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KNOWLEDGE AND ATTITUDES TOWARD BIOTECHNOLOGY IN STEM EDUCATION AS AN INDICATOR OF SCIENTIFIC LITERACY

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Abstract. *Biotechnology has great importance as a socioscientific issue in STEM education. This study aimed to explore the knowledge and attitudes of college students toward biotechnology. A total of 236 university students participated in the study. Questionnaires on knowledge and attitudes towards biotechnology were used for data collection. The results revealed that participants had inadequate knowledge about several basic concepts related to genetics and biotechnology, particularly those concerning genetically modified organisms. The results regarding the attitudes revealed more neutral results. The participants had a neutral attitude towards biotechnology, with mean scores ranging from 2.71 to 3.55. They were generally against buying genetically modified products but supported biotechnology for medical purposes and strongly desired to increase their knowledge about genetically modified products. The participants did not have a negative opinion of biotechnology in general but were critical of its purpose and use. The correlation analysis between knowledge and attitudes produced weak correlations. Offering supplementary resources on biotechnology can enhance students' and individual's understanding and attitudes of this topic.*

Keywords: *biotechnology education, attitudes toward biotechnology, knowledge of biotechnology, socioscientific issue, STEM education*

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Introduction

The conjunction of science, technology, engineering, and mathematics (STEM) has encouraged innovative developments, exerting a profound influence on society. Biotechnology is central to this interdisciplinary field, which connects the power of living organisms, cells, and biological systems to revolutionize industry, medicine, and agriculture (Erdogan et al., 2012; Singh et al., 2019). With its transformative potential, biotechnology represents the convergence of biology, chemistry, and technology and provides a dynamic platform for students to engage with real-world applications of scientific principles (López-Banet et al., 2020). In the context of STEM education, biotechnology offers a unique approach to elucidating complex biological processes and fosters a holistic understanding of the natural world (Bahri et al., 2014; de la Hoz et al., 2022). The significance of biotechnology in developing a society with a high level of scientific literacy has become essential due to its nature as a socio-scientific issue (Carver et al., 2017; Kidman, 2009; Dawson & Venville, 2009). Biotechnological advancements are revolutionizing various fields and posing challenges to conventional frameworks, exemplified by the use of genetically modified organisms (GMOs) to enhance agricultural productivity and the development of personalized medicine customized to individual genetic characteristics (Prokop et al., 2007; Sorgo & Ambrožič-Dolinšek, 2010; Sorgo et al., 2011). Therefore, it is imperative to have a well-informed society to effectively address the ethical, social, and environmental consequences associated with these advancements (Bybee, 2009; Hafte & Jemal, 2023). For example, in agriculture, biotechnology interventions have paved the way for genetically engineered crops that are resistant to pests, tolerate harsh environmental conditions, and have improved nutritional profiles (Malik & Chaudhary, 2019). Biotechnology has also revolutionized diagnostics, treatment methods, drug development, and an era of personalized medicine tailored to an individual's genetic makeup (Ahmed et al., 2013; Dwivedi et al., 2017). By immersing students in the study of biotechnology, the understanding of the transformative potential of science fosters an appreciation for the role of STEM subjects in solving real-world problems (Bahri et al., 2014; Movahedzadeh et al., 2012; Widiarti et al., 2022).

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Biotechnology is central to advancing scientific literacy for several reasons and contributes to a comprehensive understanding of science and its applications in various fields (Casanoves et al., 2015; de la Hoz et al., 2022). Biotechnological innovations are ubiquitous in everyday lives, from genetically modified organisms in agriculture to personalized medicine in healthcare. Understanding these applications allows individuals to connect theoretical knowledge with practical, everyday scenarios, developing a deeper understanding of the relevance of science. Researchers have implied that scientific literacy goes beyond knowledge of facts to understanding the ethical dimensions associated with scientific advances (Bybee et al., 2009; Prokop et al., 2007; Zoller et al., 2012). As biotechnological innovations shape the future, a scientifically literate society is better positioned to meet the challenges and opportunities that arise (de la Hoz et al., 2022). Because biotechnology is at the forefront of addressing global issues such as food security, health disparities, and environmental sustainability, scientifically literate people can better contribute meaningfully to discussions and decisions impacting these critical areas. Biotechnology bridges the gap between theoretical knowledge and practical applications, promotes interdisciplinary thinking, develops critical thinking skills, addresses ethical considerations, prepares individuals for the future, cultivates curiosity, fosters global citizenship, creates employment opportunities, and demystifies the world of science for learners from diverse backgrounds. Determining individuals' knowledge and attitudes toward biotechnology is, therefore, essential to having a scientifically literate society capable of understanding and contributing to the complex scientific landscape of the 21st century.

In exploring students' knowledge and attitudes toward biotechnology, it is essential to recognize that fostering scientific literacy is about imparting information and instilling attitudes and affective factors. Identifying, analyzing, and applying scientific knowledge is increasingly essential in an era characterized by abundant information. Biotechnology provides an ideal platform to cultivate these skills by linking concepts from the classroom to real-world scenarios. However, the effectiveness of education in preparing students for the biotechnology landscape depends on more than just teaching theoretical concepts. Exploring students' attitudes toward biotechnology and assessing their receptivity to ethical dilemmas, social implications, and potential risks associated with biotechnological advances is necessary. Integrating biotechnology into STEM education should allow students enable them to think critically about the social implications of scientific advances.

Biotechnology is a promising component of STEM education, but the success of its integration depends heavily on students' perceptions and attitudes toward this field. Exploring these perceptions is critical for educators and policymakers alike, as it enables the identification of potential barriers to effective learning and provides information for strategies to increase engagement. In seeking this understanding, it is essential to consider the diversity of student populations and varying levels of engagement with biotechnology. Students from different demographic backgrounds, educational levels, and geographic locations may bring unique perspectives and experiences (de la Hoz et al., 2022; Erdogan et al., 2012; Sorgo et al., 2011). Consequently, a nuanced examination of student attitudes toward biotechnology should consider these contextual factors to provide a holistic view of the educational landscape. Biotechnology, with its complicated mix of biological principles and technological applications, requires students to understand and apply basic concepts in new and evolving contexts. Therefore, examining their theoretical understanding is necessary to assess students' knowledge of biotechnology. In addition, the ethical aspects of biotechnology contribute to students' even more complex understanding. Understanding the societal implications, ethical considerations, and potential risks associated with biotechnology innovations is essential to educating students to be responsible and informed citizens. Hence, students' knowledge and attitudes toward biotechnology are critical to raising a generation familiar with the complexities of modern science.

From this perspective, scholars have conducted some studies to examine college students' knowledge and attitudes toward biotechnology and its applications. For example, Bahri et al. (2014) determined biotechnology literacy based on the factors influencing students' attitudes toward biotechnology. Their results showed that overall, students have an intermediate knowledge, perception, and attitude toward biotechnology. The study of Ozturk-Akar (2016) examined the knowledge and attitudes of science and non-science students toward biotechnology applications. The results indicated that science undergraduates had higher knowledge and attitude scores than non-science students. However, both groups had sufficient knowledge of biotechnologies and no significant correlation between students' attitudes and their knowledge of biotechnology. De la Hoz et al. (2022) studied the knowledge and attitudes of Swedish about biotechnology. Their results showed that pre-service elementary teachers had knowledge gaps regarding basic genetic concepts, and their attitudes toward biotechnological applications in health were positive but less toward purchasing and using genetically modified products. They also found a correlation between a higher level of knowledge and a more positive attitude.

Among previous studies on students' knowledge and attitudes toward biotechnology at the undergraduate

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level, Prokop et al. (2007) found that Slovak college students had poor knowledge of biotechnological processes and had less favorable attitudes toward biotechnology, regardless of their understanding of genetic engineering. There was a reluctance to purchase genetically modified products due to negative attitudes towards the control of genetic engineering. Usak et al. (2009) found a significant correlation between the level of knowledge and attitudes towards biotechnology. Their study revealed a positive attitude towards agricultural biotechnology, although they had a limited understanding of biotechnology processes and negative attitudes toward genetically modified products.

Šorgo and Ambrožič-Dolinšek (2010) explored attitudes toward genetically modified organisms (GMOs) among prospective Slovenian teachers. The study uncovered that genetically modified plants and microorganisms, which were perceived advantageous, are generally embraced. However, there was uncertainty regarding organisms employed for research or medical purposes and resistance to organisms used for food and enjoyment. Moreover, they detected a weak relationship between knowledge and attitude and knowledge and acceptance of GMOs. However, a strong relationship was noticed between attitude and acceptance. Erdoğan et al. (2012) examined prospective teachers' knowledge and attitudes toward biotechnology in four countries. Their results showed that prospective teachers' knowledge about biotechnology was below average in all four samples. The results also showed significant differences in attitudes toward biotechnology among prospective teachers in the four countries. A study conducted by Prokop et al. (2013) aimed to explore the relationship between perceptions of modern risk technologies, risky behaviors, and neophobia towards genetically modified (GM) products. The study found that people who believed they were more vulnerable to infectious diseases had a more negative view of genetically modified (GM) products. Additionally, women were less likely to have a favorable attitude toward GM products. However, there was no connection between engaging in risky behaviors, women's reproductive goals, and fear of new foods with attitudes toward GM products.

Casanoves et al. (2015) conducted a study on the attitudes and knowledge of Spanish pre-service teachers toward biotechnology. The findings revealed that the teachers had a good understanding of the applications of biotechnology. Furthermore, the pre-service teachers opposed the acquisition of genetically modified products, supported the use of biotechnology for medical purposes, and expressed a desire to increase their knowledge of biotechnology and other scientific advancements. The study also found a positive correlation between a better understanding of biotechnology and a positive attitude toward it. AbuQamar et al. (2015) researched the educational awareness, perceptions, and attitudes of university students in the United Arab Emirates toward biotechnology. The results showed that educational awareness of biotechnology knowledge and the environment was significantly related to the enrolled college and students' academic achievement. They also found a poor performance in students' understanding. Research by Alanazi (2021) determined students' and science teachers' knowledge and attitudes toward biotechnology in Saudia Arabia. The results revealed limited awareness of biotechnology.

China is among the countries that seek to leverage biotechnology to attain a high-income economy. However, the countries need to consider social acceptance and opinions regarding the issues emerging in this field. This is especially important as China has established itself as one of the primary national economic drivers in biotechnology. There is currently no available research on Chinese students' attitudes and understanding towards biotechnology. However, it is essential to note the importance of this research since it provides insight into the attitudes of students in STEM fields who will eventually become policymakers, leaders, and consumers and represent the future society of China. Previous research conducted with STEM students in other countries has revealed that they lack a comprehensive understanding of biotechnology, genetics, and genetically modified (GM) products. Studies. Additionally, these studies have found a weak but significant relationship between their content knowledge and attitudes related to the identified problems. However, no educational research has examined Chinese students' attitudes and understanding toward biotechnology. The existing research in the literature on attitudes towards and understanding biotechnology is mostly outdated, with data lacking from specific contexts such as Chinese STEM students. A notable gap exists in studies concerning the understanding and attitudes of STEM students towards biotechnology. This topic is of major significance as these students have a pivotal role in influencing the understanding and attitudes of future generations about biotechnology. This study examines STEM students' knowledge and attitudes towards biotechnology to address this gap. Accordingly, the research question that guides this research is to examine the knowledge and attitudes of STEM students toward biotechnology.

The results of this research offer insights into the effectiveness of current practices in STEM education in preparing the next generation of scientifically literate individuals. The findings inform educators and policymakers and guide the development of curricula, pedagogical approaches, and outreach initiatives to cultivate a scientifically literate citizenry. By understanding the factors that shape students' perceptions and knowledge gaps about biotechnology, educators can adapt their teaching strategies to improve engagement and understanding.

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Research Methodology

Background

The authors used a survey method to answer the research question in this study. The quantitative research method uses a questionnaire as an instrument (Creswell & Creswell, 2017). For this aim, questionnaires were used to collect the data. The questionnaires included statements regarding knowledge and attitudes toward biotechnology. The questionnaires were administered to the participants in May 2023. According to the research question, the dependent variable was attitudes and knowledge about biotechnology applications.

Participants

The study involved a group of students selected from a single university in the Republic of China. A total of 236 students (144 female, 61% and 92 male, 39%) were in grade 1 (106, 44.9%), grade 2 (41, 17.4%), grade 3 (31, 13.1%), grade 4 (34, 14.4%), and master (24, 10.2%). These students were selected from different parts of the country based on their performance on university entrance exams. While the universities in this study may not be nationally representative, it is worth noting that the students came from diverse social and cultural backgrounds, making them typical of public universities. It is important to indicate that the purpose of this study is not to generalize the findings to all students in the country but rather to serve as a starting point for future nationwide research. All participants had taken at least one course in STEM subjects at different levels. The participants were involved in the research voluntarily. In addition, the authors considered the ethical issues with the participants' participation in the research in data collection and analysis.

Data Collection Instruments

The participants' knowledge of biotechnology was assessed using the Biotech XXI questionnaire developed by Casanoves et al. (2015). The Biotech XXI questionnaire is based on a framework that covers various subjects regarding genetically modified organisms and biotechnology. It consists of 21 questions that test the participants' knowledge, with response options of "true", "false," and "do not know." The primary objective of the questionnaire is to evaluate the participant's level of understanding of biotechnology, particularly in terms of genetic knowledge and the practical applications of biotechnology. Many researchers have used it to assess individuals' knowledge of biotechnology in previous studies (Casanoves et al., 2015; de la Hoz et al., 2022).

To administer the questionnaire to the participants, a standardized English version of the original questionnaire was used to produce a Chinese translation. A second independent back-translation was performed in English to confirm the accuracy of the translation. The final questions were revised and then evaluated with a sample of 20 participants to determine the readability and comprehensibility of the questionnaire. The biotechnology attitude questionnaire is a 28-item survey developed by Erdogan et al. (2009). It comprises seven dimensions that measure attitudes towards biotechnology and its applications. The questionnaire consists of seven key factors that assess individuals' attitudes toward biotechnology and genetically modified organisms. The factors are related to the consumption of GM products, the use of GM in the agro-industry, public awareness of GMOs, shopping of GM products, ethics of genetic modifications, the ecological impact of genetic engineering, and the use of genetic engineering in human medicine. This reliable and valid research tool makes it useful for examining participants' attitudes toward biotechnology. Numerous researchers (e.g., Alanazi, 2021; Erdogan et al., 2012; Ozturk-Akar, 2016) have employed it to evaluate participants' attitudes toward biotechnology and genetically modified organisms.

Data Collection

The researchers distributed a paper questionnaire to students in their class. This created a controlled environment where all participants received the same instructions. The data was gathered from a group of individuals enrolled in a publicly-funded research institution in the Republic of China. All the participants in the study had completed STEM coursework. The researchers made sure that the questionnaire was administered consistently. Moreover, they ensured that the ethical standards of each respective country were followed.

When conducting research studies, it is crucial to consider the reliability of the questionnaire used. In this study, the Biotech XXI and BAQ instruments showed satisfactory results regarding their first internal consistency,

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with Cronbach's alpha scores of 0.87 and 0.71, respectively. Data collected during the study was used to determine the subdimensions' reliability scores, their corresponding abbreviations, and the number of items in each subscale to evaluate their reliability. The subscale titles are abbreviated and referenced throughout the text for clarity. Table 1 displays subdimensions' mean and standard deviation and reliability scores, their corresponding abbreviations, and the number of items inside each subscale.

The study found that the Biotech XXI and BAQ instruments used to measure participants' scores demonstrated satisfactory results, with Cronbach's alpha of .87 and .71, respectively, indicating good internal consistency. The instruments' reliability was further analyzed using participant data, revealing a Cronbach's alpha of .87 for the Biotech XXI and .71 for the BAQ. The reliability analysis was conducted for 7 subdimensions, with the Cronbach's alpha for the BAQ subscales ranging from .70 to .80. Table 1 below presents the reliability values, abbreviations, and number of items per subdimensions. The abbreviations for each subdimension are used throughout the rest of the text.

Table 1
The Results Regarding Each Factor

Factor names	*M*	*SD*	Number of the items	Reliability (*α*)
Factor 1. Consumption of GM products (CGMP)	3.03	0.94	4	.80
Factor 2. GM in Agro-Industry (GMAI)	3.49	0.66	5	.71
Factor 3. Public awareness of GMO (PAGMO)	3.03	0.60	3	.72
Factor 4. Shopping of GM products (SGMP)	2.74	0.70	6	.79
Factor 5. Ethics of genetic modifications (EGM)	2.71	0.84	3	70
Factor 6. Ecological impact of genetic engineering (EIGE)	3.10	0.66	4	.70
Factor 7. Use of genetic engineering in human medicine (UGEHM)	3.55	0.91	3	77
Whole instrument			28	.71

Research Results

Knowledge of Biotechnology

The questionnaire included 21 questions testing biotechnology knowledge. The obtained Cronbach's alpha coefficient was .87, indicating that the research had acceptable reliability. Table 2 shows results according to the percentage of respondents who responded correctly and incorrectly and did not know the responses. Most participants correctly answered the first 12 questions and question 14 with more than 50% accuracy. On the other hand, the remaining 8 questions were mostly answered incorrectly or marked as "do not know" by over 50% of participants.

Based on the findings in Table 2, it can be inferred that the participants lacked sufficient knowledge about various fundamental concepts related to genetics and biotechnology, especially those related to GMOs. For example, most students (86%) gave incorrect answers or were unaware that DNA is chemically identical in all living organisms. In addition, a mere 31% of the students recognized that GMOs are not inherently larger than ordinary organisms, and many students expressed uncertainty over the presence of toxic substances in GMOs. However, the respondents demonstrated a good understanding of certain biotechnology applications, such as the use of bacteria in the production of cheese and vinegar (80% of students knew this) and the modification of genetic characteristics against disease, nutritional value, or productivity (64% of students were aware of this).

To determine the difference between genders in terms of knowledge about biotechnology, a t-test for independent samples was performed. The results showed no significant differences [$t_{234} = .204$, $p > .05$] between the average mean score of females ($M = 2.02$, $SD = .35$) and males' mean score ($M = 2$, $SD = 0.44$). Based on this result, no significant differences existed between genders. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' knowledge of biotechnology. The main effect of grade level [$F_{(4, 231)} = 5.81$, $p < .05$]. Significant differences were found between the scores from grades one-third, two-third, third-four, and four and master students.

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Attitudes toward Consumption of GM Products

Participants showed neutral attitudes toward the consumption of GM products. A significant difference was found between female students' mean scores (M = 3.22) and males' mean scores (M = 2.72) [t_{234} = 4.129, p < .05]. Based on this result, it can be concluded that gender has a significant effect on the consumption of GM products. The results show that female students had higher mean scores than male students. The effect size (η2 = .91) calculated as a result of the test showed that this difference was moderate. In particular, females and males indicated positive attitudes on item 10 about not giving GM food to children. This item's mean score was higher than the other three items in this subdimension. In addition, females had higher mean scores about altering the genes in fruits to improve their taste and against altering the genes of fruits and vegetables and the risks of using genetically modified food. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' attitudes in this dimension. The main effect of grade level [$F_{(4, 231)}$ = 2.66, p < 0.05] was found significant. These significant differences were found between the scores from third to fourth grades. The mean scores of third grades were higher than those of fourth grades.

Attitudes toward GM in the Agro-Industry

All items' scores for females and males exceeded 3, indicating that students in the Agro-industry hold neutral attitudes about GM. Participants showed higher attitudes than neutral regarding the use of GM in the Agro-industry. A significant difference was not found between female students' mean scores (M = 3.49) and males' mean scores (M = 3.5) [t_{234} = -.06, p > .05]. Based on this result, it can be concluded that gender has no significant effect on the use of GM in the Agro-industry. The results show that female and male students had similar scores regarding the items in this subdimension. In particular, both females and males indicated positive attitudes about the items related to agreeing with the use of genetic engineering in the therapy of genetically determined diseases and wanting to know more about genetically engineered foods. These items' mean scores were higher than the other three items in this subdimension. The results indicate that male and female participants held positive attitudes about using genetic engineering to treat genetically determined diseases and wanted to learn about genetically modified foods. Furthermore, a one-way ANCOVA was conducted to explore the impact of grade level on students' perceptions in this particular aspect. The main effect of grade level [$F_{(4, 231)}$ = 1.17, p >.05] revealed no significance among grade levels.

Attitudes toward Public Awareness of GMO

Participants showed neutral attitudes toward public awareness of GMOs. The average mean score for the three items in this dimension was 3.03. No significant difference was found between female students' mean scores (M = 3.05) and males' mean scores (M = 3.00) [t 234 =.693, p > .05]. Based on this result, it can be concluded that gender has no significant effect on the attitudes toward public awareness of GMOs. The results show that female and male students had similar mean scores. In particular, females (M = 3.67) and males (M = 3.65) indicated positive attitudes on item 25 about trusting the food industry to take necessary actions to provide safe genetically engineered foods. This item's mean score was higher than the other two items in this subdimension. For the other two items, females and males had similar mean scores. Specifically, the average scores for both females and males were below the mean scores by approximately 3 points. This suggests that the existing governmental regulations effectively protect the public from the risks linked to genetically engineered foods and that the public is adequately informed about these risks. In addition, the effect of grade level on students' attitudes toward public awareness of GMOs was examined through one-way ANCOVA analysis. Accordingly, the main effect of grade level [$F_{(4, 231)}$ = 1.97, p >.05] was found not significant. This result shows there are no statistical differences among grade levels.

Attitudes toward Shopping for GM Products

The average mean score for the three items in this dimension was 2.74. This mean score was less than 3, referring to students' neutral attitudes toward shopping for GM products. A significant difference was found between female students' mean scores (M = 2.64) and males' mean scores (M = 2.9) [t_{234} = -2.84, p < .05]. Based on this result, it can be concluded that gender significantly affects the shopping of GM products. The results

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show that male students had higher mean scores than female students when shopping for GM products. The effect size (η2 = .69) calculated as a result of the test showed that this difference was moderate. Participants showed only neutral attitudes toward an item related to eating genetically modified tomatoes. The lowest mean scores were found for the item related to inserting genes from human cells into the fertilized eggs of sheep. The other four items were found to have the lowest mean scores (less than 3 mean scores) related to the effects of GM food on human health, thinking about GM products having a better taste, buying the GM product, and supporting changing the genes in cattle to make their meat more nutritious. In particular, males had more positive attitudes than females for all six items in the subdimension. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' attitudes in this dimension. The main effect of grade level [$F_{(4, 231)} = 4.42$, $p < .05$] was found significant. The effect size (η2 = .07) calculated as a result of the test showed that this difference was moderate. These significant differences were found for grades 1-4, 2-3, and 3-4. The mean scores of the fourth grade were higher than the other grades.

Attitudes Toward Ethics of Genetic Modifications

The mean score for the three items in this dimension was 2.71, on average. The mean score was below 3, indicating that students held neutral attitudes about the ethics of modifications to genes. A significant difference was found between female students' mean scores ($M = 2.81$) and males' mean scores ($M = 2.55$) [$t_{234} = 2.6$, $p < .05$]. Based on this result, it can be concluded that gender significantly affects the ethics of genetic modifications. The results show that female students had higher mean scores than male students. The effect size (η2 = .84) calculated as a result of the test showed that this difference was moderate. In particular, females had neutral attitudes on item 1 about transferring genetic material between plants and animals. This item's mean score was higher than the other two items in this subdimension. In addition, females had higher mean scores than males. Based on the results for the other two items in this subdimension, the participants indicated that DNA manipulation is unethical and human beings do not have the right to intervene in DNA; it is against nature. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' attitudes in this dimension. No significant differences regarding the effect of grade level [$F_{(4, 231)} = 1.41$, $p > .05$] were found. Thus, there are no significant differences in grade level.

Attitudes toward Ecological Impact of Genetic Engineering

Participants showed neutral attitudes toward the ecological impact of genetic engineering. The average mean score for the three items in this dimension was 3.10. A significant difference was found between female students' mean scores ($M = 3.15$) and males' mean scores ($M = 3.01$) [$t_{234} = 1.585$, $p > .05$]. Based on this result, it can be concluded that gender has no significant effect on the ecological impact of genetic engineering. The results show that female students had higher mean scores than male students, but this difference is insignificant. Both females and males expressed favorable attitudes towards item 23, which pertains to the potential hazard of hybridization between genetically modified and regular plants, posing a risk to the original genetic resources of wild plants. This item's mean score was higher than the other three items in this subdimension. The lowest mean score in this subdimension was found to ban the production and purchase of genetically engineered products. Regarding the remaining two aspects of this dimension, the participants were neutral about refraining from modifying plant genes to enhance oil production for industrial purposes and the potential disruption of ecological linkages caused by genetic manipulations. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' attitudes in this dimension. The main effect of grade level [$F_{(4, 231)} = 2.67$, $p < 0.05$] on the attitudes toward the ecological impact of genetic engineering was found to be significant. These significant differences were found only between the scores from grades 1 and 4. The average scores for fourth-grade students were higher than those for first-grade students.

Attitudes Toward Use of Genetic Engineering in Human Medicine

Participants showed more positive attitudes toward using genetic engineering in human medicine. The average mean score for the three items in this dimension was 3.55. This mean score had the highest score in

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all subdimensions. No significant difference was found between female students' mean scores (M = 3.53) and males' mean scores (M = 3.57) [t_{234} = -.29, p > .05]. Based on this result, it can be concluded that gender has no significant effect on using genetic engineering in human medicine. In particular, females and males indicated positive attitudes on item 8 about using genetic engineering for nonfood purposes, such as the production of human medicines. This item's mean score was higher than the other two items in this subdimension. Participants had favorable attitudes about using GM microbes to decompose human sewage and insulin production using genetically modified microbes for the other two items. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' attitudes in this dimension. The main effect of grade level [$F_{(4, 231)}$ = .44, p > 0.05] on the use of genetic engineering in human medicine was not significant. Thus, no significant differences were found in grade level.

Table 2
Results of Knowledge of Biotechnology

	Items	Correct answer	Responded correctly (%)	Responded incorrectly (%)	Do not know (%)
1	AIDS is a genetic disease	False	83	6	11
2	Bacteria are used in the elaboration of daily products (cheese, vinegar, vitamin C)	True	80	6	14
3	Only when we eat GM food, we eat genes	False	64	4	32
4	In our body, there are more bacteria than people in the world	True	70	7	23
5	A good hygiene helps to prevent genetic diseases	False	69	13	18
6	Children resemble their parents because they share the red blood cells	False	63	6	31
7	It is possible to change the genetic characteristics of a plant to make it more resistant to a given plague	True	64	8	28
8	Mutations are only possible by genetic manipulation in the laboratory	False	76	9	15
9	A high production of vitamins by a fruit is only possible by genetic manipulation of that fruit	False	56	15	29
10	Through genetic modification, foods with higher nutritional values can be achieved	True	62	9	29
11	Microorganisms are used to purify sewage	True	64	6	30
12	A yoghurt is a biotechnological product	True	59	13	28
13	Insulin is obtained by the use of genetically modified (GM) bacteria	True	25	16	59
14	Genetic material exchange between different species is only possible by manipulation in the laboratory	False	52	14	34
15	The most powerful toxic substances are naturally occurring	True	46	23	31
16	GMOs have a high number of toxic substances	False	37	29	34
17	Chemically, the genetic material (DNA) is identical in all the organisms	True	14	55	31
18	In the kidney cells genome, you can also find information about the color of your hair	True	34	13	53
19	Genetically modified organisms (GMOs) are larger than normal	False	31	24	45
20	Crocodiles have the same genetic material as ostriches	True	15	25	60
21	A GMO is always a transgenic	False	20	15	65

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Correlations between Knowledge and Attitudes

A multivariate partial correlation was performed while holding the grade level variable constant to examine the correlation between knowledge of biotechnology and subdimensions of attitude toward biotechnology. The findings presented in Table 3 suggest that out of 28 correlations, 16 are statistically significant and exceed 0.15. Among these significant correlations, six were observed to be negative. Four correlations linked to knowledge were not found to be significant. Notably, significant correlations were identified between knowledge and Ethics of genetic modifications (EGM) [r (233) = .243, p < .01], Use of genetic engineering in human medicine (UGEHM) [r (233) = -.229, p < .01], GM in Agro-Industry (GMAI) [r (233) = -.330, p < .01]. The association between knowledge and GM in Agro-Industry exhibited a moderate connection, while the remaining correlations were very modest. In summary, these findings indicate that possessing knowledge of biotechnology was partially associated with a more favorable attitude toward biotechnology.

Table 3
Results of Correlation Analysis between Knowledge and Attitudes

	1	2	3	4	5	6	7	8
Consumption of GM products (CGMP)	-							
Shopping of GM products (SGMP)	-.572**	-						
Ethics of genetic modifications (EGM)	.708**	-.350**	-					
Ecological impact of genetic engineering (EIGE)	.604**	-.431**	.492**	-				
Use of genetic engineering in human medicine (UGEHM)	.113	.161*	-.083	.151*	-			
GM in Agro Industry (GMAI)	-.107	.298**	-.238**	.015	.638**	-		
Public awareness of GMO (PAGMO)	-.027	.348**	.065	-.054	.084	.153*	-	
Knowledge	.088	.086	.243**	-.089	-.229**	-.330**	.074	-

**. Correlation is significant at the .01 level (2-tailed).
*. Correlation is significant at the .05 level (2-tailed).

Discussion

The study found that many participants lacked an understanding of basic concepts in genetics and biotechnology, with a majority providing incorrect answers or being unaware of the universality of DNA among living organisms. Additionally, merely 31% of the students knew that GMOs do not inherently possess a bigger size than ordinary organisms, and a significant number of them were uncertain about the presence of toxic substances in GMOs. The participants exhibited a commendable comprehension of specific biotech practices, such as leveraging bacteria in the production of vinegar and cheese and manipulating genetic traits to bolster an organism's resistance to illnesses, nutrient content, or efficiency. (64% of students were aware of this). In addition, the results showed no significant differences between female and male participants and some significant differences among grade levels.

These findings are consistent with those of previous research (AbuQamar et al., 2015; Erdogan et al., 2012; Lamanauskas & Makarskaite-Petkeviciene, 2008; Ozturk-Akar, 2016; Turkmen & Darçın, 2007; Usak et al., 2009), which found that participants at the college level did not have satisfactory levels and reported a weak knowledge of biotechnology. According to a recent study by De la Hoz et al. (2022), Swedish pre-service teachers demonstrated a good understanding of comprehension of genetic disease and biotechnology applications. However, they scored lower on questions related to basic concepts of genetics and GMOs. These findings are consistent with those of

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Casanoves et al. (2015). The results between gender and knowledge are not similar to those of (Erdogan et al., 2012), who have significant differences in biotechnology knowledge regarding gender variables.

The study suggests that participants have difficulty with complex biotechnologies due to a lack of genetic knowledge. The study's results indicate that the lack of knowledge found in participants still seems to exist among undergraduate participants compared to the results of previous studies conducted with undergraduate participants. This result suggests a lack of biotechnology literacy. The study found that the participants held a neutral attitude towards biotechnology, with mean scores ranging from 2.71 to 3.55. They were generally opposed to purchasing GM products but supported using biotechnology for medical purposes. Furthermore, they strongly desire to expand their knowledge about GM products. The participants did not have a negative opinion of biotechnology in general but were critical of its purpose and use. The discovery, as mentioned above, indicates the presence of an inherent utility-value framework that is exerting an impact on the alteration of perspectives about the implementation of genetically modified organisms (GMOs), contingent upon the intended purpose of this technology. Therefore, the use of GMOs should be acceptable if they can save human lives or prevent diseases, but not if they are used solely for economic advantage. These findings are consistent with those of previous studies (Erdogan et al., 2012; Ozturk-Akar, 2016; Özel et al., 2009; Prokop et al., 2007; Prokop et al., 2013; Sorgo et al., 2011; Usak et al., 2009).

Participants displayed a neutral attitude toward consuming genetically modified (GM) products. A significant difference was found in favor of female participants. This result is inconsistent with those of de la Hoz et al. (2022), who found that preservice teachers had opponent's attitudes toward buying GM products. Also, the results are not inconsistent with Erdogan et al. (2012) and Prokop et al. (2007), who found lower attitudes about consuming GM products. The findings regarding gender differences are not similar to those of Erdogan et al. (2012) and Prokop et al. (2007). They found that male participants' attitude scores had higher attitudes than female undergraduates.

The discrepancies observed between previous research and the present study regarding the consumption of GMPs may have arisen from varying attitudes prevalent in different countries. The educational approaches, backgrounds, and discourses in the countries' media may have influenced the participants' attitudes toward GMPs. Differences in participants' perception regarding the level of risk associated with consuming genetically engineered products could be attributed to the different attitudes among participants toward the same dimensions and items (Erdogan et al., 2012; Usak et al., 2009). Moreover, the presence of biotechnology goods (Bailey & Lappé, 2002; Prokop et al., 2007; Özel et al., 2009) may serve as an additional factor contributing to these variations.

Students had neutral attitudes toward GM in the agro-industry. The scores were higher than 3 mean points. In particular, males and females had positive attitudes towards genetic engineering for treating genetically determined diseases and learning more about genetically engineered foods. In this study, the positions of the participants were found to be similar to those in previous studies conducted with preservice teachers, such as the studies conducted by Erdogan et al. (2012) and Massarani and Moreira (2005), and Ozturk-Akar (2016). The results of these studies indicate that a majority of participants were in favor of using genetic engineering for treating genetically determined diseases. For example, De la Hoz et al. (2022) conducted research showing that 71% of preservice teachers favored using GMOs for medical purposes and disease studies. Additionally, three out of four respondents approved of using genetic studies to develop medicine. A significant difference was not found between genders. In addition, grade level had no significance among grade levels.

Participants showed neutral attitudes toward public awareness of GMOs. No significant difference was found between both genders. It was found that the participants had lower attitudes towards three specific items, which suggests that they believe the government regulations are adequate for protecting the public from the risks associated with genetically engineered foods. Additionally, the participants believe the public is already well-informed about these risks. These findings differ from those of Erdogan et al. (2012) and Usak et al. (2009), who came to different conclusions about the effectiveness of governmental regulations. The lower attitudes are similar to those of Ozturk-Akar (2016), who found lower attitudes about public awareness regarding GMOs. They found positive results about governmental regulations. On the other hand, the findings about sufficiently informing the public about the risks associated with genetically engineered foods are similar to those of Erdogan et al. (2012). A lack of knowledge regarding biotech procedures and a distrust of governmental regulations and oversight of GEFs may have caused this. In addition, the grade level did not impact the attitudes in this dimension.

The attitudes toward shopping for GM products had lower than three mean scores. Male students had statistically higher mean scores than female students when shopping for GM products. Participants showed only neutral attitudes toward an item related to eating genetically modified tomatoes. The lowest mean scores were found for the item related to inserting genes from human cells into the fertilized eggs of sheep. Grade levels had a significant impact on the attitudes in this dimension. This result is similar to the findings of Erdogan et al. (2012), Ozturk-Akar

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(2016), and Usak et al. (2009). In previous studies, participants hesitated to consume genetically modified products and were unwilling to purchase them **(**Erdogan et al., 2012; Ozturk-Akar, 2016; Usak et al., 2009). The participants also had the lowest mean scores (less than 3 mean scores) related to the effects of GM food on human health, thinking about GM products having a better taste, buying the GM product, and supporting changing the genes in cattle to make their meat more nutritious. These results confirm the results of Erdogan et al. (2012), Ozturk-Akar (2016), and Usak et al. (2009**).** The participants' fear and distrust of GM products may stem from potential dangers, such as an assumed link between GMOs and cancer [32]. The fourth grade was higher than the other grades.

Students' attitudes toward the ethics of genetic modifications had lower mean scores. Female students had significantly higher mean scores than male students. The participants indicated that DNA manipulation is unethical, and humans do not have the right to intervene in DNA. This result is partly similar to Erdogan et al. (2012) and Usak et al. (2009). No significant differences regarding the effect of grade level. Participants showed neutral attitudes toward the ecological impact of genetic engineering. The female students had significantly higher mean scores than male students. This result is different from the study of Erdogan et al. (2012) and Usak et al. (2009). All participants displayed favorable attitudes regarding the risk of hybridization between genetically modified and non-modified plants, potentially harming the original genetic resources of wild plants. The mean scores were lowest regarding prohibiting genetically modified product manufacturing and purchase. In addition, the participants expressed a lack of bias towards modifying the genes in plants to enhance their oil production for industrial purposes, as well as concerns about the potential disruption of ecological interactions resulting from genetic modifications. Moreover, their grade level highly influenced the participants' perceptions of the ecological impact of genetic engineering. The average scores of grade 4 participants outperformed those of grade 1 participants. The participants in the study expressed positive attitudes towards the use of genetic engineering in human medicine. The mean score for this subdimension was the highest among all the subdimensions, although no significant difference was found. The participants also showed favorable attitudes towards using genetic engineering for non-food purposes, such as producing human medicines. They also expressed positive attitudes towards using genetically modified microbes to decompose human sewage and produce insulin. The study found that the participants' grade level did not significantly affect their attitudes toward genetic engineering.

The correlation study yielded both statistically significant and insignificant findings concerning knowledge. Four associations related to knowledge did not show statistical significance. Strong relationships were observed between knowledge and ethics, human medicine, and agro-industry. The association between knowledge and agro-industry exhibited a moderate level, whereas the remaining relationships showed relatively low levels. Collectively, these findings indicate that possessing expertise in the field of biotechnology is associated, to some extent, with having more favorable attitudes toward biotechnology. Previous studies have shown that having a better knowledge of biotechnology leads to a more positive attitude (e.g., de la Hoz et al., 2022; Özel et al., 2009; Prokop et al., 2007; Usak et al., 2009). However, our study yielded different results. Despite having little knowledge of biotechnology, the participants had a positive attitude toward the biotechnological applications mentioned in the study, such as human medicine. This is in agreement with the conclusions drawn by de la Hoz et al. (2022), Prokop et al. (2007) and Usak et al. (2009). Furthermore, the correlation analysis revealed a weak association between participants' knowledge about biotechnology and their attitude towards biotechnology applications, contradicting prior study findings. Hence, discerning the lack of a meaningful correlation between participants' knowledge of biotechnology and their attitudes toward biotechnology applications is challenging, similar to the findings of Ozturk-Akar (2016) and Sorgo et al. (2011).

Conclusions and Implications

STEM students need to have adequate knowledge and positive attitudes about biotechnology as they play a crucial role in shaping the understanding of future generations regarding the impact of biotechnology on society. Personal, social, and cultural background factors may likely influence participants' attitudes toward biotechnology, independent of their level of education. However, education continues to be one of the most important determinants. Studies indicate a difference in attitudes towards biotechnology between younger students (12-year-olds) and older students (17-year-olds), with the former exhibiting less favorable attitudes. This underscores the significance of incorporating biotechnology concepts into the curriculum during the early stages of school. To promote biotechnological literacy among the participants, it is crucial to possess basic knowledge about biotechnology and

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have a positive attitude toward it. Although some participants may not be fond of science and technology and their practical applications, a positive attitude towards these subjects is essential for having a science literacy society.

This study establishes an empirical basis for creating instructional methods focusing on attitudes and knowledge for students studying STEM in biotechnology. An effectively structured curriculum can establish a firm basis, but its subsequent enhancement and advancement ultimately depend on policy decisions and implementation strategies. Hence, raising participants' knowledge and attitudes about biotechnology is crucial to elevate the education standard. This research suggests that formal education alone is insufficient for STEM students to acquire scientific literacy about biotechnologies. The scientific literacy of science students in biotechnologies cannot be confirmed either. Additionally, the study revealed no significant correlation between participants' knowledge of biotechnology and their views toward biotechnology applications. The research was conducted on a group of individuals in a college setting. However, to achieve more extensive results within a nationwide context, additional research is required to assess the suitability of these findings. What is lacking in this current study is the crucial consideration of participants' informal learning experiences and the importance of public presentation of biotechnology applications in China when concluding their knowledge and attitudes towards biotechnologies.

Recommendations

The future occurrence of the legalization of genetically modified products is anticipated. Hence, people and society must comprehensively understand this subject matter since research suggests increased knowledge correlates with more favorable perceptions of biotechnology (de la Hoz et al., 2022; Usak et al., 2009). The results of this study indicate that incorporating biotechnology messages within the STEM curriculum may not sufficiently equip students with the necessary knowledge and skills in the biotechnology field. The limited comprehension of biotechnology processes may stem from a superficial comprehension of biotechnology as presented in educational materials and media. A more comprehensive comprehension of biotechnology can be achieved by critically examining the STEM curriculum and engaging in public discourse with scientists, potentially facilitated through media platforms such as television or publications. The study reveals that attitudes towards biotechnology are generally unfavorable when it comes to the acquisition of genetically modified products. This finding holds significant implications for future food policy in many nations. Providing additional sources of information about biotechnology can facilitate the acquisition of a more profound comprehension and heightened awareness of this field among students and the general public. Moreover, educators can employ this knowledge to enhance their instruction on genetic engineering. Simultaneously, it is imperative to acknowledge the significance of adequately equipping STEM educators to teach biotechnology effectively. However, further study and scholarly inquiry are warranted to deepen our understanding of this subject matter.

Limitations

The present study is subject to many limitations. First, the present study comprised a group of participants drawn from a suitable sample of individuals enrolled in a university setting. Further research should be undertaken to assess these findings' applicability and gain broader outcomes within a national framework. Second, the study employed well-established instruments for data collection, and the findings gained in this study hold the potential to yield generalizable conclusions for the existing body of literature. Nevertheless, using nonrandomized sampling limits the research design and the comparatively limited sample size. It is impossible to assert the generalizability of the findings to all students in the studied country; nonetheless, the results offer some preliminary insights. The selection of students at the university where the present study was done is based on a national examination.

Consequently, a standardized curriculum is implemented throughout all universities within the nation. The students in these programs exhibit comparable demographic traits, rendering the selected cohort a suitable representation. Furthermore, this study presents remarkable findings from many educational and cultural contexts. Hence, it would be stimulating for future inquiries to broaden the study's scope to assess the applicability of the results in diverse educational and cultural contexts. When evaluating participants' understanding and attitudes regarding biotechnologies, it is crucial to consider the influence of their informal learning experiences and the importance of public demonstration of biotechnology applications.

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Declaration of Interest

The authors declare no competing interest.

References

Ahmed, M. U., Saaem, I., Wu, P. C., & Brown, A. S. (2013). Personalized diagnostics and biosensors: A review of the biology and technology needed for personalized medicine. *Critical Reviews in Biotechnology*, *34*(2), 180–196. https://doi.org/10.3109/07388551.2013.778228

Alanazi, F. H. (2021). Saudi students' and science teachers' knowledge of and attitudes towards biotechnology. *Journal of Biological Education*, *57*(1), 196–213. https://doi.org/10.1080/00219266.2021.1884584

AbuQamar, S., Alshannag, Q., Sartawi, A., & Iratni, R. (2015). Educational awareness of biotechnology issues among undergraduate students at the United Arab Emirates University. *Biochemistry and Molecular Biology Education*, *43*(4), 283-293. https://doi.org/10.1002/bmb.20863

Bahri, N. M., Suryawati, E., & Osman, K. (2014). Students' biotechnology literacy: The pillars of STEM education in Malaysia. *Eurasia Journal of Mathematics, Science and Technology Education, 10*(3), 195-207. https://doi.org/10.12973/eurasia.2014.1075a

Bailey, B., & Lappe´ , M. (2002). *Engineering the farm: Ethical and social aspects of agricultural biotechnology*. Island Press.

Bybee, R., McCrae, B., & Laurie, R. (2009). PISA 2006: An assessment of scientific literacy. *Journal of Research in Science Teaching*, *46*(8), 865–883. https://doi.org/10.1002/tea.20333

Carver, R. B., Castéra, J., Gericke, N., Evangelista, N. A. M., & El-Hani, C. N. (2017). Young adults' belief in genetic determinism, and knowledge and attitudes towards modern genetics and genomics: The PUGGS questionnaire. *PLOS ONE*, *12*(1), Article e0169808. https://doi.org/10.1371/journal.pone.0169808

Casanoves, M., González, N., Salvadó, Z., Haro, J., & Novo, M. (2015). Knowledge and attitudes towards biotechnology of elementary education preservice teachers: The first Spanish experience. *International Journal of Science Education*, *37*(17), 2923–2941. https://doi.org/10.1080/09500693.2015.1116718

Creswell, J. W., & Creswell, J. D. (2017). *Research design*. SAGE Publications.

Dawson, V., & Venville, G. J. (2009). High-school students' informal reasoning and argumentation about biotechnology: An indicator of scientific literacy? *International Journal of Science Education*, *31*(11), 1421–1445. https://doi.org/10.1080/09500690801992870

de la Hoz, M. C., Solé-Llussà, A., Haro, J., Gericke, N., & Valls, C. (2022). Student primary teachers' knowledge and attitudes towards biotechnology—Are they prepared to teach biotechnological literacy? *Journal of Science Education and Technology*, *31*(2), 203–216. https://doi.org/10.1007/s10956-021-09942-z

Dwivedi, S., Purohit, P., Misra, R., Pareek, P., Goel, A., Khattri, S., Pant, K. K., Misra, S., & Sharma, P. (2017). Diseases and molecular diagnostics: A step closer to precision medicine. *Indian Journal of Clinical Biochemistry*, *32*(4), 374–398. https://doi.org/10.1007/s12291-017-0688-8

Erdoğan, M., Özel, M., BouJaoude, S., Lamanauskas, V., Uşak, M., & Prokop, P. (2012). Assessment of preservice teachers' knowledge of and attitudes regarding biotechnology: A cross-cultural comparison. *Journal of Baltic Science Education*, *11*(1), 78–93. https://doi.org/10.33225/jbse/12.11.78

Hafte, L., & Jemal, K. (2023). Awareness, knowledge, and attitude of high school students toward modern biotechnology in Addis Ababa, Ethiopia. *SN Social Sciences*, *3*(1). https://doi.org/10.1007/s43545-022-00580-9

Kidman, G. (2009). Attitudes and interests towards biotechnology: The mismatch between students and teachers. *Eurasia Journal of Mathematics, Science and Technology Education, 5*(2), 135-143. https://doi.org/10.12973/ejmste/75265

Lamanauskas, V., & Makarskaitė-Petkevičienė, R. (2008). Lithuanian university students' knowledge of biotechnology and their attitudes to the taught subject. *Eurasia Journal of Mathematics, Science and Technology Education*, *4*(3). https://doi.org/10.12973/ejmste/75349

Malik, A.A., Chaudhary, G. (2019). Global food security: A truncated yield of underutilized and orphan crops. In: Khoobchandani, M., Saxena, A. (Eds.), *Biotechnology products in everyday life.* Springer. https://doi.org/10.1007/978-3-319-92399-4_11

Massarani, L., & Moreira, I. D. C. (2005). Attitudes towards genetics: A case study among Brazilian high school students. *Public Understanding of Science*, *14*(2), 201–212. https://doi.org/10.1177/0963662505050992

Movahedzadeh, F., Patwell, R., Rieker, J. E., & Gonzalez, T. (2012). Project-based learning to promote effective learning in biotechnology courses. *Education Research International*, Article 536024. https://doi.org/10.1155/2012/536024

Öztürk-Akar, E. (2016). Turkish university students' knowledge of biotechnology and attitudes toward biotechnological applications. *Biochemistry and Molecular Biology Education*, *45*(2), 115–125. https://doi.org/10.1002/bmb.20996

Prokop, P., Lešková, A., Kubiatko, M., & Diran, C. (2007). Slovakian Students' Knowledge of and Attitudes toward Biotechnology. *International Journal of Science Education*, *29*(7), 895–907. https://doi.org/10.1080/09500690600969830

Prokop, P., Ozel, M., Usak, M., & Senay, I. (2013). Disease-threat model explains acceptance of genetically modified products. *Psihologija*, *46*(3), 229–243. https://doi.org/10.2298/psi130416002p

Singh, V., Shikha, K., Singh, S., Singh, A. P., & Jaiswal, D. K. (2019). Application of plant biotechnology in improvement of vegetable breeding. *International Journal of Current Microbiology and Applied Sciences*, *8*(04), 1428–1435. https://doi.org/10.20546/ijcmas.2019.804.166

Šorgo, A., & Ambrožič-Dolinšek, J. (2010). Knowledge of, attitudes toward, and acceptance of genetically modified organisms among prospective teachers of biology, home economics, and grade school in Slovenia. *Biochemistry and Molecular Biology Education*, *38*(3), 141–150. https://doi.org/10.1002/bmb.20377

https://doi.org/10.33225/jbse/24.23.76

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Šorgo, A., Ambrožič-Dolinšek, J., Usak, M., & Özel, M. (2011). Knowledge about and acceptance of genetically modified organisms among pre-service teachers: A comparative study of Turkey and Slovenia. *Electronic Journal of Biotechnology*, *14* (4), 1-16. http://dx.doi.org/10.2225/vol14-issue4-fulltext-5

Özel, M., Erdogan, M., Uşak, M., & Prokop, P. (2009). High school students' knowledge and attitudes regarding biotechnology applications. *Educational Sciences: Theory & Practice*, *9*(1), 321-328.

Turkmen, L., Darçın, E. S. (2007). A comparative study of Turkish elementary and sciences education major students' knowledge levels at the popular biotechnological issues. *International Journal of Environmental and Science Education, 2*(4), 125-131.

Usak, M., Erdogan, M., Prokop, P., & Ozel, M. (2009, March). High school and university students' knowledge and attitudes regarding biotechnology. *Biochemistry and Molecular Biology Education, 37*(2), 123–130. https://doi.org/10.1002/bmb.20267

Widiarti, A., Ibrahim, M., & Yuliani, Y. (2022). Development of STEM-based biotechnology learning tools to practice critical thinking. *International Journal of Recent Educational Research*, *3*(4), 489–499. https://doi.org/10.46245/ijorer.v3i4.232

Zoller, U. (2012). Science education for global sustainability: What is necessary for teaching, learning, and assessment strategies? *Journal of Chemical Education, 89*, 297–300. https://doi.org/10. 1021/ed300047v

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