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Current knowledge and attitudes of students towards biotechnology: A long way to go

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Current knowledge and attitudes of students towards biotechnology: A long way to go

Ikasleek bioteknologiari buruz dituzten egungo ezagutzak eta jarrerak: Bide luzea aurretik

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Abstract

Thanks to technological innovations, science is rapidly evolving, and therefore, development of effective and engaging learning strategies is needed to ensure knowledge transmission. But first, we need to know what the current situation is. In this work, we focused on biotechnology, a scientific branch that is present in many of aspects of our daily life, but also a source of controversy. We developed a questionnaire to investigate the knowledge of 124 Baccalaureate students about biotechnology and its uses, as well as their awareness about the transgenic food as a socioscientific issue, and their attitudes towards applications of transgenics. Most students cannot give an appropriate definition of biotechnology. Besides, students have misconceptions about transgenics, and easily change their attitudes. Thus, new strategies to get students interest and improve knowledge transfer should be implemented.

Key words: Biotechnology; Transgenics; Socioscientific issues; Misconceptions; Attitudes

Laburpena

Zientzia oso azkar garatzen ari da aurrerapen teknologikoei esker eta, beraz, hezkuntza estrategia apropos eta eraginkorrak garatu behar ditugu ezagutza transmisioa bermatzeko. Lehenengo pausoa, egungo egoera ezagutzea da. Lan honetan bioteknologian jarri dugu arreta. Bioteknologia gure egunerokoan guztiz txertatuta dagoen zientziaren adarra da, baina kontrobertsia ugari ere sortzen ditu. Galdetegi bat garatu eta batxilergoko 124 ikasleren bioteknologia eta honen erabileren ezagutzak aztertu ditugu, baita elikagai transgenikoen eztabaida soziozientifikoaren inguruan dauzkaten jarrerak. Gehienek ez dute bioteknologiaren definizio aproposa ezagutzen. Gainera, transgenikoen inguruko ezagutza okerrak dauzkate eta ez daukate jarrera finkorik. Beraz, gaia landu eta ezagutza arazoen jatorriak identifikatu behar dira, hezkuntza estrategiak garatu ezagutza zientifikoa laguntzeko.

Hitz gakoak: Bioteknologia; Transgenikoak; Eztabaida soziozientifikoak; Ezagutza okerrak; Jarrerak

1. Introduction

Biotechnology has been used for centuries and it has developed rapidly in the last decades thanks to the exhaustive characterization of living organisms and to technological innovations (Barcelos et al., 2018). It can be defined as the branch of science that by means of research and innovation uses/applies organisms or biological systems for human benefit (Young, 1986). Thus, biotechnology was used to bake bread thousands of years ago, like it is applied nowadays in cutting-edge laboratories to produce drugs (Fraczek et al., 2018).

However, information related to biotechnology is not always correctly transferred to society (Edmondston et al., 2010; McHughen, 2007), and socioscientific controversies emerge. In fact, controversies influence the opinions and attitudes of young people (Díaz-Moreno and Jiménez-Liso, 2012). Therefore, the aim of this work is to gather and analyse the knowledge and attitudes of young students about biotechnology to describe the current situation, identifying misconceptions and knowledge gaps. This identification is essential to adapt or develop new educational approaches.

2. Theoretical framework

2.1. Socioscientific issues, controversies, and biotechnology

Socioscientific issues and controversies are social dilemmas with a conceptual link to sciences or technology (Sadler, 2004). Indeed, science and society have a tight connection: once a scientific development or innovation is accomplished, the scientific community transmits the new knowledge to society, opinions start to emerge, and various social actors take diverse positions about its implementation. In this way, a controversy about the application of the new scientific development can arise, which evaluates science from an ethical, moral, or political perspective (Díaz-Moreno and Jiménez-Liso, 2012).

One of the most widely known applications of biotechnology is the production of transgenics or genetically modified organisms, and it is also the one of the most controversial applications (Frewer et al., 2013). Even if there are many applications of transgenics, when discussed in our society, it is usually referred to transgenic food. Transgenic food, indeed, is a well-known socioscientific issue (Tidemand and Nielsen, 2017). It should be noted that the World Health Organization (WHO) indicates that all transgenic food approved for commercialization are safe, and no effects on human health have been linked to the consumption of such foods in the countries where they have been approved. However, the production and consumption of transgenic food – by humans and animals – has been extended only in the last decades, and monitoring is still required for the evaluation of long-term effects.

In contrast, there are other applications of biotechnology and transgenics that are not controversial, like bioremediation. Bioremediation consists in the application of living organisms, or enzymes isolated from them, to reduce pollutants in contaminated media. This biotechnological application can be carried out with native strains, but a faster and more effective remediation is achieved with transgenic microorganisms (Sharma et al., 2018).

Other application of biotechnology, which is highly relevant, but that can also be controversial, is biomedicine. Most drugs are produced with biotechnological methods, using molecules or components present in other living organisms, including microorganisms, plants, or even other animals. Moreover, there are drugs produced with transgenic organisms, such as insulin. The use of transgenic bacteria and yeast that produce human insulin has been proven to be efficient and safe (Baeshen et al., 2014). Therefore, millions of people make use of a drug that is produced with transgenic organisms, but this application is not controversial in our society (McHughen, 2007).

In contrast, vaccines are commonly debated. Vaccines represent a socioscientific issue, even if their safety has been demonstrated, they confer long-lasting immunological memory and induce population-level herd immunity (Maguregi González et al., 2017; Sheerin et al., 2017). As emphasized by the WHO in the blueprint published in 2019 – before the emergence of the COVID-19 pandemic and the consequent profound debates –, we need to continue working on vaccines and vaccination at a global level: on one side, to enable vaccination in low-income regions and, on the other side, to improve risk communication in high-income countries, which are facing a rise of vaccine hesitancy (World Health Organization, 2019).

Regarding the biomedical application of research on diseases, discussions are scarce. When compared to transgenic food, the utilization of transgenic organisms for research is not very controversial, even if transgenic animals are routinely used (Cheon and Orsulic, 2011). This difference could be due to the lack of information about this application on the mass media and other social networks, while transgenic food is constantly mentioned.

2.2. Teaching biotechnology: current knowledge, misconceptions, and attitudes

As shown above, biotechnology is a broad science, and it is present in many aspects of our daily life. Therefore, teaching biotechnology is essential to achieve scientific literacy, to develop their informed opinions and to take consequent attitudes.

The inclusion of biotechnology in educational curricula is relatively new, and it is commonly underrepresented (Borgerding et al., 2013). In the region of the Basque Country, where this work has been carried out, the Secondary Education and Baccalaureate curricula are collected in individual decrees (Eusko Jaurlaritza, 2015; Eusko Jaurlaritza, 2016). Here, the concept of biotechnology and some of its applications are mentioned at the third and fourth year of Secondary Education (14-16-year-old students). For the Baccalaureate (16-18 years), it indicates that students must get a closer view. However, at this stage biological subjects are optional. The decree underlines the importance of teaching about genetic engineering, the applications of microorganisms, bioremediation, the food and pharmaceutical industry, stem cells and biomedicine. The moral dilemmas and socioscientific issues that arise from these applications are also mentioned. Therefore, the teaching of the main concepts of biotechnology and its applications to young students are regulated.

Nevertheless, even if educational curricula are extensive and ambitious, frequently not all topics can be explained thoroughly. Besides, it should also be noted that the level of knowledge of teachers has a deep influence on knowledge transmission to student. In this sense, it has been shown that there are knowledge gaps and misconceptions about biotechnology among Elementary and Secondary Education preservice teachers (Casanoves et al., 2015; Moreno, 2017; Usak et al., 2009).

Regarding Secondary Education students, several works point to their limited knowledge of biotechnology. A study conducted in Lebanon indicated that most students, despite expressing a high interest in studying biotechnology, had misconceptions and difficulties in learning basic genetic concepts, such as DNA structure, patterns of inheritance and DNA technologies (Osman et al., 2017). A work from Brazil showed that students were familiar with the "transgenic" term, but they did not master neither its definition nor its applications. Besides, students received information about transgenics not only from teachers or reliable primary or secondary sources, but also from mass media and other networks, and these had an influence on their opinions (Pedrancini et al., 2008). Correspondingly, an investigation performed in Argentina reported that most students did not understand the "biotechnology" concept and apart from school, they received information from the internet and television. Despite this, most students had positive attitudes towards the biotechnological applications (Occelli et al., 2011). Remarkably, a work from Sweden investigating the attitudes towards genetically modified plants found that students' attitudes were more positive after working on this controversial issue in class (Ekborg, 2008). Similarly, a study conducted in Australia reported an overall positive attitude of students towards biotechnology processes, which were more positive among students that recently completed a 10-week genetics and biotechnology course (Dawson and Schibeci, 2003).

Furthermore, de la Vega-Naranjo, Lorca-Marín and de las Heras-Pérez (2018) recently evaluated the knowledge and attitudes towards biotechnology of Secondary Education students in Spain. Traditional applications of biotechnology and applications related to environmental processes were only identified by half of the students. Moreover, they had misconceptions: 30% indicated natural tomatoes do not have genes and genetically modified ones do (or that they to not the answer to this question), and 53% was not aware they were ingesting DNA and genes when eating meat. These data demonstrate that students do not master the basic knowledge about cells and genetic information and, therefore, they cannot develop justified opinions towards controversial issues. Indeed, when asked about attitudes, 16% of students were against the use of yeast to produce wine and beer, while 30% indicated that they would like to choose the eye colour of their future children.

2.3. Socioscientific issues and science education

Based on the presented data, there is a need to address biotechnology education. Teaching science through lesson plans based on socioscientific issues is an interesting approach, as it has been documented to have positive effects on students' motivation and interest, and to contribute to the development of scientific literacy (Zeidler et al., 2019). Socioscientific issues-based lesson plans have been used to teach many topics, including biotechnology and transgenics. For instance, Domènech-Casal (2017) developed two activities to work on genetic determinism and transgenics and found that they promoted knowledge and scientific thinking skills. Likewise, non-epistemic aspects that are part of the construction of scientific knowledge can be highlighted, addressing the social nature of science (Acevedo-Díaz and García-Carmona, 2017; Díaz-Moreno and Jiménez-Liso, 2012). However, the complexity of socioscientific issues related to biotechnology and transgenics should be mentioned, as students can face limitations to interpret scientific and non-scientific information (Solli, 2021).

3. Purpose

As explained above, biotechnology is a rapidly evolving science with many applications. Based on the currently applied educational curricula, the theoretical basis of biotechnology and several of its uses are taught to young students. However, research works indicate that scientific literacy on this topic is not achieved in most of the cases. Thus, we should continue working on educational strategies to improve knowledge transmission about biotechnology. In order to develop appropriated strategies and focus on knowledge gaps, it is necessary to evaluate the current situation and the needs of our students. In this sense, the present work investigates the knowledge, awareness, and attitudes of Baccalaureate students from the Basque Country. Being the first study conducted in our region, we aim to describe the current state, identifying misconceptions and knowledge gaps, which is the first essential step to address biotechnology education and develop effective teaching strategies for the near future.

4. Methods

The present study was conducted with first year of Baccalaureate students, (16-18 years old) from the Basque Country (Spain). The study was presented to school directors and teachers at six high schools. Academic permission for completing the study was obtained from all high schools. At the time when this work was carried out, students were following lectures online due to the COVID-19 outbreak, so an online questionnaire was prepared. The invitation to participate was sent to all students studying the biological science subject and participation was voluntary. No personal data was recorded and only age and region were asked to obtain a general description of the sample.

The questionnaire employed for the study was designed to capture the knowledge about and attitudes towards biotechnology of students. It was based on previously published works (de la Vega-Naranjo et al., 2018; Occelli et al., 2011; Pedrancini et al., 2008) and adapted to meet the objectives of the present study. Questions were prepared, discussed, and agreed by all researchers. Prior to data obtaining, a group of 21 students of the second years of Baccalaureate that had already discussed about biotechnology in class were asked to complete the questionnaire. These students affirmed that questions were straightforward and easy to follow and, based on their comments, a couple of details of the questions were modified. Data collection was conducted under the supervision of one of the researchers (AA) and the responsible teacher at each high school. Internet connection and searching for information was not permitted, to obtain the current knowledge and sincere opinions of students. There was no time limit to complete the questionnaire. It consisted of 6 questions, they were ordered, each question was presented in a different screen, and it was not possible to go back to previous questions. This organization allowed us to introduce further information in following questions while ensuring no modifications in the previous ones.

Q1: Defining biotechnology. The following five concepts were presented: i) Branch of science, ii) Innovation, iii) Living Organisms, iv) Human benefit and v) Research. Students were asked to select the concepts needed and then, write their definition of biotechnology in a free-text field.

Q2: Use of biotechnology throughout history. Students had to answer when biotechnology was used: i) Ancient History, ii) Middle Ages, iii) Modern History, iv) Contemporary History and v) All of the above. Only one answer could be selected, and the justification of the selected option was required in a free-text field.

Q3 and Q4: Applications of biotechnology. These questions were based on the works published by de la Vega-Naranjo et al. (2018) and Occelli et al. (2011). In Q3 students had to think and write the applications they remember (free-text field). Then, in Q4, a list of applications was presented, and participants selected the ones related to biotechnology.

Q5: Transgenics – a socioscientific issue. This question was based on the work published by Pedrancini et al. (2008). The definition of transgenics and the socioscientific issue about transgenic food were presented. Students had to list the positive and negative arguments they had heard about this controversial application. Then, they had to state which was their attitude toward transgenic food (in favour, in doubt or against). Both were free-text fields.

Q6: Specific applications of transgenics. An application was presented, and they had to take a position (in favour, in doubt or against). Q6 was composed of three questions. In a) the use of transgenic food was debated with the example of transgenic potatoes under water stress conditions (Hameed et al., 2018). Then, transgenics related to health are debated with two applications: b) transgenic animals for cancer research (Cheon and Orsulic, 2011) and c) transgenic insulin of diabetic patients (Baeshen et al., 2014).

Data were analysed depending on the characteristics of each question. A quantitative analysis of multiple-choice questions – both the single answer and multiple answer tasks – was performed, and results are presented as percentage of answers per given option. In the case of the hierarchical map about the definition of biotechnology and the attitude changes about transgenic food, results are presented with the number of students, for a straightforward interpretation.

Regarding the free-text answer of Q1 (definition of biotechnology), a phenomenographic analysis was conducted by three researchers, with the objective of gaining insight into the whole spectrum of conceptions students presented (Marton 1986; Marton 2014). In this study, the range of conceptions of the term biotechnology given by students is enclosed into a hierarchic series of descriptive categories, following the criteria of Marton and Booth (1997). Such categories were constructed based on students' responses, and the system of categories intends to reflect an increasing level of understanding and experiencing about what biotechnology is. The first step was familiarization, analysing all answers individually. Independently, researchers performed an initial analysis on the totality of definitions and drafted a list of outstanding conceptions. By contrasting analyses, a system of categories was proposed, discussed, and established by the three researchers, reaching a consensus on the final hierarchic system of categories. Next, two researchers analysed independently all the data, evaluated again students' definitions of biotechnology using the system of categories verifying that defined categories were sufficiently descriptive and covered the full range of evidenced views (Marton and Booth, 1997), and categorized the answers. The third researcher reanalysed the data and proposed a category for the answers distinctly classified. Lastly, the three researchers together commented these cases and agreed on the final categorization. Thus, the refined final system of categories and classification of students' answers were obtained after an iterative process of comparison, discussion, and re-definition to consensus.

For Q2 (use of biotechnology throughout history) justifications given by students choosing the correct answer in the multiple-choice question were analysed and grouped. For this analysis one of the researchers carefully read all responses and proposed a categorization based on the similarity of the used terms and the sense of the justification. The categorization was discussed and agreed with the other two researchers. This enabled the identification of random and informed answers, as well as the level of knowledge. Following the same strategy, for Q3 (applications of biotechnology) and Q5 (positive and negative arguments about transgenic food), the open answers given by students were analysed and similar and related terms grouped for a visual representation. In these two questions, multiple examples could be mentioned by each student. Again, one of the researchers carefully analysed the data and proposed groups that resume all given answers, and these were then discussed and agreed with the other two researchers. For Q3, the applications of biotechnology were grouped based on the major field (food, biomedicine, and industry), while misconceptions were placed in another group and the "I do not know" answers were also counted. For Q5, the given arguments were grouped based on the general reason stated, such as health or productivity, among others.

Finally, a correlation and correspondence analysis was performed between Q1 and Q6. For the correlation analysis, Q1 categorization was converted to a numerical scale as follows: A1=4, A2=3, B=2, C=1 and D=0. Similarly, Q6 was converted to a numerical scale by giving 2 points for each "in favour" answer, 1 point for "in doubt" answer and 0 points for "against" answer, and the answers of Q6 a), b) and c) were added. The correlation between the two questions was plotted and Spearman's rank correlation coefficient and p-value were calculated. Then, a correspondence analysis was performed to evaluate the percentage of students of each Q1 group that had a positive attitude for the three applications of transgenics proposed.

Moreover, aiming to solve students' potential doubts and questions about biotechnology that could originate when completing the questionnaire, an online presentation was prepared. The presentation included figures, explanations, and links to further information (news, videos, reports, bulletins, and scientific papers). All the topics of the questionnaire were described. The presentation was provided after completing the questionnaire and, besides, the contact of one of the researchers was included to answer additional questions that students could have. The presentation is in Basque (the language in which the participating students learn Biology), and the links with additional information are in Basque, Spanish and English. It is available at:

https://drive.google.com/file/d/1fI_Cxmbo_fqFJEW3aFx5wpOVI1RAJW3H/view?usp=sharing

5. Results

The questionnaire was completed by 124 students of the first year of Baccalaureate. All participants were studying the biological science subject and the mean age was 16.4 (range 16-18 years). Students from the three provinces of the Basque Country were enrolled (50% Gipuzkoa, 37.1% Bizkaia and 12.9% Araba).

5.1. Definition of Biotechnology

The first objective was to evaluate the knowledge of students about the definition of biotechnology and, thus, the different ways they have to understand it. To this end, we presented 5 concepts and asked them to select the ones related to biotechnology. The obtained results were: i) Branch of science (77%), ii) Innovation (53%), iii) Living Organisms (48%), iv) Human benefit (47%) and v) Research (59%). These results show that a relevant proportion of students does not relate biotechnology to broad ideas such as innovation and research. Moreover, more than half of the students fail to identify more specific concepts, like living organisms and human benefit.

For a deeper analysis of the results, we organized the concepts and constructed a hierarchical map that depicts the paths taken by participants (Figure 1).

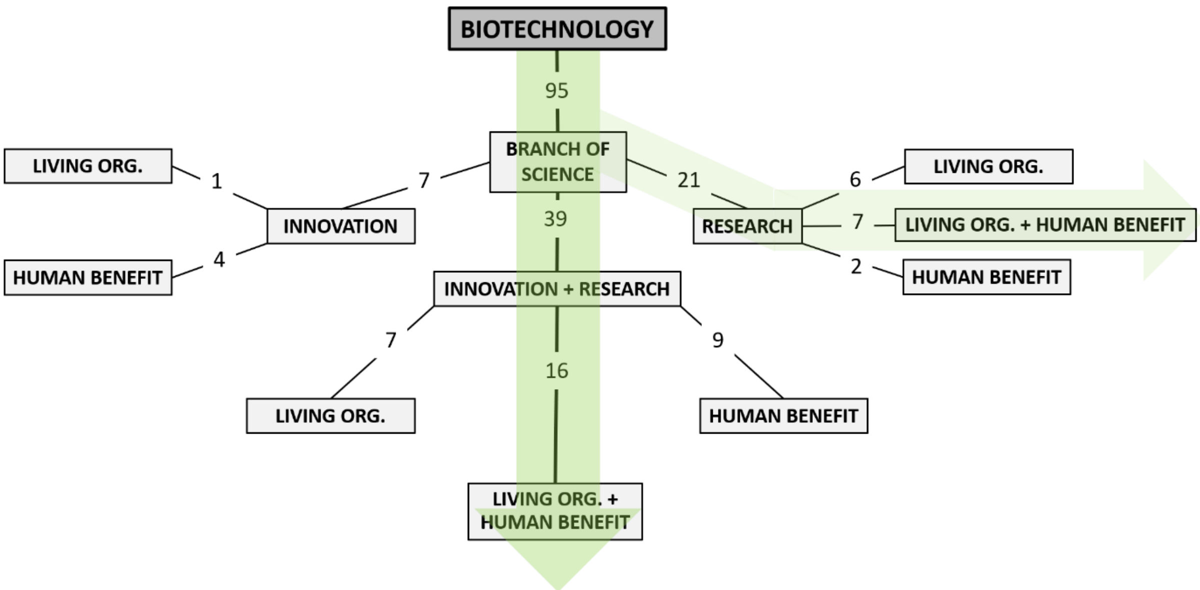

Figure 1. Hierarchical map of the definition of biotechnology based on the concepts presented to students. The numbers presented in the connectors indicate the students that followed that path.

The broadest idea about biotechnology is that it is a branch of science, it is conducted by means of research and innovation, and specifically, it works with living organisms for human benefit. As shown in the figure, only 16 students completed the whole path, and there are 7 students more that, even if they did not identify all the concepts, only missed innovation. Based on the selection of the given concepts we can conclude that 23 students (19%) had an informed view on biotechnology.

Then, definitions written by all participants in the free-text field were evaluated. After the first categorization, the accordance between the two researchers was K=0.74 (Cohen's Kappa reliability coefficient average). After the reanalysis by the third researcher and the discussion of discrepancies, the categorization of all responses was agreed. The phenomenographic analysis conducted shows there are 5 categories that gather the knowledge of students about biotechnology (Table 1).

Table 1. Results of the phenomenographic analysis of students' answers. Identified categories and percentages of students grouped in each category are shown.

Category	Description	Percentage
A1	Utilitarian (production): Technological **use** of, or **research** on, living organisms/biological processes by humans **to produce** products/processes	6%
A2	Utilitarian: Technological **use** of, or **research** on, living organisms/biological processes by humans for **innovation, welfare,** or **health**	37%
B	Epistemic: **Knowledge/Research** about living organisms/biological processes, or the technology to acquire the knowledge	11%
C	Tautology	14%
D	Nonsense / Incoherent / Misconceptions	32%

Remarkably, one third of students (32%) gave incoherent definitions or included misconceptions (D category), such as "From my point of view biotechnology is progress for humans" and "Materials and bioelements". Besides, 14% of the participants wrote tautological phrases based on the given concepts, adding no further meaning (C category). These included definitions like "Biotechnology is the science that mixes biology and technology" and "It is the technology that is related to living organisms". There was also a group of students (11%) with an epistemic view (B category), with definitions such as "Biotechnology is the branch of science that investigates living organisms applying innovation". On the other hand, 43% of the participants demonstrated a good knowledge and gave a utilitarian definition of biotechnology (A2 category)– and even some of them mentioned the final goal of production (A1 category). Representative examples of these definitions include: “Biotechnology is the use of organisms to get products or services that are good for humans” and “In biotechnology organisms are manipulated to change them and to create new products for our benefit”. The mentioned categories, their descriptions and the frequencies among students are presented in Table 1.

5.2. Use of biotechnology throughout history

Our second objective was to investigate whether students know in which historical period humans have used biotechnology. The results obtained for the multiple-choice single answer question were: i) Ancient History (1%), ii) Middle Ages (2%), iii) Modern History (12%), iv) Contemporary History (49%) and v) All of the above (36%).

However, when analysing the justifications given, it became evident that students choosing Ancient History (1 student) and Middle Ages (3 students), as well as some of those choosing Modern History (6 out of the 15 students selecting this answer), did not correctly understand the presented question, and answered to “for how long biotechnology has been used”. Justifications like “fermentation has been used for a long time” and “biotechnology was not possible in Ancient History and Middle Ages, it is used since Modern History” are representative examples of the misunderstanding. These answers are not correct but show that they are aware that biotechnology has been used for centuries. In the case of the justifications by students that selected Contemporary History, many mentioned that biotechnology needs advanced technologies. An exhaustive analysis of the justifications for the correct answers (All of the above) was carried out. We found 5 distinct categories or groups of answers, which are presented and described in Table 2.

Table 2. Categorization of the justifications given by students to explain the history of biotechnology.

Category	Description	Percentage
4	Humans have always, in a different way in each period, carried out research and innovation for their own benefit (medicine, food, plants, animals)	31%
3	Humans have always carried out research and innovation for their own benefit	13%
2	Humans have always needed/carried out research and innovation	22%
1	It has always been there	18%
0	Incoherent / Answers not related to Biotechnology	16%

5.3. Applications of Biotechnology

Next, we evaluated students' knowledge about the applications of biotechnology, with two different approaches. First, they were asked to list the applications they remembered. 17% of the participants did not mention any application of biotechnology and wrote sentences like "I don't know" or "I cannot say any" in the form. When analyzing the responses given by the rest of the students, it becomes clear that the applications they mention are related mainly to food (51%) and biomedicine (36%). Only a couple of answers included industrial applications (2%). Notably, 14% of the students listed medical and chemical applications that do not use biotechnology (misconceptions). The representation shown in Figure 2 summarizes the obtained results and the examples mentioned by students.

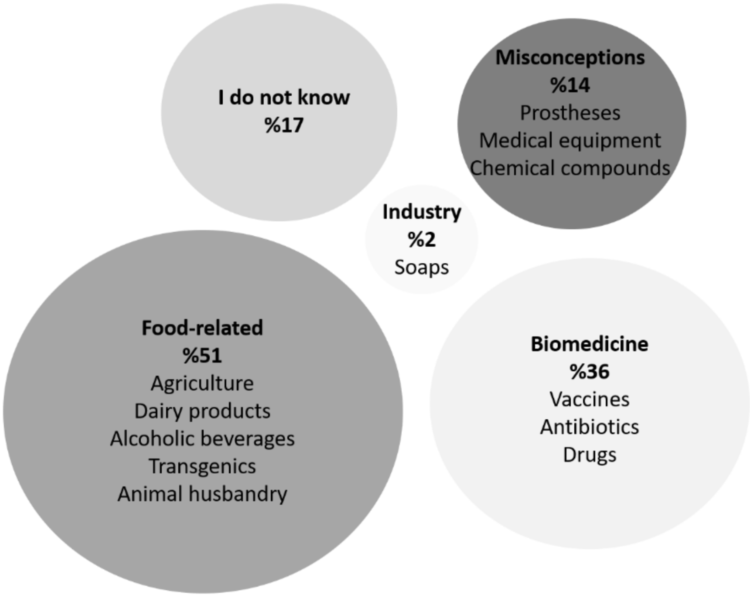

Figure 2. The applications related to biotechnology listed by students in a free-text field. Applications are grouped in mayor fields, and misconceptions and no answers are shown in different circles.

In the second approach, we listed products and applications and asked the students to select the ones in which biotechnology is used for their production. All the items in the list make use of biotechnology nowadays, but only 8% of students selected all of them. The most widely known applications of biotechnology are drugs (90%), transgenic food (89%) and vaccines (86%). In contrast, the less identified applications were the production of clothes (26%) and paper (25%). Besides, it is worth mentioning that traditional and well-known applications such as wine, beer and bread are selected by less than half of the participants. All the items and the proportion of students that selected them are presented in Figure 3.

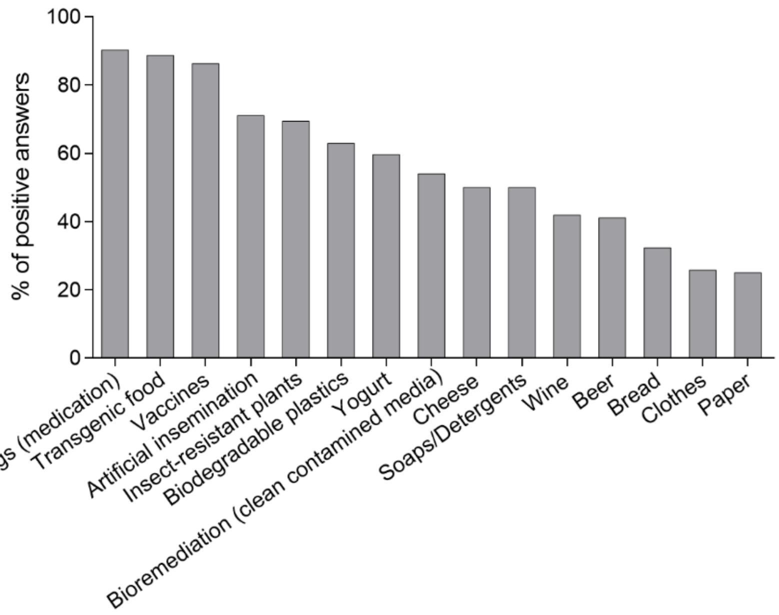

Figure 3. Items presented in the list of products and processes for which production biotechnology is used nowadays. Applications are ordered from left to right based on the % of positive answers by students.

5.4. Transgenics – a socioscientific issue

Some applications of biotechnology, and specially transgenics, are controversial in our society. We asked students whether they were aware of this controversy, and if so, which were the positive and negative arguments they had heard. 19% of the participants stated that they are not aware of the controversy or have not heard any argument. In consequence, we see that most of the students, as part of society, get information about socioscientific issues. The analysis of the arguments listed by all students in the questionnaire resulted in a total of 111 arguments in favour and 134 arguments against transgenic food. The arguments are diverse, but most of them are mentioned several times. We grouped the arguments presented by students by similarity. Among the positive arguments 5 mayor groups were identified, while 7 groups resumed the negative arguments. All these and their frequencies are presented in Figure 4. The most mentioned positive argument is the higher yield of transgenic food, while the most repeated one among the negative arguments is that their consumption is not healthy. Besides, the positive arguments included statements such as “they are more resistant”, “transgenics are healthier and cheaper”, “the production of transgenic can reduce global hunger” and “they are more beautiful”. In contrast, arguments against this application of biotechnology were represented by statements such as “they are not natural”, “we still do not know whether they are healthy”, “they reduce biodiversity” and “transgenics have more chemicals and can induce diseases.

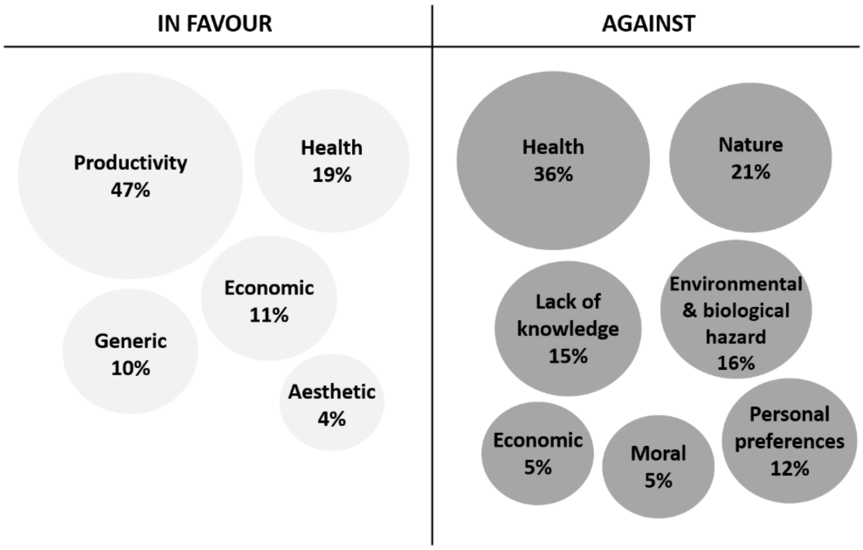

Figure 4. Schematic representation of the arguments heard by students about transgenic food. Positive and negative arguments were grouped and are the frequencies of each of them are shown.

Afterwards, students were asked about their personal attitudes towards transgenic food. The analysis of the given answers indicates that attitudes are divided, with 40% (49 students) in favour, 29% (36 students) in doubt and 31% (39 students) against. Then, a specific application of transgenics for food production was presented to students: growing transgenic potatoes under water stress conditions. Their attitudes towards this application were recorded and compared to previous positions. As shown in Figure 5, when transgenic foods are presented in a specific context, most of the students that were in doubt or against transgenic food change their attitude and indicate they are in favour of the presented case.

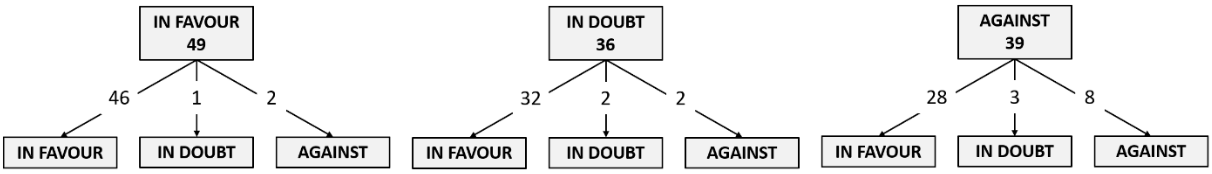

Figure 5. Students attitude towards transgenic food. The upper row presents the positions taken by students when asked about the use of transgenic food. The lower row shows the changes in attitudes when their position towards a specific application (transgenic potatoes under water stress conditions) was discussed.

5.5. Applications of transgenics

Next, we analysed the attitudes of students towards the previously mentioned application of transgenic potatoes, as well as other two other examples of controversial applications of transgenics: i) the use of transgenic animals for cancer research and ii) the use of transgenic insulin for the treatment of diabetic patients. As shown in Table 3, most students (85-92%) have a positive attitude towards the use of transgenics in these cases. When justifying their positioning, the most mentioned argument is achieving benefits for humans, and they indicate that the use of transgenics for improving health and quality of life is appropriated.

Table 3. Students' attitudes towards specific applications of transgenics. Three examples were presented, the attitudes of students recorded, and the obtained percentages are shown.

Controversial Issue	Position	Percentage
Transgenic potatoes under water stress conditions	In favour	85%
	In doubt	5%
	Against	10%
Transgenic animals for cancer research	In favour	92%
	In doubt	3%
	Against	5%
Transgenic insulin for diabetic patients	In favour	91%
	In doubt	2%
	Against	7%

Lastly, to evaluate the correlation and correspondence between the definitions of biotechnology and the attitudes of students towards the applications of transgenics, we compared the results obtained in the first question and in the presented examples of transgenic applications. As shown in Figure 6A there is a significant positive correlation between the knowledge about the definition of biotechnology and the positive attitudes towards the applications of transgenics. Next, for each of the identified categories based on the definition of biotechnology in Q1, the percentage of students with positive attitudes for the three given applications was calculated. Interestingly this correspondence analysis showed that all students from category A1 were in favour of the use of transgenics, while only the 55% of students from category D had the same positive attitude (Figure 6B).

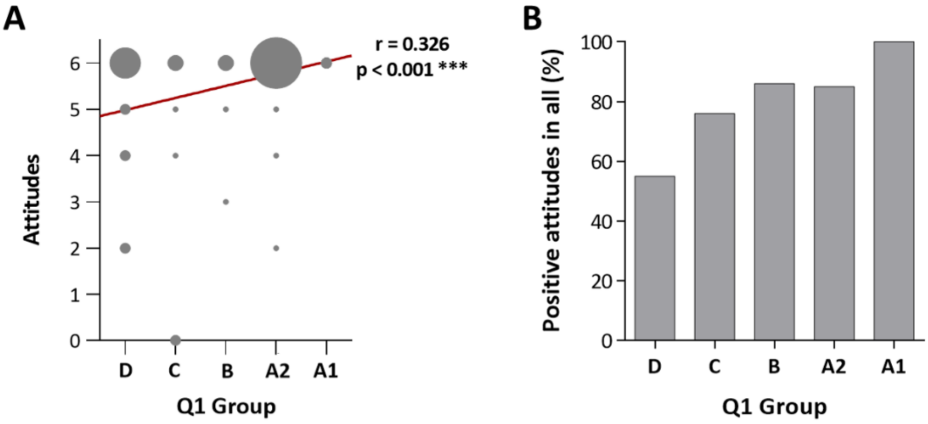

Figure 6. Correlation and correspondence between biotechnology definition and attitudes towards transgenics. (A) A positive correlation was found between the knowledge about the definition of biotechnology and the positive attitudes towards the applications of transgenics. The size of each dot at the graph is proportional to the number of students at the position. Spearman's rank correlation coefficient and p-value are shown. (B) The percentage of students that was in favour of the three applications of transgenics is presented for each of the categories defined based on the definition of biotechnology. There was a complete correspondence between A1 and positive attitudes.

6. Discussion

Our research focused on the knowledge and attitudes of first year Baccalaureate students. The questionnaire used was designed to capture the choices and justifications of participants. Besides, an online presentation that included explanations and links to further information about all the topics of the questionnaire was sent to students.

Regarding the results obtained, more than half of the students do not master the definition of biotechnology, its meaning, and objectives. On the one side, only 18.5% of the participants selected all the concepts related to biotechnology (or all except innovation) that were presented. On the other side, the phenomenographic analysis (Han and Ellis, 2019) of the definitions written by students demonstrated that more than 42% have a good knowledge and give a utilitarian definition of biotechnology. These results show that the concepts presented did not help all students to build the definition of biotechnology, and many of them manage to give an appropriated definition using their own words in the free-text field. Besides, the phenomenographic approach reveals that each person has a different way to perceive and understand reality, and qualitatively different categories of description can be used to illustrate the understanding of a concept (Marton, 1981).

Similarly, the answers given to the question about the use of biotechnology throughout history show that only the 36.3% of the participants selected the right answer and know that biotechnology has been used for thousands of years. Furthermore, when the justifications given by these students were analysed, we identified different categories of reasoning and that one third of the students gave incoherent or arbitrary reasons.

In the case of the applications of biotechnology, our results are in line with previously published works (de la Vega-Naranjo et al., 2018; Occelli et al., 2011), and clearly show that students are more familiar with modern applications of biotechnology, especially the ones related to biomedicine and transgenic food, than with traditional and industrial applications of biotechnology. When comparing the applications of biotechnology mentioned by the students in the free-text question and the multiple-choice question, where options were provided, a higher number of answers were obtained with the later, with better results for all fields and especially for the industrial applications, that were only mentioned by a couple of students in the free-text. Moreover, misconceptions were identified in the answers given by 13% of the students in the free-text field.

Regarding the use of transgenic food, it becomes clear that this socioscientific issue is widely known by young students, and many positive and negative arguments were mentioned. Apart from scientific arguments, others with no evidence are included for both positive and negative arguments. Interestingly, socioscientific issues and misconceptions can be applied as teaching strategies (e.g. Díaz-Moreno and Jiménez-Liso, 2012; Domènech-Casal, 2017).

As stated before, three real examples of transgenics applications were presented to students: transgenic potatoes under water stress conditions, the use of transgenic animals for cancer research and the use of transgenic insulin for the treatment of diabetic patients. We see that the attitude of students towards the use of transgenic animals for biomedical research have significantly changed. In the study performed by Hill, Stannistreet, O'Sullivan and Boyes (1999) 42% of students was against this application, while in our study it was only the 4.8%. In the case of transgenic food, previous reports showed that around 60% of the students were in favour of transgenic food (de la Vega-Naranjo et al., 2018; Seethaler and Linn, 2004). Our results show that students' positions are not fixed, and many of them change their attitude towards transgenic food when a specific application is presented. However, it should be mentioned that the application of transgenic potatoes, as well as the two biomedical applications presented in this study can be considered of general interest, and other applications of transgenics could get lower acceptances among students, such as potential applications that would only benefit agriculture or pharmaceutical companies, or applications of transgenics together with potentially toxic chemicals. Finally, the correlation and correspondence analysis demonstrates that students with a better knowledge about biotechnology are more positive about the use of transgenics. Furthermore, all students who gave a utilitarian definition of biotechnology with a focus on production, were in favour of the applications of transgenics presented. Our results are in accordance with a recent work from Slovenia, in which a significant correlation between the knowledge about biotechnology and attitudes towards the consumption of genetically modified food and the use of biotechnology in medicine or agriculture was found in 17-18-year-old students (Paš et al., 2019).

Still, it should be mentioned, that certain study limitations exist. The present study included students from six schools and different towns and cities, and answers from 124 students were analysed. We think this is a representative sample, but more precise results could have been obtained with a larger number of participants. In addition, due to the COVID-19 outbreak, the only possible approach for carrying out our research was an online questionnaire. It included explanations and clear questions and, even if in most of the cases a straightforward completion was achieved, some misunderstandings were identified. As commented in the results section, based on answers and justifications given, 10 students did not correctly understand Q2. In any case, these misunderstandings were restricted to Q2, and they did not affect further analyses.

In brief, misconceptions and poor knowledge of biotechnology were identified in a significant proportion of high school students. This identification is the first step to realize of current limitations, to drive new teaching strategies forward and to ultimately improve students' scientific literacy (Hilton et al., 2011). Thus, the identification of learning problems is essential for the design of teaching strategies that catch the attention and interest of students. In this sense, the use of socioscientific issues – despite being complex and challenging (Kolstø, 2001) – has been demonstrated to be an appropriated approach (Zeidler et at., 2019) and, in the case of biotechnology, it has been shown to promote critical thinking, reasoning and scientific knowledge (Nordqvist and Aronsson, 2019).

7. Conclusions

Many the first year Baccalaureate students have problems to define biotechnology, and therefore, also to identify its applications. We need to advance on the utilitarian conception of biotechnology and on its benefits. Interestingly, knowledge transfer about cutting edge technologies seems to be better accomplished than traditional applications, which are indeed closer to students' everyday life. Regarding transgenic organisms, their use is a controversial issue well-known by students. Even if many of them do not dominate the basis of transgenics, and despite many of the arguments commonly heard in our society are not based on scientific evidence, students take a position. In consequence, these positions are not fixed and, when specific applications of transgenics are presented, a significant proportion of students change their attitude. Therefore, there is a need to reinforce the scientific knowledge of young students about transgenics.

In short, the present work identifies students' knowledge gaps and misconceptions about biotechnology. Biotechnology and its applications are included in educational curricula, but students do not reach the expected competences and we need to continue working on teaching strategies to achieve an efficient knowledge transfer. It is essential that students gain knowledge about a scientific field that is widely used and from which we all benefit, but which it is also controversial. Young students, as the rest of society, need to understand socioscientific issues in order to make informed decisions and have justified opinions.

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