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3 **Is judgement of biotechnological ethical aspects related to high school students'**
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5 **knowledge?**
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10 **Abstract**

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12 Quantitative and qualitative studies of various aspects of the perception of biotechnology
13 were conducted among 469 Slovenian high school students of average age 17 years. Our
14 research aimed to explore relationships among students' pre-knowledge of molecular- and
15 human genetics, and their attitudes to four specific biotechnological applications. These
16 applications – Bt corn, genetically modified salmon, somatic- and germ line gene therapy –
17 were investigated from the viewpoints of usefulness, moral acceptance and risk perception. In
18 addition, patterns and quality of moral reasoning related to the biotechnological applications
19 from the aspect of moral acceptability were examined. Clear gender differences were found
20 regarding the relationship between our students' pre-knowledge of genetics and their attitudes
21 to biotechnological applications. While females with a better genetics background expressed a
22 higher risk perception in the case of genetically modified salmon, their similarly well-
23 educated male colleagues emphasized risk associated with the use of germ line gene therapy.
24 With all four biotechnological applications, patterns of both rationalistic – deontological and
25 teleological – and intuitive moral reasoning were identified. Students with poorer genetics
26 pre-knowledge applied an intuitive pattern of moral reasoning more frequently than their
27 peers with better pre-knowledge. A pattern of **emotive** reasoning was detected only in the case
28 of genetically modified salmon. A relatively low quality of students' moral reasoning, as
29 demonstrated by their brief and small number of supporting justifications (explanations),
30 show that there is a strong need for practising skills of argumentation about socio-scientific
31 issues in Slovenian high schools on a much larger scale. **The implications for future research**
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3 and classroom applications are discussed.
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10 **Introduction**

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12 Over recent decades, biotechnology has made tremendous development and is now offering a
13 new generation of unprecedented products and services to society. Modern biotechnology,
14 including gene technology, has been increasingly applied in healthcare and in a number of
15 industrial and agricultural industries. Due to the potential benefits as well as the risks that it
16 poses to our society, an assessment of the public perception of these issues, especially among
17 young people who will have to make decisions related to the use of biotechnology products in
18 the near future, is vital. We have already published an article about Slovene students' attitudes
19 in relation to four different biotechnological applications – Bt corn, genetically modified
20 (GM) salmon, somatic- and germ line gene therapy (GT) – from the viewpoints of usefulness,
21 moral acceptance and risk perception (Črne-Hladnik, Peklaj, Košmelj, Hladnik, & Javornik,
22 2009). In the present paper, we have focused on ethical aspects of the perception of gene
23 technology and on the relationship between students' pre-knowledge and their moral
24 reasoning.
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46 **Ethics of biotechnological applications and moral reasoning**

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48 Ethics seeks to find reasoned, consistent and defensible solutions to moral problems.
49 Bioethics, a subsection of ethics, uses ethical principles and decision making to solve actual
50 or anticipated dilemmas in medicine, biology and biotechnology. Since biotechnology raises
51 numerous ethical questions, various science educators (Pedretti, 1999; Zeidler, 1984) suggest
52 that, when dealing with issues such as genetic engineering, a consideration of morality and
53 ethics must be taken into account. In our study, four biotechnological examples – Bt corn,
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3 GM salmon and somatic- and germ line GT – were investigated. Each of them involves
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5 bioethical dilemmas that can be characterized by one or more of the following features:
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8 “- Good reasons are proposed both for supporting and for opposing a particular course of
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10 action;
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12 - The ethical acceptability of a course of action depends to a significant degree on
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14 scientific evidence, which may be complex and/or incomplete and/or debatable;
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17 - A decision has to be made by, and/or for, society as a whole, in which a significant
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19 number of people may oppose the opinion held by most scientific experts” (Mephram, 2005: p.
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21 45).
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25 Biotechnological practices, such as cloning, stem cells, GT, GM food and environmental
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27 challenges – e.g. global change – are referred to as socio-scientific issues (SSI). They differ
28
29 from other issues in science in that they are open-ended, ill-structured, debatable problems
30
31 subject to multiple perspectives in finding solutions (Kuhn, 1991; Means & Voss, 1996).
32
33 Recent conceptualization of SSI education distinguishes it from previous approaches, such as
34
35 the Science – Technology – Society (STS) movement. While the STS curriculum typically
36
37 stresses the impact of decisions in science and technology on society, it does not deal
38
39 explicitly with the ethical issues contained within choices about means and ends, nor does it
40
41 consider the moral or character development of students (Zeidler et al., 2005). According to
42
43 Zeidler et al. (2002), "SSI is a broader term that subsumes all that STS has to offer, while also
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45 considering the ethical dimensions of science, the moral reasoning of the child, and the
46
47 emotional development of the student" (p. 344). Fowler et al. (2009) investigated how
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49 teaching a year-long curriculum using SSI affects the development of students' moral
50
51 sensitivity. The curriculum for the experimental (treatment) group included multiple activities
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53 that required participants to evaluate claims, analyse evidence and sources, and make moral
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55 decisions for a particular genetic modification scenario. Although both the experimental and
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3 the comparison groups showed an increase in moral sensitivity, the increase in the case of the
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5 former was significantly higher than with the latter.
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8 Although often used interchangeably, there are some subtle but important differences
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10 between the terms informal and moral reasoning. Some scholars argue that moral reasoning is
11
12 an integral part of informal reasoning (Andrew & Robottom, 2001; Solomon, 1994). Means
13
14 and Voss (1996) provided an illustrative description: “Informal reasoning assumes
15
16 importance when information is less accessible, or when the problems are more open-ended,
17
18 debatable, complex, or ill-structured, and especially when the issue requires that the
19
20 individual build an argument to support a claim” (p. 140). Bioethicists have linked issues
21
22 associated with genetic engineering to moral reasoning (Evans, 2002; Haker & Beyleveld,
23
24 2000; Stock & Campbell, 2000). They see it as the process of determining right or wrong in a
25
26 given situation. Ethical theories and principles are the foundations of ethical analysis because
27
28 they are the viewpoint from which guidance can be obtained along the pathway to a decision.
29
30 Much of applied ethics is concerned with three ethical theories that philosophers have
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32 proposed with the aim of systematizing, and hence facilitating, ethical decision-making:
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38 - “The ethical approach called consequentialism is the view that our actions should be
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40 ethically determined by the consequences likely to result from them. The desired
41
42 consequences clearly need to be specified to make this a useful theory and, in the most
43
44 prominent form of consequentialism, called utilitarianism, the aim is to “produce the greatest
45
46 good for the greatest number”. This theory was introduced by Jeremy Bentham in the 18th
47
48 century and was further developed by John Stuart Mill (1806-1873)” (Mepham, 2005: p. 31).
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51
52 - “The deontological theory refers to the rights and duties we have as individuals with
53
54 respect to other individuals. It is only the intention of an act that is good, not the outcome. The
55
56 theory had its origins in the ideas of the philosopher Immanuel Kant (1724-1804)”.
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3 - "The virtue theory, derived from Aristotle's and Confucius's notions, puts emphasis on
4
5 the person who performs the actions and makes the choices, rather than on the situations in
6
7 which choices have to be made" (Mepham, 2005: p. 34).
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10 Some investigators (e.g. Andrew & Robottom, 2001; Zeidler et al., 2002) have argued
11 that SSI, by definition, involve morality, and various studies have been performed that
12 support this claim. Sadler and Zeidler (2004) conducted interviews with students from a
13 public university in the southeastern United States. The interviewer asked explicit questions
14 regarding students' feelings and reactions to GT and cloning and the role of moral or ethical
15 considerations in their decision-making. The research questions were: To what extent do
16 students construe genetic engineering issues as moral problems? and How do moral
17 considerations influence construal and resolution of genetic engineering issues? Qualitative
18 analysis of the interview transcripts showed that, in most cases, students construed the issues
19 as moral problems and demonstrated decision-making patterns consistent with moral
20 construal. The emergent moral-based patterns of decision-making included moral reasoning
21 based on consequences or principles, moral emotion-based choice, and moral intuitionism.
22 The first pattern – also called rationalistic – describes reason-based considerations. In the case
23 of moral emotion-based choice, students did not base their judgements on rational
24 deliberations of consequences or principles; they rather expressed them as an unfavorable or
25 favorable emotion, such as empathy and sympathy (Hoffman, 2000). Individuals who showed
26 emotive reasoning seemed genuinely to care about the well-being of others. Ethical
27 intuitionism, on the other hand, means that students did not support these resolutions with an
28 analysis of consequences, principles, emotions, or any other discernible factors: they simply
29 perceived a particular genetic engineering application as morally right or wrong. Intuitive
30 informal reasoning describes considerations based on immediate reactions to the context
31 (Sadler & Zeidler, 2004).
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Reiss (2008) reported on the use of ethical frameworks by 16-18-year old students following an advanced biology course. The course was taught through contexts and had a strong emphasis on social aspects of biology and ethical analysis of biological issues. Examination of a sample of reports on the topic of global warming written by students showed that utilitarian ethical reasoning – maximising the amount of good in the world – was used widely and that other ethical frameworks to which students were introduced in the course – rights and duties, autonomy and virtue ethics – were used substantially less often. That the prevailing ethical framework always depends on the context, i.e., on the nature of the investigated topic, was shown by Dawson and Taylor (2000), who came to different conclusions in their study. They surveyed 15-year old science students after they had undertaken a transplantation technology course. Students were asked to respond to a series of bioethical dilemmas, determine an outcome, and justify their reasons using the four bioethical principles of autonomy ("the right to choose"), justice (fairness), beneficence (promoting good), and non-maleficence (avoidance of harm). The focus of that paper was to compare the moral reasoning of students to that of three experts. The students' justification of their decisions seemed to be based largely on the bioethical principle of autonomy. In contrast, the responses and reasons stated by the experts seemed to indicate that, in addition to autonomy, they also considered the principles of non-maleficence, justice, and beneficence. The students did not appear to be able to extrapolate the long-term consequences of their decisions.

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In his survey, Sjöberg (2004) investigated attitudes to ten specific applications of gene technology among the general population in Sweden; the age distribution of participants was fairly similar to national statistics. Moral aspects emerged as the most important ones. However, different kinds of gene technology were assessed in different ways in terms of morality. The use of gene technology in the food industry was judged to be morally less acceptable than for medical use, and changing the genes of plants was more acceptable than

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3 doing the same in the case of animals. Medical applications were judged to be more morally
4 acceptable when applied to people living today than to coming generations. **Five conclusions**
5 **can be discerned behind these results on morality judgement:**
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10 - Utility. What is useful is seen as morally correct.
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12 - Risk. What is risky is seen as morally incorrect.
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14 - Naturalness. What is "normal" and "natural" is seen as morally correct.
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16 - Humanness. Animals are more similar to humans than plants are; hence, it is morally
17 less acceptable to modify their genes.
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19 - It is less acceptable to modify genes of coming generations than those of the present
20 one, perhaps because people living now can have some influence over what happens to them.
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27 In our study the focus was on moral reasoning since we were investigating the moral
28 acceptability of four specific biotechnological examples.
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34 **Relationship between students' knowledge and their attitudes to biotechnology and** 35 **informal reasoning** 36 37

38 The relationship between genetics knowledge and attitude to biotechnology is fairly complex.
39 Klop and Severiens (2007) found in a cluster analysis-based study that only a small subset
40 (22%) of students with the highest level of content knowledge were also highly positive about
41 the attributes of biotechnology. They were referred to as "confident supporters of
42 biotechnology in their daily life". Some studies have shown that people with a sound
43 knowledge base find it easier to express a decided view, irrespective of whether they are
44 positive or negative about issues related to gene technology (Jallinoja & Aro, 2000). Sadler
45 and Zeidler (2005) examined the effects of genetics knowledge on the patterns and quality of
46 informal reasoning about genetic engineering issues. Participants with more advanced
47 understanding of genetics demonstrated fewer instances of reasoning flaws, i.e. a better
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3 reasoning quality as defined by *a priori* criteria, and were more likely to incorporate
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5 knowledge in their reasoning patterns than participants with a more naive understanding of
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7 genetics. On the other hand, data obtained from interviews produced no noticeable qualitative
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9 patterns that distinguished individuals with high levels of genetics knowledge from those with
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11 relatively low levels of genetics knowledge in terms of the reasoning patterns (i.e.
12
13 rationalistic, emotive, and intuitive informal reasoning). According to this research, it can be
14
15 suggested that educators who use socioscientific curricula, particularly materials related to
16
17 genetic engineering, need to maintain a critical awareness of their students' content
18
19 knowledge. Chang and Chiu (2008) conducted a survey that dealt only partly with
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21 biotechnological issues, and similarly found that science majors showed better argumentation
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23 skills than non-science majors and that background knowledge was related to the ability of
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25 argumentation.
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34 **Research questions**

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36 In the present paper, the knowledge of the molecular and human biology, and the complexity
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38 of ethical dilemmas on the assessment of four different biotechnological applications – Bt
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40 corn, GM salmon, somatic- and germ line GT – from the viewpoints of usefulness, moral
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42 acceptance and risk perception are investigated. In addition, the patterns and quality of moral
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44 reasoning about the four biotechnological examples are discussed. In our study, the following
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46 three research questions were formulated:
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51 1. How does the assessment of four biotechnological applications correlate with pre-
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53 knowledge of molecular and human genetics?

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55 2. What kind of patterns of moral reasoning can we expect about the biotechnological
56
57 applications from the viewpoint of moral acceptability? Is there any relationship between pre-
58
59 knowledge and patterns of moral reasoning?
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Methods and procedures

In this section, we describe the participants and the administration of the study, the development of the instruments, the data collection process and the analytical procedure.

Participants and administration

A total of 469 students (299 females and 170 males) from eight general secondary schools from various Slovenian regions participated in the study, which was conducted over the course of one school year. The study was carried out in the third class, after the students, aged 17 in general, had been taught the fundamentals of molecular and human genetics. We first tested the students to obtain an overview of their pre-knowledge on these topics (see subsection *Development of the instrument for assessing the pre-knowledge of genetics*).

Since the assessment of biotechnological applications always depends on the particular case, we selected four different applications – two from the fields of agriculture and food production and two from medicine. Several science educators (Pedretti, 1999; Sadler & Zeidler, 2004) have reported in studies that some participants cited a lack of knowledge about genetics as a factor contributing to their inability to discuss genetic engineering issues. To avoid this potential problem, the above mentioned applications were presented to our students using MS PowerPoint (Table 1) and three excerpts from two documentary films – DNA: Promise and Price (Discovery Channel, 2002) and "Harvest of Fear" (Frontline and Nove coproduction, director Jon Palfreman, 2001) (Table 2). Each excerpt was carefully selected to provide a balanced view of the presented issues, exploring both the potential risks (ecology, health) and the benefits.

Finally, the students individually expressed their opinions on each of the four biotechnological applications from the viewpoints of usefulness, moral acceptance and risk

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3 perception, by filling out pencil and paper questionnaires (see subsection *Ranking difficulty of*
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5 *moral dilemmas accompanying biotechnological applications and assessment of moral*
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7 *reasoning patterns*).
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12 [Insert Table 1 about here]
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15 [Insert Table 2 about here]
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18 19 20 **Development of the instrument for assessing the pre-knowledge of genetics**

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22 Since we found no preexisting instruments in the pertinent biology literature that would meet
23
24 our requirements, we developed a test for use in assessing pre-knowledge and understanding
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26 of molecular and human genetics and biotechnology fundamentals. The basic concepts of
27
28 molecular and human genetics are part of students' regular biology curriculum (20 hours)
29
30 during the first three years of study. In addition, until very recently, practically no information
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32 on biotechnology and genetic engineering issues was presented to secondary school students
33
34 until their fourth year of study, in which biology is no longer a compulsory subject. In spite of
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36 the lack of formal education, we anticipated that the students would have some knowledge
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38 about these topics acquired by other means, such as TV, internet and other media. The
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40 instrument comprised a total of 24 questions (n) consisting of 17 multiple choice questions
41
42 with four possible answers and 7 true-false (bivariate) items. Some of them were designed to
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44 assess only knowledge, while others addressed also understanding and use of knowledge. The
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46 test was previously reviewed by eight secondary school biology teachers and two experts
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48 from the field of genetics, for accuracy and clarity with respect to the secondary school level.
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50 After the review, several questions/items were modified, improved or omitted. The
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52 Cronbach's alpha – coefficient of reliability – for the final instrument was 0.69 (n = 24).
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Ranking difficulty of moral dilemmas accompanying biotechnological applications and assessment of moral reasoning patterns

Eight experts from the field of natural sciences and seven from social studies were asked to rank the difficulty of ethical dilemmas related to the four biotechnological applications. We wanted in this way to explore whether ethical dilemma difficulty affects the students' judgements of the usefulness of each biotechnological application. A questionnaire and a semi-structured interview were used for this purpose. The experts ranked the applications in decreasing order of moral acceptability as follows: somatic GT, Bt corn, GM salmon and germ line GT.

One of the goals of our study was to investigate the moral reasoning patterns of ethical dilemmas. Similar to the study *The Morality of Socioscientific Issues: Construal and Resolution of Genetic Engineering Dilemmas*, performed by Sadler and Zeidler (2004), we conducted a qualitative analysis of the arguments given by the students, who were asked to reason their opinion on the moral acceptability of the four biotechnological applications. The question they had to answer was the following: *What is your opinion of the moral acceptability of Bt corn production (GM salmon, somatic GT of haemophilia, germ line GT of haemophilia)? Do you find this type of treatment acceptable?* Possible responses were: 1 – absolutely not, 2 – little, 3 – somewhat, 4 – pretty much 5 – completely. For each biotechnological application, the students supported their opinion by citing one or – rarely – several arguments. After reading their arguments, we created several categories (see subsection *Statistical and Qualitative Analysis*), which belonged to one of the three patterns of moral reasoning: rationalistic (a), **emotive** (b) and intuitive (c) (Sadler & Zeidler, 2004):

a) rationalistic moral reasoning is based on either the consequences of the biotechnological applications (teleological reasoning) or moral principles (deontological approach to morality);

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3 **b) moral emotive-based reasoning** is characterized by the fact that students do not base
4 their judgements on rational deliberation of consequences or principles, but rather on
5 emotions;
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10 **c) in the case of moral intuitive-based reasoning**, students respond to the applications
11 intuitively (instinctively), whereby their decisions are not a result of an analysis of
12 consequences, principles or emotions.
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17 As mentioned in the introduction, students also assessed the usefulness and risk
18 perception of the four biotechnological applications. Questionnaires were structured similarly
19 as described above and students reasoned their responses. Since the focus of this paper is on
20 analyzing students' attitudes to the ethical acceptability of biotechnological applications, we
21 only presented questions related to their moral assessment.
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31 **Statistical and qualitative analysis**

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33 Spearman's rank correlation coefficient was used to detect possible correlations between the
34 students' pre-knowledge – separately for males and females – and their attitudes towards the
35 four biotechnological applications from the viewpoints of usefulness, moral acceptability and
36 risk perception. The same instrument was applied to determine correlations between the DIT
37 (i.e., P score) and the students' attitudes towards the biotechnological applications.
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45 A general inductive approach was adopted to qualitatively analyse the students' reasoning
46 of the four biotechnological applications from the viewpoint of moral acceptability. Their
47 written argumentations were read, compared with each other and classified into 8 categories.
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51 An expert from the field of biotechnology examined 25% randomly selected questionnaires to
52 evaluate the appropriateness of the methodology. The reliability of evaluation, acquired as a
53 proportion of equally evaluated students' answers by the authors and the expert, exceeded
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60 95%,

To investigate the relationship between pre-knowledge and the pattern of moral reasoning, two approximately equal groups of students (61 and 56 for low and high knowledge groups, respectively) were created from the total population, based on the results of the genetics pre-knowledge test. In the low knowledge group, the female/male ratio was 36/25, while in the high knowledge group, the ratio was 31/25. We could not obtain gender-balanced groups, since there were 64% females and 36% males in the total population. Decisions regarding which scores represented high and low knowledge were made *post hoc* so that maximum variation subsamples could be obtained. Individuals scoring in the 87th percentile or higher (18 – 23) comprised the high knowledge group and individuals scoring in the 14th percentile or lower (5 – 9) comprised the low knowledge group.

Results and discussion

Relationship between the students' pre-knowledge and attitudes towards the biotechnological applications

The maximum possible score on the genetics pre-knowledge test was 24, the actual values ranged from 5 to 23. The mean score for the whole population was 13.77, with a standard deviation of 3.80 and the scores approximated the normal distribution. Statistical tests – comparison of means (t-test; $p = 0.67$) and Mann-Whitney-Wilcoxon test ($p = 0.79$) – showed no statistically significant differences in knowledge between females and males. With respect to the scores achieved, each student was assigned a grade according to the following criteria: 0-49% = 1, 50-62% = 2, 63-75% = 3, 76-89% = 4 and 90-100% = 5.

Since we wanted to explore whether there are any correlations between the pre-knowledge test grades and the students' attitudes to the four biotechnological applications from the three viewpoints, the Spearman's rank correlation coefficient (Spearman's rho) test

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3 statistics was calculated (Table 3). The results showed clear gender differences in some
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5 instances. Among females, five statistically significant correlations were found between the
6
7 pre-knowledge test and their attitudes regarding:
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- 10 - risk perception of GM salmon (p=0.00)
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- 12 - usefulness of Bt corn (p=0.04)
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- 14 - usefulness of GM salmon (p=0.05)
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- 16 - usefulness of somatic GT (p=0.04)
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- 18 - usefulness of germ line GT (p=0.04)
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[Insert Table 3 about here]

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30 In males, only one such correlation was detected – between the pre-knowledge test and
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32 the risk perception of germ line GT (p=0.012). It can therefore be concluded that, due to the
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34 higher number of significant correlations in females, genetics pre-knowledge here played a
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36 more important role than it did with males. Both females and males who had a better genetics
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38 background, seemed to exhibit a higher risk perception of two ethically more difficult
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40 applications – GM salmon (females) and germ line GT (males). In addition, as shown above,
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42 only with females was a weak relationship between genetics pre-knowledge and the
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44 usefulness of Bt corn, GM salmon and somatic- and germ line GT was found.
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49 Considering that the focus of our study was predominantly on assessing knowledge and
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51 understanding of molecular and human genetics – and only partly actual knowledge from the
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53 fields of biotechnology and genetic engineering – our results cannot be directly compared to
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55 those obtained from similar studies dealing with correlations between the knowledge of
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57 biotechnology and attitudes of individuals to it. In a Dutch study (Klop & Severiens, 2007), a
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59 positive correlation was reported between the knowledge and the attitudes of a group of high-
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3 school students, so called "confident supporters", who had in common to be very positive
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5 about the attributes of biotechnology and, at the same time, expressed the highest level of
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7 content knowledge. In the other three groups – "not sure", "concerned sceptic" and "not for
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9 me" – however, the level of knowledge could not be related to the students' attitudes. The
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11 results of several other studies (Dawson & Schibeci, 2004; Chen & Raffan, 1999; Lock et al.,
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13 1995) dealing with the relationship between biotechnology knowledge and attitudes were also
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15 inconclusive.
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22 **Relationship between the difficulty of moral dilemmas related to biotechnological** 23 **applications ranked by experts and the assessment of their usefulness** 24 25 26 27 28

29 Table 4 summarizes the mean values and standard errors of students' assessments of the
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31 four biotechnological applications from the viewpoints of usefulness and moral acceptability
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33 as measured using a five-point Likert scale, ranging from 1—strongly disagree, to 5—
34
35 strongly agree. It was found that both students and experts viewed Bt corn and somatic GT as
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37 ethically less problematic in comparison to GM salmon and germ line GT. Germ line GT and
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39 GM salmon, both ranked by the experts as ethically more difficult biotechnological
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41 applications, were assessed by the students as least useful. On the other hand, students
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43 considered somatic GT and Bt corn to be the most useful and the experts as morally the least
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45 difficult applications.
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53 [Insert Table 4 about here]
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58 **Qualitative analysis of moral reasoning patterns** 59 60

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3 Results showing categories of rationalistic (deontological and teleological) moral reasoning
4 pattern related to the four biotechnological applications are displayed in Table 5. Numbers
5 indicate how many students cited the particular category; they were allowed to write one or
6 several arguments (justifications) for each application, but most of them named only one or –
7 rarely – two. With each of the four applications, another category emerged that could not be
8 included in Table 5, since it does not belong to either rationalistic (deontological or
9 teleological) or **emotive** or intuitive group of reasoning patterns. This category, referred to as
10 a "two-edged sword", reflects difficulties students faced when they had to assess realistically
11 the benefits and risks related to a particular biotechnological application.
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27 [Insert Table 5 about here]
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32 Table 5 contains only those categories that appeared with at least two biotechnological
33 applications. There were two categories specific to Bt corn – "Environmentally friendlier than
34 the use of pesticides" (83) and "Specific action against pests" (29) – one for GM salmon –
35 "Animal rights issues" (35) – and also only one for somatic GT – "Last option" (13). As
36 indicated by a very high number of answers designated as "Autonomy of an individual" for
37 somatic GT (136) it can be concluded that the students consider the principle of an
38 individual's autonomy in relation to a decision about a GT procedure to be very important.
39 This widespread opinion among students undoubtedly had a strong influence on their
40 judgement of somatic GT as being ethically the most acceptable of all four biotechnological
41 applications (Črne-Hladnik, Peklaj, Košmelj, Hladnik, & Javornik, 2009). Dawson and Taylor
42 (2000), who studied bioethical attitudes in the field of human genetics among 14 to 15 years
43 old adolescents (see p. 4), came to similar conclusions. Respect for an individual's autonomy
44 received the highest ranking among the four bioethical principles.
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3 In comparison to somatic GT, our students viewed Bt corn as morally somewhat less
4 acceptable. This finding can be explained by students' responses in which they expressed
5 concern about the potential negative effects on human health and the environment, while in
6 the case of somatic GT these consequences would be limited to an individual.
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12 Both GM salmon and germ line GT, on the other hand, were much less acceptable
13 applications than the other two. First, students emphasized possible ecological damage as a
14 consequence of the accidental escape of GM salmon into the environment. Second, with
15 respect to germ line GT, students found it morally unacceptable for future parents to decide
16 about the destiny of their children and they were also afraid that the technology might be
17 abused for non-medical purposes.
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27 Sadler and Zeidler (2004) investigated moral acceptability of GT among American
28 students (see p. 5). Although their research methodology differed from ours, some common
29 results as well as differences between the two studies can be highlighted. Both American and
30 our students specified the following teleological arguments: improvement of health (in Table
31 5: "Benefits"), possible abuse of the method for non-medical use and decrease in variability
32 among individuals. While our students emphasized considerable risk related to germ line GT,
33 American students directly opposed genetic engineering due to its potential to aggravate the
34 problem of overpopulation.
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46 The results of quantitative analysis of intuitive moral reasoning for four biotechnological
47 applications are summarized in Table 6. The students did not provide any written explanation
48 for their answers; they simply indicated whether they found a particular application morally
49 highly, medium or not at all acceptable. If the students had been interviewed orally, it is
50 possible that they would have explained their opinions or attitudes more extensively.
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[Insert Table 6 about here]

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3 As shown in Tables 5 and 6, patterns of both rationalistic – deontological and teleological –
4 and intuitive moral reasoning were identified with all four biotechnological applications.
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8 **Some examples of different patterns regarding the use of Bt corn are presented in Table 7.**
9

10 The data in Table 5 suggested that a majority of students exhibited patterns of rationalistic
11 moral reasoning. In addition, a pattern of **emotive** reasoning was detected only in the case of
12 GM salmon, with which students expressed concern regarding possible adverse effects on
13 animal health or wellbeing. It is worth mentioning that all **emotive** reactions were negative
14 and opposed the use of gene technology on animals. **We can therefore conclude that of the**
15 **three patterns of moral reasoning, only emotive pattern was found to be clearly context**
16 **dependent.**
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29 [Insert **Table 7** about here]
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34 **Relationship between pre-knowledge and patterns of moral reasoning**

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36 Table 8 shows a summary of qualitative analysis of moral reasoning for the two groups of
37 students differing in the level their genetics pre-knowledge. The results show that students
38 with a lower knowledge level more frequently applied an intuitive pattern of moral reasoning
39 than their peers who achieved higher grades in the genetics' test. This leads to the conclusion
40 that students with a higher level of genetics knowledge are able to reason their answers better.
41 In addition, students in the high pre-knowledge group seem to be more aware of the difficulty
42 of making a decision when facing a moral dilemma, as indicated by a higher number of "two-
43 edged sword" answers.
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Conclusions

Modern science education strives to make education more relevant and interesting to students by teaching science in context (Boersma et al., 2007). Since in our study a large majority – 98% – of the participating students returned correctly completed questionnaires, it can be concluded that they were very interested in discussing real-world ethical dilemmas raised by SSI. Another important finding of the study was that the ethical difficulty of the selected biotechnological applications was perceived similarly by the 17-year old students and experts from the fields of natural and social sciences alike. This means that our high school students possess the ability to discuss complex questions related to the use of biotechnology, about which they will soon have to make important decisions, perhaps as voters or in relation to issues regarding their personal health. As stated by Aikenhead (2006) and Levinson (2006), such discussions can help to prepare students for future citizenship. It would also be highly beneficial to incorporate other SSI topics, such as genetic testing, stem cell research, cloning, and global warming into our high school regular biology curricula more often and more extensively. While doing so, however, it is important to make sure that the biology teachers are equipped well enough to teach these controversial topics. By introducing to them some basic bioethical principles they would undoubtedly feel more confident to discuss various moral issues such as those dealt with in our study.

The findings presented in the paper support the notion that the genetics pre-knowledge is related both to the attitudes towards the use of biotechnological applications among adolescents as well as to the patterns of their moral reasoning. A lower level of genetics pre-knowledge is related to a more frequent appearance of intuitive patterns of moral reasoning, while students with higher levels of genetics pre-knowledge use more rationalistic patterns of

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3 moral reasoning. We can hypothesize that if some basic scientific background information on
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6 biotechnological applications had not been provided to students at the beginning of the study,
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8 the number of intuitive and **emotive** moral reasoning patterns would have probably been
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10 higher.

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12 **Although the main focus of our study was not on the quality of students' moral reasoning,**
13 **it should be pointed out that our students mainly explained their attitudes or opinions by**
14 **providing their own claims, which were supported by one or – rarely – two justifications, i.e.**
15 **explanations. In the case of students' arguments classified as the intuitive pattern of moral**
16 **reasoning, only single statements – claims or conclusions – without any justification were**
17 **presented. Regarding the quantitative and qualitative nature of students' justifications our**
18 **results are similar to those reported by Sadler and Fowler (2006). They found that US high**
19 **school students with basic genetic knowledge, when being asked about their attitudes on gene**
20 **therapy and reproductive cloning, stated on average one or two justifications to support their**
21 **claims. On the other hand, science major students demonstrated an advanced knowledge and a**
22 **much better quality of reasoning indicating that a deeper understanding of complex**
23 **contemporary biological topics leads to a higher quality of reasoning. In our future research**
24 **we therefore intend to incorporate Slovene science majors to further investigate correlations**
25 **between the genetics knowledge and students' attitudes towards biotechnological issues.**

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46 **Another future research topic is the importance of argumentation skills – in addition to**
47 **that of genetics pre-knowledge – in providing more complex and grounded justifications.**
48 **Promotion of such skills in a high school practice, however, appears to be a difficult**
49 **educational task (Sadler, 2004) and requires time and practice. One of the positive steps**
50 **towards the solution of this problem is a closer cooperation between the teachers of biology**
51 **on one hand and those of social science subjects, such as sociology, psychology and**
52 **philosophy, on the other. It could also be helpful to follow the suggestions of Chang and Chin**
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3 (2008) to incorporate in the school practice group discussions and the evaluation process. This
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5 could help students thinking about presenting counterarguments and dealing with
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8 contradictory evidence.
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Table 1. Information presented in the PowerPoint presentations

Hour	Topic	Content
1	Gene therapy	Relationship among genes, proteins and genetic traits What are genetic diseases in general Purpose and techniques of gene therapy (how to introduce therapeutic genes into human cells) Distinction between somatic and germline gene therapy
2	Genetically modified plants	Fundamentals of genetic engineering Difference between cross breeding and genetic engineering Production of Bt corn How to introduce genes into plant cells
3	Genetically modified animals	Difference between traditional selection (cross breeding) and genetic engineering How to introduce genes into animal cells Main reasons for animal genetic modification (medicine – onco mouse, genetically modified animals for xenotransplantation, pharmacology – "biopharming", food industry – transgenic salmon)

Table 2. Information presented in the films

Film	Topic	Content
1	Gene therapy	<p>Information on haemophilia, including causes, symptoms and treatment</p> <p>Gene therapy and how it works</p> <p>Successful clinical trial of hemophilia treatment despite some complications</p> <p>Some unsuccessful clinical trials of gene therapy</p>
2	Bt corn	<p>Bt corn as an example of genetically modified crop, what it is, how it works and how to improve control over corn borer moth</p> <p>Ecological and economic benefits when using Bt protein instead of broad-spectrum insecticides</p> <p>Discussion on whether Bt corn pollen represents a significant risk to monarch butterflies</p> <p>Discussion whether the corn borer moth can become resistant to Bt protein and how to prevent it</p>
3	Transgenic salmon for aquaculture	<p>Creation and farming of transgenic salmon in Atlantic Canada to increase their growth rate by hormone gene transfer (economic benefits)</p> <p>Concerns raised about the environmental impact of transgenic fish escaping from a sea cage into the wild and interacting with the wild salmon (ecological impact); animal health and welfare (animal rights)</p>

Table 3. Spearman's correlation coefficient between the genetics pre-knowledge test and the assessment of biotechnological applications, for males and females, from three viewpoints and the corresponding p-value (in parenthesis)

Correlation coefficient (p-value)	Genetics pre-knowledge test – males (n=134)	Genetics pre-knowledge test – females (n=256)
Bt corn - Usefulness	0.09 (0.295)	0.13 (0.040*)
Bt corn - Moral acceptability	-0.03 (0.698)	0.06 (0.314)
Bt corn - Risk perception	0.13 (0.148)	0.10 (0.126)
GM salmon - Usefulness	-0.04 (0.682)	0.12 (0.046*)
GM salmon - Moral acceptability	-0.12 (0.169)	0.02 (0.732)
GM salmon - Risk perception	0.08 (0.364)	0.24 (0.00***)
Somatic GT - Usefulness	0.02 (0.810)	0.13 (0.035*)
Somatic GT - Moral acceptability	0.02 (0.781)	0.10 (0.111)
Somatic GT - Risk perception	0.10 (0.255)	0.01 (0.933)
Germ line GT - Usefulness	-0.03 (0.699)	0.13 (0.038*)
Germ line GT - Moral acceptability	-0.07 (0.424)	0.10 (0.124)
Germ line GT - Risk perception	0.22 (0.012**)	0.10 (0.121)

Note: * Statistically significant correlation ($p \leq 0.05$).

** Statistically significant correlation ($p \leq 0.01$).

*** Statistically significant correlation ($p \leq 0.001$).

Table 4. Mean values and standard errors for the four studied biotechnological applications from the viewpoints of usefulness and moral acceptability

Source	N	Mean	95% conf. intervals
<i>Usefulness</i>			
Bt corn	439	3.79	0.04
GM salmon	430	3.10	0.04
Somatic GT	443	3.73	0.04
Germ line GT	442	3.00	0.04
<i>Moral acceptability</i>			
Bt corn	439	3.44	0.04
GM salmon	430	2.51	0.04
Somatic GT	443	3.76	0.04
Germ line GT	442	2.60	0.04
<i>Risk perception</i>			
Bt corn	439	2.87	0.04
GM salmon	429	3.72	0.04
Somatic GT	443	3.60	0.04
Germ line GT	440	3.71	0.04

Table 5. Number of students' answers belonging to different categories of rationalistic – deontological and teleological – moral reasoning related to the four biotechnological examples

	Bt corn	GM salmon	Somatic GT	Germ line GT
<i>Deontological reasoning</i>				
Interfering with nature	71	91	13	64
Autonomy of an individual			136	91
No need for genetic modification	3	41		
<i>Teleological reasoning</i>				
Benefits	73	31	108	70
Unknown consequences	112	123	38	73
No harmful effects on descendants		3	27	
Possible abuse of the method			14	57
Progress of science	13	2	7	

Table 6. Number of students' answers indicating their intuitive reasoning related to the four biotechnological applications

Intuitive reasoning	Bt corn	GM salmon	Somatic GT	Germ line GT
Morally unacceptable	3	26	5	12
Medium acceptable	28	11	6	12
Highly acceptable	46	23	36	14

Table 7. Examples of different patterns of moral reasoning regarding the use of Bt corn

Pattern	Example
Rationalistic-deontological	"In my opinion, human beings interfere with nature too frequently and we will sooner or later have to pay for this. When this happens, it will be too late to take back genes we once introduced into the living organisms. I prefer conventional cross breeding to gene technology."
Rationalistic-teleological	"I find the use of Bt corn acceptable, since it is less detrimental to the environment than the pesticides."
Intuitive	"It is OK to cultivate Bt corn, but only to certain extent."
Two-edged sword	"The use of Bt corn is more environmental friendly compared to the pesticides, but can lead to monopoly of certain producers."

Table 8. Number of low- and high genetics pre-knowledge individuals exhibiting patterns of informal moral reasoning to four biotechnological applications

Pattern	Low pre-knowledge	High pre-knowledge
Rationalistic deontological	56	76
Rationalistic teleological	88	90
Emotive	7	4
Intuitive	61	28
Two edged sword	7	28
Unclassified	29	22
Total	248	248

Appendix 1: Questionnaire**GENE THERAPY****Somatic gene therapy for haemophilia**

The presentation and film provided information about somatic gene therapy for haemophilia and some other inherited diseases. Numerous clinical trials are also currently being performed for treating cancer and various contagious diseases, such as AIDS. Somatic gene therapy works by introducing new genes into the body cells of an adult human, whereby these genes will not pass to the next generation, i.e., the offspring.

1. To what extent do you agree with the applicability of somatic gene therapy for haemophilia? Indicate your attitude by marking the appropriate answer number!

Absolutely not	Little	Somewhat	Pretty much	Completely
1	2	3	4	5

Briefly explain your decision:

2. What is your opinion of the moral acceptability of somatic gene therapy for haemophilia? Do you consider this type of treatment acceptable?

Absolutely not	Little	Somewhat	Pretty much	Completely
1	2	3	4	5

Briefly explain your decision:

3. What is your opinion of the risk associated with somatic gene therapy for haemophilia? Do you consider this type of treatment risky?

Absolutely not	Little	Somewhat	Pretty much	Completely
1	2	3	4	5

Briefly explain your decision:

GENE THERAPY

Germ line gene therapy for haemophilia

Gene treatment of the above mentioned diseases could also be conducted by introducing new genes into sperms, eggs or at the early stage of embryonic development – so called germ line gene therapy. In this case, the repaired genes would pass to the offspring.

4. To what extent do you agree with the applicability of germ line gene therapy for haemophilia? Indicate your attitude by marking the appropriate answer number!

Absolutely not 1	Little 2	Somewhat 3	Pretty much 4	Completely 5
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Briefly explain your decision:

5. What is your opinion of the moral acceptability of germ line gene therapy for haemophilia? Do you consider this type of treatment acceptable?

Absolutely not 1	Little 2	Somewhat 3	Pretty much 4	Completely 5
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Briefly explain your decision:

6. What is your opinion of the risk associated with germ line gene therapy for haemophilia? Do you consider this type of treatment risky?

Absolutely not 1	Little 2	Somewhat 3	Pretty much 4	Completely 5
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Briefly explain your decision:

GENETICALLY MODIFIED PLANTS**Bt corn**

The presentation and film dealt with the production of Bt corn, a special type of corn that is resistant to corn borer moth. In the following three questions, you should quantify your attitude towards the implications of Bt corn production.

7. To what extent do you agree with the applicability of Bt corn production? Indicate your attitude by marking the appropriate answer number!

Absolutely not	Little	Somewhat	Pretty much	Completely
1	2	3	4	5

Briefly explain your decision:

8. What is your opinion of the moral acceptability of Bt corn production? Do you consider this type of treatment acceptable?

Absolutely not	Little	Somewhat	Pretty much	Completely
1	2	3	4	5

Briefly explain your decision:

9. What is your opinion of the risk associated with Bt corn production? Do you consider this type of genetic modification risky?

Absolutely not	Little	Somewhat	Pretty much	Completely
1	2	3	4	5

Briefly explain your decision:

GENETICALLY MODIFIED ANIMALS**Transgenic salmon**

The presentation and film talked about genetically modified – transgenic – salmon, whose growth rate is on average up to four times higher than that of non-transgenic salmon. In the following three questions you should quantify your attitude towards the implications of genetically modified salmon.

10. To what extent do you agree with the applicability of genetically modified salmon?

Indicate your attitude by marking the appropriate answer number!

Absolutely not	Little	Somewhat	Pretty much	Completely
1	2	3	4	5

Briefly explain your decision:

11. What is your opinion of the moral acceptability of genetically modified salmon? Do you consider this type of treatment acceptable?

Absolutely not	Little	Somewhat	Pretty much	Completely
1	2	3	4	5

Briefly explain your decision:

12. What is your opinion of the risk associated with genetically modified salmon? Do you consider this type of genetic modification risky?

Absolutely not	Little	Somewhat	Pretty much	Completely
1	2	3	4	5

Briefly explain your decision: