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Students' Knowledge and Attitude toward Genetic Engineering

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Abstract: Students are the people who will be consumers, producers, and policymakers of genetic engineering application products in the future. This paper reviewed research exploring the students' knowledge and attitude toward genetic engineering through a narrative literature review of articles published between 2012 and 2022. After applying criteria of inclusion, exclusion, and thematic belonging in google scholar databases, the sample was constituted of 20 studies. The results showed that most secondary school students needed more knowledge of genetic engineering, even in countries that produce genetically modified organisms through genetic engineering nationally. Most studies also revealed that most students expressed a negative attitude toward genetic engineering and its products. Besides that, students with a positive attitude toward genetic engineering often showed multiple attitudes, depending on which aspects they focus on.

Keywords: Attitude; Genetic engineering; Knowledge; Students

Introduction

Genetic engineering is an essential field of biotechnology and is very close to human life. In the United States, genetic engineering in agriculture was applied in 1996 to pest-resistant corn, soybeans, and cotton (Fernandez-Cornejo et al., 2014). Engineering using more sophisticated technology has even been carried out to increase the production of rice, tobacco, sorghum, wheat, corn, soybeans, tomatoes, and potatoes (Jaganathan et al., 2018; Osakabe & Osakabe, 2015; Wada et al., 2020) as well as coffee breeding (Casarin et al., 2022).

In animal husbandry, genetic engineering started in 1985 and experienced rapid development. Genetically engineered livestock products include accelerating salmon growth, pigs that are resistant to respiratory viruses (Van Eenennaam et al., 2021), and sheep with better meat and wool quality (Niu et al., 2017). The application of genetic engineering in the field of medicine for example the treatment of β-thalassemia and Sickle Cell Disease (SCD) (Hu, 2016), pathogen control, applications in clinical diagnostics and treatment of human genetic diseases, whether caused by somatic diseases (e.g., cancer) or genetic mutations (mendelian disorder) (Piergentili et al., 2021). In addition, modern genetic engineering also plays a role in treating infectious viral infections. For example, the Human Immunodeficiency Virus (HIV), Hepatitis B Virus (HBV), Human papillomavirus (HPV) (Lin et al., 2021), and other viruses that are still a global threat with potential causes of pandemics such as Covid-19 resulting from the coronavirus (SARS-CoV-2) that causing severe acute respiratory syndrome (SARS-CoV-2) (Shademan et al., 2022).

Society's views and opinions towards genetic engineering and genetically modified products need to be taken into account. It is because society's perception, knowledge, and acceptance of genetic engineering and its products determine if the commercializing process and its usage can be done (Meerah et al., 2012). Moreover, genetic engineering is often associated with social and ethical issues that cause debate in society.

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Therefore, genetic engineering has to be discussed at different levels in society. Not only among adults but also among schoolchildren. In this context, the role of school education is evident. Students are expected to understand genetic engineering as biotechnology appropriately and know its possible applications and impacts on many aspects, such as moral, social, and economic (Věra & Věra, 2014). Students should have an unbiased attitude toward biotechnology based on an accurate understanding of the issues, given that they will be consumers, producers, and policymakers in the future (Alanazi, 2021). Several countries have included the topic of genetic engineering as a subject matter in their curricula. In Indonesia, the topic of genetic engineering is often used as a prime example of the application of modern biotechnology taught in grade 12 through biology subjects (Indonesian Ministry of Education and Culture, 2018).

Previous studies reveal students' knowledge and attitudes towards genetic engineering only in one particular region or country. Nevertheless, the topic of genetic engineering has become a global issue not only in producing countries but also in importing countries of genetically engineered products. It is because the implications and effects of genetic engineering are global (Bruce & Bruce, 2012). However, no research has been done to summarize students' knowledge and attitudes toward genetic engineering globally (across nations). Therefore, this study attempts to review students' knowledge and attitudes toward genetic engineering more broadly by reviewing previous studies.

Method

This paper reviewed research exploring the knowledge and attitude of secondary school students toward genetic engineering and its applications through a narrative literature review of articles published between 2012 and 2022. The search was limited to peer-reviewed journal articles and was conducted utilizing google scholar as a science database. The terms used were "student genetic engineering", "student GMO", "student genetically modified", "student transgenic", "student gene technology", "student gene modification", "student biotechnology". The term "student biotechnology" was also used as a search term because people often associate genetic engineering with biotechnology (Alanazi, 2021; Meerah et al., 2012; Věra & Věra, 2014). Meanwhile, the words "attitude" and "knowledge" were not used because only a few articles on genetic engineering associated with students could be found. Including of these two words in search terms would further limit the search. After applying criteria of inclusion, exclusion, and thematic belonging, the sample was constituted of 20 studies. A thorough review was carried out to answer the objectives of this study. The research process steps are shown in Figure 1.

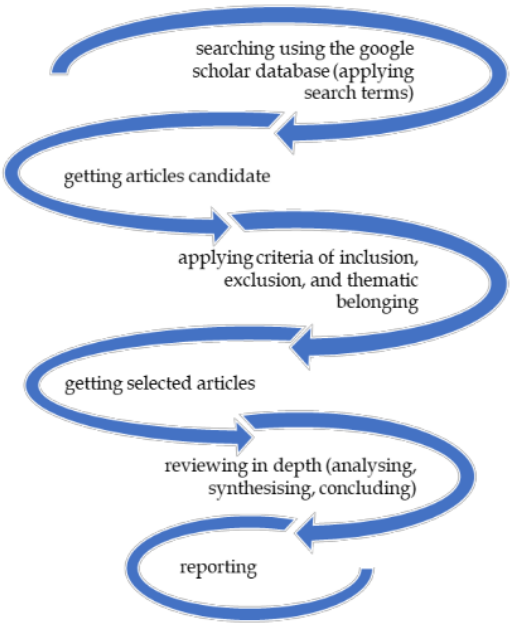

Figure 1. Research process steps

Result and Discussion

Genetic engineering has long been a social issue that continues to be debated. The various benefits that can be obtained from genetic engineering are often limited by the issue of its potential risks and possible negative effects, such as genetically modified organisms are a threat to biodiversity, farmer autonomy, and food safety (Lucht, 2015). Not only the general public but the knowledge and attitude of students towards genetic engineering are also important. Students are the people who will influence the sustainability of this innovation in the future. Several studies have attempted to measure the knowledge and attitudes of students in secondary schools toward genetic engineering and its products. The research comes from various countries in the world.

Student's knowledge of Genetic Engineering

As an example of modern biotechnology, genetic engineering is often included as one of the materials in school. It is done by countries that produce genetic engineering products and those that are not producers. Even in several countries, news about genetic engineering is carried out massively in the mass media.

Several researchers have explored students' knowledge related to engineering genetics. From 2012 to 2022, students from at least 15 countries have their

knowledge measured. Even though the instrument items were not exactly the same, based on the results of the review, the focus of the items asked for was mainly related to the concepts, processes, benefits, and risks of genetic engineering. In addition, most researchers used not only students from one grade of secondary school as respondents. However, in Indonesia, research had yet to be found that explored knowledge or attitudes toward genetic engineering at the school student level. Research has been done only at the university student level (Ma'rifah & Purbosari, 2021; Purbosari & Ma'rifah, 2021). Data regarding students' knowledge related to genetic engineering is presented in Table 1.

Table 1: Students' Knowledge of Genetic Engineering

Year	Authors	Students	Country	Measured Aspects	Results
2012	Meerah et al.	Secondary school students (16 years old)	Malaysia	- Genetic engineering process - Benefits of genetic engineering application - Risks of genetic engineering application	The student's level of knowledge was high (mean=3.279) but limited only to medical issues.
2012	Fonseca et al.	High school students (17–18 years old)	Portugal	- Concept of genetic engineering (as biotechnology) - Process of gene transfer - Applications of genetic engineering - Risks of genetic engineering - Process of genetic engineering	Most students showed adequate knowledge about applications of genetic engineering, such as the disease resistance enhancement of plants and animals. However, there were some cases demonstrating students' knowledge limitations. For example, students believed that transferring genes from plants to animals is impossible. Moreover, students believed that consuming Genetically Modified (GM) foods could induce gene alterations.
2012	Nisztuk et al.	High school students	Poland	Definition of Genetically Modified Organisms (GMOs)	56% of high school students answered correctly. However, from the results of measuring student opinion, researchers infer that the students lacked knowledge about GM foods' benefits and side effects.
2012	Montuori et al.	High school students (17-19 years old)	Italy	The definition and concept of GMO	More than 78% of students knew the definition of GMO and that a GMO is any organism whose genetic inheritance has been modified by people (83.9%).
2013	Goldschmidt & Bogner	Tenth graders (Professionally oriented secondary school)	Germany	Not fully informed, only two examples of questions were presented, namely regarding the position of GM foodstuffs legally in Germany and the mandatory distance between fields with GM plants and fields with conventional plants.	According to the results of the multiple-choice questionnaire, students' objective knowledge was rather low.
2014	Haidar et al.	Secondary school students (Grade 10, 11, 12) (15-18 years)	Lebanon	- GMO and medicine - GM Plants and quality - GM Plants and productivity - DNA transfer - GM animals - Recombinant DNA - GMF definition - Cloning definition	Based on student responses to open and closed questions, researchers concluded that the students' knowledge of genetic engineering was relatively low.

2014	Věra & Věra	Secondary school (range of age 14 to 19 Years)	Czech Republic	Explanation of genetic engineering, giving an example of genetic engineering, and eplanation of the concept of cloning.	Only about 20% of students could describe the concept of genetic engineering, and 47% of students could give at least one example of the application of genetic engineering.
2015	Maes et al.	Secondary school student	Belgium	The concept and topic related to genetic engineering	Students' objective knowledge levels were poor.
2016	van Lieshout & Dawson	Year 10 High School Students	Australia	- Genetically Modified Organisms - Genetically Modified Foods - Application of genetic engineering in health	Some students demonstrated precise prior knowledge of genetic engineering. Nevertheless, this knowledge was cursory in many students, especially in the mastery of definition and ability to differentiate current benefits from hypothetical and future possibilities. Further, a proportion of students demonstrated little knowledge of genetic engineering.
2016	Chen et al.	High school students	Taiwan	Concept of genetic engineering and its examples.	Less than 40 percent of current students were able to answer each item asked regarding the concept of genetic engineering correctly. However, 84% and 74% of current students studying and not studying advanced biotechnology could give examples of genetic engineering.
2016	Maes et al.	Secondary education students (12-18 years old)	Belgium	Instrument about genetic engineering, including the concept, process, also characteristics of product and commercial status of GMOs	21,39% of student had low level of genetic engineering knowledge, 44,52% of student had medium level, only 34,09% had high level of genetic engineering knowledge.
2020	Gerçek	High school students (17-19 years old)	Turkey	Concepts of GMOs	Students obtain incorrect knowledge, confuse related concepts of GMOs, fail to associate their learning of GMOs with daily life, or forget what they learn. Besides that, there was no significant variation in the concepts of GMOs.
2021	Kooffreh, et al.	Secondary school students (16-20 years old)	Nigeria	genetic engineering and genetically modified products.	Generally, students' knowledge of genetic engineering was low. 34.21% of students had limited knowledge of genetic engineering and genetically modified products.
2021	Occelli & Valeiras	High School Students (Year 6)	Argentina	Definition focused on Genetic Engineering: only includes Genetic Engineering processes without considering processes linked to traditional modification, nor it is multidisciplinary character	Only 26% of the students could identify what GMOs are, and 18% said that genetic modification is required for the genetically modified organism development.
2021	Alanazi	Secondary school students (grade 10, 11, 12)	Saudi Arabia	- The advantages of genetic engineering application in plants, animals, microbes, foods, and medicine. - The process of genetic engineering - The risk of genetic engineering	Students had limited knowledge of Genetic engineering. Nevertheless, the survey questionnaire data showed statistically significant differences in knowledge between grade 10, 11, and 12 students. The grade 12 students had the most excellent knowledge than others.

2022	Castro	High school students (grade 9) (13-16 years old)	Philippines	Basic knowledge about GMOs includes the differentiation of GM plants from normal ones and the genes of GMOs	13% of students answered that there is no difference between GM and natural plants. Regarding genetically modified organisms' genes, 87% of the students could not tell the difference between the gene of GMOs and non-GMOs.

Based on the studies conducted, it was known that most secondary school students needed more knowledge of genetic engineering, even in countries that produce GMOs nationally, like Argentina (Occelli & Valeiras, 2021). Data from the United States Department of Agriculture (2016) showed that 100% of soybeans and 95% of corn grown in Argentina were genetically engineered seeds. However, in defining the concept of GMOs, many high school students were still unclear (Occelli & Valeiras, 2021).

It is a big challenge. Knowledge can change the base of people's opinions. Knowledge also has direct and indirect effects on acceptance. Besides that, knowledge also has moderating effects on the effects of antecedents on acceptance (Huijts et al., 2012). That is also in line with the opinion of Wundeerlich and Gatto (2015) that knowledge of GMOs is an area of interest because it may affect people's opinions, attitudes, and behaviors. Thus, knowledge of genetic engineering is an important starting point from various aspects that can appear and be owned by people.

This low knowledge about genetic engineering can be caused by the lack of targeted teaching about biotechnology, especially genetic engineering. It is like what happened in Czech schools (Věra & Věra, 2014) and in Saudi Arabia (Alanazi, 2021). Thus, the results of this study can be used as a basis for policy for the government and real action by teachers to incorporate biotechnology content, especially genetic engineering, into learning by attracting.

Lessons on biotechnology in school, including genetic engineering, must otherwise cater to the heterogeneous nature of students. Introduction to genetic engineering can be done with various media and

Based on the study, it was known that good knowledge regarding genetic engineering was only found in Malaysia (Meerah et al., 2012), Portugal (Fonseca et al., 2012), and Belgium (Maes et al., 2016). In Malaysia, the high level of knowledge related to genetic engineering was due to the fact that the use of genetic engineering applications in Malaysia was currently quite developed. In Portugal, the twelfth-grade biology integrates modern molecular biology and biotechnology (genetic engineering) contents with a predominant focus on their mobilization into factual everyday situations (Fonseca et al., 2012). Likewise, in Belgium, the topic of genetic engineering has been included in the curriculum (Maes et al., 2016).

methods. It must also allocate significant time to deepening scientific literacy in biotechnology, particularly regarding genetic engineering (Anderton & Ronald, 2017). In addition, integrating genetic engineering topics in school curricula can articulate creative concepts and strategies by discussing the social, economic, and environmental consequences of genetic engineering. Teaching programs must enable students to overcome the usually controversial approaches of genetic engineering advantages and risks and explain their decisions based on balanced assessments of its benefits and limitations (Fonseca et al., 2012).

Increasing biotechnology knowledge can increase the students' tolerance toward biotechnological applications (Věra & Věra, 2014). Biotechnology lessons, especially if the learning process can be accepted easily and interesting for students, can significantly increase interest in biotechnology research. It can also improve confidence in accessing and understanding biotechnological research (Haga et al., 2013).

Moreover, genetic engineering is a global issue that is contextual in learning in many countries. The contextualization of science content by exploring socially relevant issues (socio-scientific issues/SSI) is critical in education. It positively impacts student learning and practices related to science content knowledge, argumentation, motivation, interest, and the nature of science (Sadler & Dawson, 2011). Real-life situations are scientific but also influenced by other factors, such as political, social, and ethical issues. When the teacher makes SSI a topic in the learning process, it will challenge students to exercise their scientific literacy and their literacy about genetic engineering (Kumnuanek et al., 2022).

Based on the study results, it was also known that knowledge about genetic engineering was found to be different for male and female students. Věra & Věra (2014) found that females had less knowledge about genetic engineering than males. Females often evaluated the presented examples more negatively than men. However, other results shown by Meerah et al. (2012) that no significant difference between the score of male and female students' knowledge of genetic engineering.

Students' Attitude towards Genetic Engineering

The review results regarding students' attitudes toward genetic engineering are presented in Table 2.

Table 2: Students' Attitudes toward Genetic Engineering

Year	Authors	Students	Country	Measured aspect	Result
2012	Meerah et al.	Secondary school students (16 years old)	Malaysia	- Consumption of GM products - GM in agroindustry - Shopping for GM products - Ethics of genetic modifications - Ecological impact of genetic engineering - Use of genetic engineering in human medicine	Overall, the students showed a neutral attitude towards consuming genetically modified products, shopping for GM products, and the ethic of genetic modifications. Besides that, students showed a positive attitude towards genetic modification in agroindustry and using genetic engineering in human medicine. Nevertheless, as a whole, students showed a negative attitude toward the ecological impact of genetic engineering.
2012	Fonseca et al.	High school students (17–18 years old)	Portugal	- Application of genetic engineering products in waste treatment, gene alteration, treatment of genetic disorders, medicine, pesticide resistant plants, insulin production, organ transplant, human cloning. - Labels of transgenic foods - Transgenic food	Students were optimistic about gene therapy. It could be seen from the mean score. However, they disagreed with animal manipulation applications.
2012	Montuori et al.	High school students (17-19 years old)	Italy	The risk of GMOs and the consumption of GM food	More than 47% of students declared that genetically modified organism production reduces vegetable species and damages the world's nourishment potential. Moreover, 66% of students do not recommend genetically modified food consumption.
2012	Herodotou et al.	Secondary school students (Grade 10, 11, 12)	Cyprus	GMO implications on health, Interest in the topic of GMOs, and GMO implications on the environment	Students had rather non-supportive attitudes toward genetically modified organisms' cultivation and use.
2013	Freire et al.	High School Students (the third year of high school) (16-18 years)	Brazil	Transgenics and GMO	47% of 329 students agreed with transgenics, 24% disagreed, and 29% were neutral. Besides that, 46% of 328 students agreed with genetically modified organisms, 16% disagreed, and 38% were neutral.
2014	Haidar et al.	Secondary school students (Grade 10, 11, 12) (15-18 years)	Lebanon	Genetic engineering in food, medical, and environmental applications (the manipulation of plant genes in order to increase their nutritional values, the modification of genes of algae to produce biodiesel, the use of genetically modified animals to produce drugs, the use of human embryonic cells for therapeutic reasons and the modification of human genes to	Related to genetic engineering application, students showed positive attitudes. However, for the consumption of genetically modified food if they were cheaper, students showed negative attitude.

				treat certain diseases, the consumption of GMF, the consumption of medicine issued from GMO, and the participation in protests against certain biotechnological applications)	
2014	Věra & Věra	Secondary school students	Czech Republic	- Traditional biotechnology (using organisms) versus modern biotechnology (genetic engineering) - genetic engineering in plants and animals (including humans) - genetic modifications of plants that lead to more excellent resistance to pests - genetic modifications of plants that lead to more excellent resistance to an increase in yields - inserting a gene of microorganisms and animals into the genome of plants - inserting genes of plants into the genome of animals	Students showed a more conservative attitude to genetic engineering (modern biotechnological technique) plants than animals, including humans, unless the stress was placed on treating human diseases. Students' attitudes toward genetically modifying microorganisms to enhance their capability in degrading waste were very positive. The better-accepted genetic engineering of plants led to more excellent resistance to pests than increased yields. Genetic engineering of plants leading to more excellent resistance to an increase in yields was better than inserting a gene of microorganisms.
2016	van Lieshout & Dawson	Year 10 High School Students	Australia	- Genetically modified foods - Gene therapy	No evident resistance to genetically modified food was shown by students. In contrast, students showed trust in the production and regulation of genetically modified food. Regarding gene therapy, students showed resistance to it.
2016	Chen et al.	High school students (grade 9, 10, 11, 12)	Taiwan	- Genetic engineering in plants and animals - The risk of genetic engineering	Students studying advanced biology or not showed less favorable opinions toward genetic engineering in agriculture. 76% of current students believed that new medicine or vaccine development from genetic engineering might have risks to human health. However, the students agreed that genetic engineering research for human development was acceptable.
2016	Maes, et al.	Secondary education students (12 -18 year)	Belgium	Five questions, including questions about the use of genetic engineering products "I believe that the use of: - GM crops are positive - GM crops are wrong - GM food should be encouraged - Genetic modification in food production should not be avoided - GM crops are unnecessary"	Attitudes scores of students ranged from neutral to rather positive, while students showed a rather positive intention towards genetically modified foods consumption.
2018	Paš et al.,	Upper-secondary education	Slovenia	- Consumption of GM food - Use of modern genetic engineering methods in human medicine	The most negative attitudes were showed by students of technical schools. The highest score in positive attitudes toward genetic engineering was found among students of

		programs (17-18 years)		- Use of modern genetic engineering methods in agriculture - Ethics, fears and general doubts about Genetic engineering	biotechnical gymnasia, followed by students of general gymnasia.
2019	Nordqvist & Johansson	Secondary school students (grade 10-12) (15 and 18 years old)	Sweden	To investigate the dimensions of students' attitudes towards genetic engineering, measurement models of affective, behavioral, and cognitive attitudes toward biotechnology were used, including genetic engineering in plants, animals, food, and medicine.	The older students were more generally more experienced in the subject genetic engineering. The educational programs differed regarding student background and the fact that boys had a more positive attitude than girls.
2021	Alanazi	Secondary school students (grade 10, 11, 12)	Saudi Arabia	- The process of genetic engineering - The ethics of genetic engineering - Willingness to use genetic engineering products - Willingness to purchase genetically engineered products - Agreeing on the use of genetic engineering products - Curiosity towards genetic engineering products - Support for the use of genetic engineering products	Overall, the attitude of students toward genetic engineering was negative. However, grade 10 students showed the most positive attitudes among the three grades (10, 11, 12).

Most studies revealed that most students showed a negative attitude toward genetic engineering and its products. Even when compared to conventional biotechnology, which utilizes the help of microorganisms to make a product, students better accept traditional biotechnology (Věra & Věra, 2014).

Many factors can influence this negative attitude, but what often becomes a concern is the knowledge factor. A lack of knowledge about genetic engineering and its products can lead to a negative attitude toward it. As shown in a study by Fernbach et al. (2019) that the less objective knowledge about science and genetics people had, the more negative attitudes people had toward genetic engineering and its product, like genetically modified foods.

However, if we looked at the specific aspects more deeply, there were several studies that revealed different things. Students' positive attitudes regarding genetic engineering were found in Malaysia, particularly regarding the agroindustry and the use of genetic engineering in human medicine. It was because the use of genetic engineering applications in Malaysia was currently quite developed. Even so, students in Malaysia also showed a negative attitude toward other aspects, namely the ecological impact of genetic engineering (Meerah et al., 2012).

In Lebanon, students' attitudes toward genetic engineering were positive. This may be related to genetic engineering material in the curriculum there. Since 1998, modern biotechnology teaching has been introduced in the biology curriculum in Lebanon. In the secondary classes, the introduced concepts concern the techniques of genetic engineering, such as transgenesis, genetic screening, cloning, producing high-performance plants, and producing hormones and antibodies (Haidar et al., 2014). Nevertheless, if we looked at the findings of Haidar et al. (2014), students also had an opposite attitude regarding genetic engineering. For the consumption of GMF, if they were cheaper than non-GMO foods, students showed negative views at this level.

In Australia, students represented trust in the production and regulation of genetically modified food. It could be because the wide range of genetically modified foods was allowed to be grown and imported into Western Australia. However, in terms of germline gene therapy, students resisted it. In contrast, somatic gene therapy found much approval for its values to human health, similar to findings elsewhere (Anderton & Ronald, 2017).

The findings above show that students may show multiple attitudes towards genetic engineering,

depending on which aspects they focus on. This is also the case in Portugal. Students supported gene therapy. But they disapproved of applications mentioning animal manipulation (Fonseca et al., 2012).

Besides being related to the curriculum, correct and scientifically solid information delivered through the newspaper, internet, and other multimedia exposures should be of great concern. That is important to re-educate the students and society with correct attitudes towards genetic engineering and other biotechnology applications. It is because the relationship between knowledge and attitudes toward genetic engineering or other biotechnology applications is complex. Developments in genetic engineering and other biotechnology applications received coverage not only in textbooks but also in the newspaper, social media, the internet, and films with varying degrees of reliability (Chen et al., 2016). Not only for students but for adults, the media also has a significant role as a provider of information about the products of genetic engineering. As in Turkey, 74.3% of nursing students received genetic engineering product information from television or radio (Turker et al., 2013), while 77.3% of Latvian consumers received genetic engineering product information from the Internet (Aleksejeva, 2014).

Based on the study results, it was also known that attitudes toward genetic engineering were found to be different in male and female students. Males showed a more positive attitude toward genetic engineering applications than female students (Meerah et al., 2012; Nordqvist & Johansson, 2020). Science subjects that were taken also influenced students' attitudes toward genetic engineering. There was a significant difference between students studying Biology and General Science in attitude toward genetic engineering (Fonseca et al., 2012; Meerah et al., 2012).

Nevertheless, attitudes are not rigid psychological constructs unreceptive to change. Some treatments, such as educational interventions and engaging students with specific tasks, can shift some of these more complex affective constructs in real time (Volet and Vauras 2013). Some studies have even found that people's attitudes toward biotechnology applications change over time. The research by Henneman et al. (2013) revealed that in 8 years, attitudes regarding the benefits and potential use of genetic testing had been raised among the public in the Netherlands.

Conclusion

The results showed that most secondary school students lack knowledge about genetic engineering, even in countries that produce genetically modified organisms through genetic engineering nationally. Most studies also revealed that most students expressed a negative attitude toward genetic engineering and its products. Besides that, students with a positive attitude toward genetic engineering often showed multiple attitudes, depending on which aspects they focus on.

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