In the interview, the selected students were asked the reason for choosing the option they ticked and investigators sorted the reasons broadly in the following four categories, based on their responses (**Table 8**):

1. Textbook-driven misconceptions, where the students got confused with the concepts presented in their textbook(s) (denoted as text concepts).
2. Misconceptions arising from the classroom transaction, where the teaching-learning process was faulty or the transmission of knowledge contained doubts or teacher was unable to explain properly (denoted as class trans).
3. Misconceptions rooted in everyday experiences, much like perceiving the socially specious information as reliable scientific information (denoted as everyday exp).
4. Misconceptions arising from the confusion of language (vernacular) like the use of words that are phonetically and morphologically quite similar to each other (denoted as vernacular conf).

Concerning those 16 individuals who have marked 5 incorrect answers, it was observed that the 1st statement was commonly marked by all of them (11.348%) and their collective response can be quoted as,

> "We found both the terms different as they ended with dissimilar words, even though both began with similar words."

Upon further questioning, the students admitted that the cause of the mistake was the past experiences with biological morphemes where it started with a similar term but ended differently, resulting in meaning differently, just like *ecology* and *ecosystem*, *herbicide* and *herbivore*, *monocyte* and *monosaccharide*. This can be concluded as a misconception that arose from a 'vernacular confusion' creating a flawed preconceived notion. The next statement that is a common mistake among all the 16 students is 2nd statement that asked if 'tomato is a fruit' (11.348%) which revealed the source behind the misconceptions as 'everyday experiences'. The interviewees collectively replied,

> "Elders have informed that we cook vegetables and tomato is cooked, so, it cannot be a fruit."

The maximum mistakes were observed for the three statements, i.e., 5th, 7th, and 8th (19.858%). The students mainly answered in favor of an improper classroom transaction (responses like

> "The teacher said mushroom is a fungus, but never showed its spores", "teacher used the term 'zygote' or 'embryo' interchangeably while teaching", "teacher never talked about which pollination type is advanced").

One interesting answer was received from a student while discussing the eighth question, when she said,

> "Our book has mentioned about self-incompatibility under the topic of pollen pistil interaction, and it was full of so many mechanisms, so, I thought self-pollination is more advanced than cross-pollination."

This brought us to the fourth source of misconceptions, the Textbook and it is reported by 14.184% of students that the concepts of the textbook confused them to mark the given option. Regarding the 4th statement, a student expressed his discontent regarding the diagram where the concept of plant embryo was explained while quoting the paragraph as stuffed with too much information in the textbook (text concept). He also added that there was mention of 'plumule as stem tip and radicle as root tip' but the accompanying diagram was very confusing to understand that. As investigators proceeded with the interview of those 4 students who marked six wrong answers, the responses were quite similar to the former cohort. In this group as well, the statements 1, 2, 5, 7, and 8 were mostly encountered with wrong responses, and the reasons were quite similar as discussed above, with a slight difference as more students, in this case, held the textbook as their source of misconception (6.383%). Four of the students in this group marked the 6th statement, "only fungi can reproduce via spores" as 'agreed' and reported that the textbook had only one illustration of sporic reproduction where the diagram of a fungal sporangium is shown to burst open to release spores. One of them added,

> "the teacher provided only one example of sporic reproduction and that was Fungi when she illustrated the bread mold in the class"

–implying the misconception induced by imprecise classroom transaction (4.965%, including all the students). Three boys who marked seven wrong responses and apart from the statements 1,2,5,6,7 and 8, all the three have marked 3rd statement,

> "it is not possible to make a graft if the scion is not put over the stock,"

as 'disagreed' and 'don't know'. All three students consented collectively that they are confused about the terms, 'stock' and 'scion' since the teacher just explained the concept with no visual aids or real-life examples (5.674%). They either guessed and chose 'disagree' or ticked against 'don't know'. Finally, two boys belonged to the last unit of interviewees who committed eight mistakes; it was observed that apart from the statements 1, 2, 3, 5, 6, 7, and 8, one of the two students have marked 4th statement, "plumule grows up and radicle goes down" as 'disagreed' and confessed that the terms confused him as he couldn't understand what was taught in the class that particular day. The other one, however, responded wrongly to the 9th statement, "banana doesn't have seeds, so it is not a fruit". He admitted to the fact that he is always said,

> "all fruits contain seeds and he has seen watermelon, apples, grapes, sapodillas, pears containing seeds."

This is, undoubtedly, a misconception arising from the social experience of a child's everyday life.

The investigators hypothesized that there is a significant relationship between the source(s) of the misconceptions and the incorrect responses of the two genders of students. The hypothesis is tested using the Chi-square test and the results are shown in **Table 5**. In all the cases, we obtained the condition of $\chi^2_{observed}<\chi^2_{critical}$, inferring that the null hypothesis is not rejected and there is no significant relationship between the source(s) of the misconceptions and the wrong responses of the two genders of students (**Table 8**).

From this analysis, it can be pointed out that students find classroom transactions and textbook concepts mostly responsible for developing misconceptions (third research question).

DISCUSSION

Existing literature has shown that the identification of misconceptions in Biology is imperative for mitigation of the misconceptions and finally eliminating the same to help students acquire accurate scientific knowledge (Halim et al., 2018; Karakaya et al., 2020; Karpudewan et al., 2017). Therefore, the main objective of this study was to identify and conduct gender-based analysis of misconceptions in plant reproduction among the senior secondary students, followed by tracing their sources through student narratives. Our investigative instrument could be related to the tool proposed by Mann and Treagust (1998) where they suggested true/false type questions as a potential diagnostic instrument, rather than multiple-choice questions.

This study revealed an alarming level of misconceptions among the Indian students of class XII–essentially, the last tier in the academic level of school education. Around half of the student population (48.824%) displayed to bear misconceptions in the first section of the concept inventory that dealt with correct statements. Less to it, 31.961% of students have misconceptions in the second half of the concept inventory that comprised of incorrect statements. Hershey (2005) listed a few misconceptions in plant reproduction which resonated with the misconceptions in our findings. Alternate conceptions in plant reproduction like 'after fertilization, the flower's ovule will develop into fruit' and 'some species of flowering plants also could reproduce asexually by planting roots only, not stems and leaves' were found in high school students (Lin, 2004). Stein et al. (2008) reported that there was no notable pattern in the right responses of students when surveyed across a set of correct and incorrect statements–we also observed in a similar line through the results of the Kruskal Wallis test, where we found there is no significant difference between the correct responses of the correct and incorrect statements (through the concept inventory). Several studies have reported that girls outperform boys in school (Wong et al., 2002), owing to their deeper interest and learning-focused abilities as compared to boys (Katz, 2017). Few studies have also reported boys performing better than girls in subjects like physical sciences and engineering (Alghadir et al., 2020). The gender-based analysis of the present study reported that girls showed significantly greater conceptual understanding of plant reproduction than boys with overall fewer misconceptions. This is in line with Hadjichambis et al. (2016) who found that girls have a better conceptual build of human reproduction as compared to boys. Our observations are, however, inconsistent with the results of Ahmad and Jamil (2020) since their study showed girls having more misconceptions in biology as compared to boys in class IX. One can assert that the relationship between misconceptions and gender cannot be generalized since that depends on subjects, preferences, and specific learning needs.

Barrass (1984) in his study on 'misconceptions in biology' raised a cogent question–"What attention is paid to misconceptions and misunderstandings that are perpetuated by teachers and textbook authors?" In this study, textbooks are ranked second (31.206%) by students as a source of misconceptions. Schussler (2008) found five inaccuracies in children's science books that could be probable 'baits' for misconceptions about plant reproduction. Hershey (2005) also reported published content about plants and plant reproduction in textbooks and educational websites that create misconceptions. Hershey (2004) quoted a textbook sentence that read like, "all plants develop fruits through pollination and fertilization"–this is a fallacious assertion given there are fruits like seedless bananas and apples that are developed through parthenocarpy. In a recent study, Roy and Singh (2021) reported the discordance between schematic diagrams in the Indian biology textbook and the real-life biological concepts (phenomenon/entity) as a source of learning gaps among the senior seconadary students. The authors also observed that teachers often completely ignore the learning gaps imbibed by the child in pursuit of finishing the syllabus within a stipulated time (Roy & Singh, 2021)—thus, building student misconceptions. After interviewing the selected students, it is realized that teacher(s) and classroom transaction(s) is the first source of misconceptions with maximum students nodding for it (32.624%). There is a valid association between these two sources- textbooks and classroom transactions–limited students appreciate the lecture-style textbook-centric pedagogy (NRC 2000, 2003), and that at times, results in the post-instructional persistence of misconceptions (Nehm & Reilly, 2007). Teachers carrying erroneous ideas is the reason behind classroom transactions being sources of misconceptions to the students. In a study with science teachers, Kwen (2005) observed multiple teachers holding misconceptions like each plant type is limited to one reproductive method whereas some plants are adept with several methods to reproduce. The belief that 'plants absorb food from the soil' was appeared to be utterly common in post-graduates and teacher trainees (Wynn et al., 2017). 38% of pre-service science teachers participating in a study by Crawley and Arditzoglou (1988) reflected misconceptions in three out of four topics in plant biology. The interview results further recorded that 18.44% of students found their everyday life-personal and social–experiences responsible for the conceived misconceptions. Yip (1998) informed that misconceptions about certain aspects of human reproduction come from everyday experiences (like the menstrual cycle). Sometimes, in the pursuit to relate to the real biological world, students misinterpret their daily interactions resulting in the birth of misconceptions (Coley & Tanner, 2015). Misconceptions emanating from vernacular confusions accounted for 17.730% of interview responses. Flores et al. (2003) opined on the confusions between terms and processes as instigated through textbooks and classroom transactions. One example of such kind in their study was–'the need for oxygen' in human respiration and 'production of oxygen' by photosynthesis can create vernacular misconceptions. Vernacular misconceptions are not widely studied in plant reproduction but in general biological studies, there are references of contradictions of scientific terms and colloquial depictions like population is perceived as inhabitants, species is perceived as sort, the greenhouse effect is perceived as greenhouse cultivation (Yucel & Ozkan, 2015). The effects of vernacular and semantic reasons of misconceptions are acutely entrenched in student minds since it is linked to the socio-cultural and informal lives of the students- hence, it is more challenging to address such misconceptions.

Misconceptions are refractory in their nature–through the present study, it can be suggested to the instructors of biological sciences, or any discipline of science per se to be vigilant about the misconceptions, apply different approaches to diagnose, treat and remove the misconceptions, and facilitate proper understanding of the concepts. The results of this study, however subject-specific, can be widely applied internationally across different curricula and educational boards. The study's conclusions do direct towards some transformations in teaching discourses adopting a bottom-up approach: students reflect their misconceptions for a given topic- eliminating them by mapping their sources–relating past experiences (devoid of misconceptions) with present information- net of complex, higher-level knowledge at different levels. Classroom instructions should engage the students (practical activities, discussions, demonstrations) in a structured design in order to ease the students to reflect on their misconceptions themselves. Textbook developers and curriculum planners are encouraged to conduct and refer studies to reach the roots of such misconceptions in different disciplines. Constructivist strategies like mind mapping, concept cartoons, group-based activities, role plays, and word association tests can help elicit and eliminate misconceptions in the students. In special cases, subject teachers need to personally invest in specific students to help them dismiss misconceptions, while the students self-instruct the acquisition of a new set of beliefs.

CONCLUSION

Misconceptions in biology are a major factor affecting students' understanding of science at higher secondary school level with it being carried onwards to a college education. In this context, this study attempted to critically analyze misconceptions in a subset of the school-level biological topic of plant reproduction using concept inventories.

Awareness of the distribution of common misconceptions and their assessment will aid the teachers to teach certain sensitive, misconception-prone concepts to improve the quality of the teaching-learning process. In this study, the level of misconceptions among the Indian senior secondary students varied within the statements; maximum students reported the incorrect option for "no difference between vegetative propagation & vegetative reproduction". The study found no significant relationships between the misconceptions and student gender in most of the statements. Boys reflected to have more misconceptions than girls, except for two statements in the concept inventory. Considering the perspectives of students who committed more than four incorrect options, textbooks and classroom transactions are the major reasons for having misconceptions. This study can be further extended to review student and teacher misconceptions in other domains of plant biology and biological sciences at large.

As a reformative suggestion, the authors encourage the teachers to design lesson plans that involve student interactions with the real world (either through hands-on activities or audio-visual aids). Additionally, teachers should create assessment frameworks to (regularly) identify the student misconceptions and eventually help students actively address that to help them self-acquire the right information.

Author contributions: **AR** and **AKM** conceptualized the study and designed the research. **AR** developed the research tool, carried out data collection, conducted the interviews, and drafted the manuscript. The work was supervised by **AKM**. Both authors read, reviewed and approved the final version of the manuscript.

Funding: No external funding is received for this article.

Acknowledgements: The authors sincerely thank the students for participating in the study and the concerned authorities for permitting the study in the school.

Declaration of interest: The authors declare that they have no competing interests.

Ethics approval and consent to participate: Not applicable.

Availability of data and materials: All data generated or analyzed during this study are available for sharing when appropriate request is directed to corresponding author.

REFERENCES

Adesoji, F. A., & Babatunde, A. G. (2008). Investigating gender difficulties and misconceptions in inorganic chemistry at the senior secondary level. *International Journal of African and African American Studies, 7*(1), 1-7.

Ahmad, S., & Jamil, S. (2020). Development and application of structural communication grid tests for diagnosing students' misconceptions in the subject of biology at secondary level. *Journal of Contemporary Teacher Education, 4*, 73-96.

Ainiyah, M., Ibrahim, M., & Hidayat, M. T. (2018). The profile of student misconceptions on the human and plant transport systems. *Journal of Physics: Conference Series, 947*(1), 012064. https://doi.org/10.1088/1742-6596/947/1/012064

Akinbadewa, B. O., & Sofowora, O. A. (2020). The effectiveness of multimedia instructional learning packages in enhancing secondary school students' attitudes toward biology. *International Journal on Studies in Education, 2*(2), 119-133. https://doi.org/10.46328/ijonse.19

Awan, A., Khan, T., & Aslam, T. (2012). Gender disparity in misconceptions about the concept of solution at secondary level students in Pakistan. *Journal of Elementary Education, 22*(1), 65-79.

Barrass, R. (1984). Some misconceptions and misunderstandings perpetuated by teachers and textbooks of biology. *Journal of Biological Education, 18*(3), 201-206. https://doi.org/10.1080/00219266.1984.9654636

Bhattacharjee, J. (2015). Constructivist approach to learning–An effective approach of teaching learning. *International Research Journal of Interdisciplinary & Multidisciplinary Studies, 1*(4), 23-28.

Bruning, R. H., Schraw, G. J., & Norby, M. N. (2011). *Cognitive psychology and instruction*. Pearson Publishing House.

Cahyanto, M. A. S, Ashadi, A., & Saputro, S. (2019). An analysis of gender difference on students' misconceptions in learning the material classification and its changes. *Jurnal Inovasi Pendidikan IPA [Journal of Science Education Innovation], 5*(2), 157-167. https://doi.org/10.21831/jipi.v5i2.26613

Capik, C., & Gozum, S. (2015). Psychometric features of an assessment instrument with likert and dichotomous response formats. *Public Health Nursing, 32*(1), 81-86. https://doi.org/10.1111/phn.12156

Chattopadhyay, A. (2005). Understanding of genetic information in higher secondary students in northeast India and the implications for genetics education. *Cell Biology Education, 4*(1), 97-104. https://doi.org/10.1187/cbe.04-06-0042

Chen, C., Sonnert, G., Sadler, P.M., Sasselov, D., & Fredericks, C. (2020). The impact of student misconceptions on student persistence in a MOOC. *Journal of Research in Science Teaching, 57*(6), 879-910. https://doi.org/10.1002/tea.21616

Coley, J. D., & Tanner, K. (2015). Relations between intuitive biological thinking and biological misconceptions in biology majors and nonmajors. *CBE—Life Sciences Education, 14*(1), 1-19. https://doi.org/10.1187/cbe.14-06-0094

Crawley, F. E., & Arditzoglou, S. Y. (1988). Life and physical science misconceptions of preservice elementary teachers. In *Proceedings of the Annual Meeting of the School Science and Mathematics Association, Austin, Texas, USA*.

Deshmukh, N. D. (2015). Why do school students have misconceptions about life processes? In E. G. S. Daniel (Ed.), *Biology education and research in a changing planet* (pp. 31-43). Springer. https://doi.org/10.1007/978-981-287-524-2_4

El-Uri, F. I., & Malas, N. (2013). Analysis of use of a single best answer format in an undergraduate medical examination. *Qatar Medical Journal, 2013*(1), 1. https://doi.org/10.5339/qmj.2013.1

Etobro, A. B., & Fabinu, O. E. (2017). Students' perceptions of difficult concepts in biology in senior secondary schools in Lagos State. *Global Journal of Educational Research, 16*(2), 139-147. https://doi.org/10.4314/gjedr.v16i2.8

Flores, F., Tovar, M. E., & Gallegos, L. (2003). Representation of the cell and its processes in high school students: An integrated view. *International Journal of Science Education, 25*(2), 269-286. https://doi.org/10.1080/09500690210126793

Garvin-Doxas, K., Klymkowsky, M., & Elrod, S. (2007). Building, using, and maximizing the impact of concept inventories in the biological sciences: Report on a National Science Foundation sponsored conference on the construction of concept inventories in the biological sciences. *CBE—Life Sciences Education, 6*(4), 277-282. https://doi.org/10.1187/cbe.07-05-0031

Gómez-Rodríguez, R., Díaz-Pulido, B., Gutiérrez-Ortega, C., Sánchez-Sánchez, B., & Torres-Lacomba, M. (2020). Cultural adaptation and psychometric validation of the standardised Nordic Questionnaire Spanish version in musicians. *International Journal of Environmental Research and Public Health, 17*(2), 653-663. https://doi.org/10.3390/ijerph17020653

González, G. M. C., Herrara, B. S., & Rosero, E. V. (2016). Development and psychometric tests of the instrument "caring" -short version to measure the competence of care at home. *The Revista de la Universidad Industrial de Santander. Salud* [*The Magazine of the Industrial University of Santander. Health*], *48*(2), 222-231. https://doi.org/10.18273/revsal.v48n2-2016007

Green, K., Roller, C., & Cubeta, M. (2019). A plethora of fungi: Teaching a middle school unit on fungi. *Science Activities, 56*(2), 52-62.

Green, S., & Thompson, M. (2005). Structural equation modeling in clinical psychology research. In M. Roberts, & S. Ilardi (Eds.), *Handbook of research in clinical psychology* (pp. 139-189). Wiley-Blackwell Publishers. https://doi.org/10.1002/9780470756980

Hadjichambis, A. C., Georgiou, Y., Paraskeva-Hadjichambi, D., Kyza, E. A., & Mappouras, D. (2016). Investigating the effectiveness of an inquiry-based intervention on human reproduction in relation to students' gender, prior knowledge and motivation for learning in biology. *Journal of Biological Education, 50*(3), 261-274. https://doi.org/10.1080/00219266.2015.1067241

Halim, A. S., Finkenstaedt-Quinn, S.A., Olsen, L. J., Gere, A. R., & Shultz, G. V. (2018). Identifying and remediating student misconceptions in introductory biology via writing-to-learn assignments and peer review. *CBE—Life Sciences Education, 17*(2), 1-12. https://doi.org/10.1187/cbe.17-10-0212

Hasibuan, H., & Djulia, E. (2016). Analisis kesulitan belajar siswa pada materi virus di kelas X Aliyah Al-fajri Tanjungbalai tahun pembelajaran 2016/2017 [Analysis of students' learning difficulties on virus material in class X Aliyah Al-fajri Tanjungbalai for the 2016/2017 academic year]. *Jurnal Pelita Pendidikan* [*Journal of Educational Pelita*], *4*(4), 16-24.

Hasyim, W., Suwono, H., & Susilo, H. (2018). Three-tier test to identify students' misconception of human reproduction system. *Jurnal Pendidikan Sains* [*Journal of Science Education*], *6*(2), 48-54.

Hershey, D. R. (2004). *Avoid misconceptions when teaching about plants*. http://www.actionbioscience.org/education/hershey.html

Hershey, D. R. (2005). More misconceptions to avoid when teaching about plants. *American Institute of Biological Sciences*. https://files.eric.ed.gov/fulltext/ED501356.pdf

Jia, C., Yang, T., Qian, Y., & Wu, X. (2020). The gender differences in science achievement, interest, habit, and creativity. *Science Education International, 31*(2), 195-202. https://doi.org/10.33828/sei.v31.i2.9

Kalas, P., O'Neill, A., Pollock, C., & Birol, G. (2013). Development of a meiosis concept inventory. *CBE—Life Sciences Education, 12*(4), 655-664. https://doi.org/10.1187/cbe.12-10-0174

Karakaya, F., Yilmaz, M., Cimen, O., & Adiguzel, M. (2020). Identifying and correcting pre-service teachers' misconceptions about the alternation of generations. *Cumhuriyet International Journal of Education, 9*(4), 1047-1063. https://doi.org/10.30703/cije.654967

Kareem, A. A. (2018). The use of multimedia in teaching biology and its impact on students' learning outcomes. *The Eurasia Proceedings of Educational and Social Sciences, 9*, 157-165.

Karpudewan, M., Zain, A. N. M., & Chandrasegaran, A. L. (2017). Introduction: Misconceptions in science education: An overview. In M. Karpudewan, A. N. Zain, & A. L. Chandrasegaran (Eds.), *Overcoming students' misconceptions in science* (pp. 1-5). Springer. https://doi.org/10.1007/978-981-10-3437-4_1

Katz, I. (2017). In the eye of the beholder: Motivational effects of gender differences in perceptions of teachers. *The Journal of Experimental Education, 85*(1), 73-86. https://doi.org/10.1080/00220973.2015.1101533

Kaufman, R., Watkins, R., & Guerra, I. (2002). Getting valid and useful educational results and payoffs: We are what we say, do, and deliver. *International Journal of Educational Reform, 11*(1), 77-92. https://doi.org/10.1177/105678790201100105

Kennedy, G., & Lodge, J. (2016). All roads lead to Rome: Tracking students' affect as they overcome misconceptions. In *Proceedings of the ASCILITE: Shaping the Future of Tertiary Education* (pp. 318-329).

Klymkowsky, M. W., Underwood, S. M., & Garvin-Doxas, K. (2010). The biological concepts instrument (BCI): A diagnostic tool to reveal student thinking. *arXiv:1012.4501v1*. https://doi.org/10.48550/arXiv.1012.4501

Kristyasari, M. L., Yamtinah, S., Utomo, S.B., & Indriyanti, N. Y. (2018). Gender differences in students' science literacy towards learning on integrated science subject. *Journal of Physics: Conference Series, 1097*(1), 012002. https://doi.org/10.1088/1742-6596/1097/1/012002

Kubiatko, M., Fančovičová, J., & Prokop, P. (2021). Factual knowledge of students about plants is associated with attitudes and interest in botany. *International Journal of Science Education, 43*(9), 1426-1440. https://doi.org/10.1080/09500693.2021.1917790

Kumandas, B., Ateskan, A., & Lane, J. (2019). Misconceptions in biology: A meta-synthesis study of research, 2000-2014. *Journal of Biological Education, 53*(4), 350-364. https://doi.org/10.1080/00219266.2018.1490798

Kwen, B. H. (2005). Teachers' misconceptions of biological science concepts as revealed in science examination papers. In *Proceedings of the AARE 2005 International Education Research Conference, Parramatta, Australia*.

Lamichhane, R., Reck, C., & Maltese, A. V. (2018). Undergraduate chemistry students' misconceptions about reaction coordinate diagrams. *Chemistry Education Research and Practice, 19*(3), 834-845. https://doi.org/10.1039/C8RP00045J

Lampert, P., Scheuch, M., Pany, P., Müllner, B., & Kiehn, M. (2019). Understanding students' conceptions of plant reproduction to better teach plant biology in schools. *Plants, People, Planet, 1*(3), 248-260. https://doi.org/10.1002/ppp3.52

Libarkin, J. C. (2008). Concept inventories in higher education science. In *Proceedings of the National Research Council Promising Practices in Undergraduate STEM Education Workshop 2, Washington, DC*.

Lin, S. W. (2004). Development and application of a two-tier diagnostic test for high school students' understanding of flowering plant growth and development. *International Journal of Science and Mathematics Education, 2*(2), 175-199. https://doi.org/10.1007/s10763-004-6484-y

Macklem, G. L. (2015). *Boredom in the classroom: Addressing student motivation, self-regulation, and engagement in learning*. Springer. https://doi.org/10.1007/978-3-319-13120-7

Mann, M., & Treagust, D. F. (1998). A pencil and paper instrument to diagnose students' conceptions of breathing, gas exchange and respiration. *Australian Science Teachers Journal, 44*(2), 55-60.

Maskour, L., Alami, A., Agorram, B., & Zaki, M. (2016). Study of some learning difficulties in plant classification among university students. *The Eurasia Proceedings of Educational and Social Sciences, 5*, 294-297.

Maskour, L., Alami, A., Zaki, M., & Agorram, B. (2019). Plant classification knowledge and misconceptions among university students in Morocco. *Education Sciences, 9*(1), 48-68. https://doi.org/10.3390/educsci9010048

Moodley, K., & Gaigher, E. (2019). Teaching electric circuits: Teachers' perceptions and learners' misconceptions. *Research in Science Education, 49*, 73-89. https://doi.org/10.1007/S11165-017-9615-5

Mulungye, M. M., O'Connor, M., & Ndethiu, S. (2016). Sources of student errors and misconceptions in algebra and effectiveness of classroom practice remediation in Machakos County-Kenya. *Journal of Education and Practice, 7*(10), 31-33.

Murat, M., Kanadli, S., & Unisen, A. (2011). Seventh grade students' misconceptions about animals' reproduction, growth and development and their likely resources. *Journal of Turkish Science Education, 8*(1), 179-197.

Nehm, R., & Reilly, L. (2007). Biology majors' knowledge and misconceptions of natural selection. *BioScience, 57*(3), 263-272. https://doi.org/10.1641/B570311

Nilson, L. B. (2010). *Teaching at its best: A research-based resource for college instructors*. Jossey-Bass Publications.

Novitasari, C., Ramli, M., & Karyanto, P. (2019). Content analysis of misconceptions on bacteria in the biology textbook of high school. *Journal of Physics: Conference Series, 1157*(2), 022076. https://doi.org/10.1088/1742-6596/1157/2/022076

NRC. (2000). *How people learn: Brain, mind, experience, and school experience*. National Academies Press.

NRC. (2003). *BIO 2010: Transforming undergraduate education for future research biologists*. National Academies Press.

Oberoi, M. (2017). Review of literature on student's misconceptions in science. *International Journal of Scientific Research and Education, 5*(3), 6274-6280.

Osorio, V. M. L., & Jaimes, L. E. (2019). Content and face validity of the Spanish version of the sexual self-concept inventory for early adolescent girls. *Investigacion y Educacion en Enfermeria* [*Nursing Research and Education*], *37*(1), 10-19. https://doi.org/10.17533/udea.iee.v37n1e02

Perrone, M. K. (2007). Addressing student misconceptions about reproduction and heredity: Classroom based research project. *Education Journal*, 545-631.

Potvin, P., & Cyr, G. (2017). Toward a durable prevalence of scientific conceptions: Tracking the effects of two interfering misconceptions about Buoyancy from preschoolers to science teachers. *Journal of Research in Science Teaching, 54*(9), 1121-1142. https://doi.org/10.1002/tea.21396

Quaigrain, K., & Arhin, A. K. (2017). Using reliability and item analysis to evaluate a teacher-developed test in educational measurement and evaluation. *Cogent Education, 4*(1), 1301013. https://doi.org/10.1080/2331186X.2017.1301013

Quansah, F. (2017). The use of Cronbach alpha reliability estimate in research among students in public universities in Ghana. *African Journal of Teacher Education, 6*(1), 56-64. https://doi.org/10.21083/ajote.v6i1.3970

Queloz, A. C., Klymkowsky, M. W., Stern, E., Hafen, E., & Köhler, K. (2017). Diagnostic of students' misconceptions using the biological concepts instrument (BCI): A method for conducting an educational needs assessment. *PLoS ONE, 12*(5), e0176906. https://doi.org/10.1371/journal.pone.0176906

Ramadhani, R., Abdullah, A., Hasanuddin, H., & Khairil, K. (2020). The implementation of constructivist modules to correct misconceptions on the human reproductive system concept. *Journal of Physics: Conference Series, 1460*(1), 012062. https://doi.org/10.1088/1742-6596/1460/1/012062

Rillo, A., Martínez, B., Castillo, J., & Rementería, J. (2020). Constructivism: An interpretation from medical education. *IOSR Journal of Research & Method in Education, 10*(3), 1-12.

Roy, A., & Singh, S. (2021). Investigating the learning gaps of senior-secondary children through original (real-life) biological Images: What really lacks? *Voices of Teachers and Teacher Educators, 10*(1), 177-190.

Rubio, D. M. (2005). Alpha reliability. In K. Kempf-Leonard (Ed.), *Encyclopedia of social measurement* (pp. 59-63). Elsevier. https://doi.org/10.1016/B0-12-369398-5/00395-9

Sadler, P. M., Sonnert, G., Coyle, H. P., Cook-Smit, N., & Miller, J. L. (2013). The influence of teachers' knowledge on student learning in middle school physical science classrooms. *American Educational Research Journal, 50*(5), 1020-1049. https://doi.org/10.3102/0002831213477680

Schussler, E. (2008). From flowers to fruits: How children's books represent plant reproduction. *International Journal of Science Education, 30*(12), 1677-1696. https://doi.org/10.1080/09500690701570248

Selcuk, A., & Mehmet, Y. (2020). The effect of constructivist learning approach and active learning on environmental education: A meta-analysis study. *International Electronic Journal of Environmental Education, 10*(1), 44-84.

Sewell, A. (2002). Constructivism and student misconceptions: Why every teacher needs to know about them. *Australian Science Teachers' Journal, 48*(4), 24-28.

Stein, M., Larrabee, T. G., & Barman, C. R. (2008). A study of common beliefs and misconceptions in physical science. *Journal of Elementary Science Education, 20*(2), 1- 11. https://doi.org/10.1007/BF03173666

Stern, F., Kampourakis, K., Huneault, C., Silveira, P., & Müller, A. (2018). Undergraduate biology students' teleological and essentialist misconceptions. *Education Sciences, 8*(3), 135. https://doi.org/10.3390/educsci8030135

Susanti, R., Rustaman, Y. N., & Sri, R. (2010). Profile material difficulty level of plant physiology according to prospective biology teachers. In *Proceedings of the 4th International Seminar on Science Education, Science Education Program School of Postgraduate Studies, Indonesia University of Education, Bandung, West Java*.

Taber, K. S. (2011). Models, molecules and misconceptions: A commentary on secondary school students' misconceptions of covalent bonding. *Journal of Turkish Science Education, 8*(1), 3-18.

Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education, 48*, 1273-1296. https://doi.org/10.1007/s11165-016-9602-2

Taiwo, S. K., & Emeke, E. A. (2014). Relationship among learning style preferences, gender, age, and students' achievement in senior secondary school biology. *West African Journal of Education, XXXIV*, 273-283.

Tristán-López, A. (2008). Modificación al modelo de Lawshe para el dictamen cuantitativo de la validez de contenido de un instrumento objetivo [Modification to the Lawshe model for the quantitative opinion of the content validity of an objective instrument]. *Avances en Medición* [*Advances in Measurement*], *6*(1), 37-48.

Trochim, W. M. (2005). *The research methods knowledge base*. http://trochim.human.cornell.edu/kb/index.htm

Unal, S., Costu, B., & Ayas, A. (2010). Secondary school students' misconceptions of covalent bonding. *Journal of Turkish Science Education, 7*(2), 3-29.

Vaishali, & Misra, P. K. (2020). Implications of constructivist approaches in the classrooms: The role of the teachers. *Asian Journal of Education and Social Studies,* 17-25. https://doi.org/10.9734/ajess/2020/v7i430205

Wartono, Batlolona, J. R., & Putirulan, A. (2018). Cognitive conflict strategy and simulation practicum to overcome student misconception on light topics. *Journal of Education and Learning (EduLearn), 12*(4), 747-757. https://doi.org/10.11591/edulearn.v12i4.10433

Wong, K. C., Lam, Y. R., & Ho, L. M. (2002). The effects of schooling on gender differences. *British Educational Research Journal, 28*(6), 827-843. https://doi.org/10.1080/0141192022000019080

Wynn, A. N., Pan, I. L., Rueschhoff, E.E., Herman, M. A., & Archer, E. K. (2017). Student misconceptions about plants–A first step in building a teaching resource. *Journal of Microbiology & Biology Education, 18*(1), 1-4. https://doi.org/10.1128/jmbe.v18i1.1253

Yalim, E. (2021). *High school students' level of knowledge and attitudes towards the use of technology in biology classrooms* [Master's thesis, Bilkent University].

Yamtinah, S., Masykuri, M., Ashadi, & Shidiq, A. S. (2017). Gender differences in students' attitudes toward science: An analysis of students' science process skill using testlet instrument. *AIP Conference Proceedings, 1868*(1), 030003. https://doi.org/10.1063/1.4995102

Yip, D. Y. (1998). Children's misconceptions on reproduction and implications for teaching. *Journal of Biological Education, 33*(1), 21-26. https://doi.org/10.1080/00219266.1998.9655632

Yucel, E. O, & Ozkan, M. (2015). Determination of secondary school students' cognitive structure, and misconception in ecological concepts through word association test. *Educational Research and Reviews, 10*(5), 660-674. https://doi.org/10.5897/ERR2014.2022

Zeilik, M., & Morris-Dueer, V. J. (2005). What are essential concepts in 'Astronomy 101'? A new approach to find consensus from two different samples of instructors. *Astronomy Education Review, 2*(3), 61-108. https://doi.org/10.3847/AER2004017