Journal of Turkish Science Education, 2022, *19*(2), 511-524.
DOI no: 10.36681/tused.2022.134

Study of Students' Moral Reasoning on Modern Biotechnology Applications Using Bioethics for Informed Decision Modules

Onrumpa Kumnuanek[1], Uraiwan Aranyawat[2] and Pongprapan Pongsopon[3]

[1]*Faculty of Education, Kasetsart University, Thailand, onrumpa.ku@ku.th, ORCID ID: 0000-0002-7287-8555*
[2]*Faculty of Science, Kasetsart University, Thailand, fsciuwa@ku.ac.th, ORCID ID: 0000-0003-1312-710X*
[3]*Faculty of Education, Kasetsart University, Thailand, pongprapan.p@ku.th, ORCID ID: 0000-0003-0213-283*

ABSTRACT
The rapid developments in biotechnology and its implications raise moral dilemmas for individuals and society. Therefore, bioethics education at all levels is necessary. Science teachers should inculcate moral values and ethics among students. However, studies on various aspects of curriculum-oriented moral education remain lacking, despite the growing focus on the prosocial and moral development of students. Moreover, most existing studies have not evaluated the effectiveness of moral education curricula in terms of both students' learning experiences and their learning results. In this light, the present study examined the growth of students' moral reasoning on the moral dilemmas of modern biotechnology applications. A total of 206 high school students participated in the study. They were randomly assigned to a bioethical enrichment module (n1 = 87) and an ordinary case-based module (n2 = 119). We compared the mean of moral reasoning scores before and after implementing the interventions between the two groups. The results showed that the means of the intervention group were higher than those of the ordinary group. Our intervention which integrated not only SSI-based teaching but also synthesized essential features of teaching bioethics explicitly could improve students' moral reasoning scores. The pedagogical implications were also discussed.

ARTICLE INFORMATION
Received:
05.05.2021
Accepted:
29.05.2022

KEYWORDS:
Moral reasoning, modern biotechnology applications, curriculum-oriented moral education.

To cite this article: Kumnuanek, O., Aranyawat, U. & Pongsopon, P. (2022). Study of students' moral reasoning on modern biotechnology applications using bioethics for informed decision modules. *Journal of Turkish Science Education, 19*(2), 511-524.

Introduction

Modern biotechnology applications raise many moral dilemmas in that they both enhance the quality of our lives while threatening our social structures. For example, genetic diagnosis techniques could enable parents to save a life and avoid a miscarriage by selecting genetically healthy embryos before a baby is born. DNA fingerprinting may help capture criminals; however, the need to keep DNA records for all citizens raises serious concerns over how this information can be misused. Doctors can now edit a patient's genes to treat genetic disorders and thereby improve their quality of life; however, it can also threaten an individual's chances of life insurance and career prospects (Nuffield Council in Bioethics, 1993). Scientists can also modify the genes of animals or plants to produce desirable characteristics. For example, cotton containing a specific gene from the soil bacterium Bacillus thuringiensis (Bt), called BT cotton, is a genetically engineered crop that reduces the need for pesticide use while potentially having long-term effects on the ecosystem. Other

genetically modified crops can help solve food shortage problems; however, they also impact the economy, environment, and ecosystem.

These moral dilemmas bridge science and society and are open-ended, ill-structured in that they lack definitive solutions and debatable problems subject to multiple perspectives in finding solutions (Sadler, 2004). Decision-making about the use of modern biotechnologies will depend on citizens' reasoning on moral dilemmas. From an educational perspective, many science educators (Herman et al., 2018; Pedretti, 1999; Tidemand & Nielsen, 2016; Zeidler, 1984;) have proposed that when discussing such applications, especially gene editing and DNA technology, morality and ethics must be taken into account. If we are to seriously consider the proposition that the science curriculum must prepare future citizens (AAAS, 1990; NRCT, 2013), then the moral dilemmas in modern biotechnology applications can provide opportunities in the science classroom to prepare students to be functional citizens who can appropriately apply their understanding of science in making well-informed decisions (Antonio & Prudente, 2021; Dawson & Schibeci, 2003; Kahn & Zeidler, 2016; Owens et al., 2017).

Surprisingly, more than one-third of students are unable to justify their reason for or to support their own decision (Gunter et al., 1998; Schibeci, 2003b). Regarding student perspectives and reasoning, Gunter (1998) and Schibeci (2003b) found that English and Australian students were more accepting of the genetic modification of microorganisms and plants than of the genetic modification of foods, animals, and humans. Their reasons against animal genetic engineering were that it is unnatural, dangerous, should not be done, and unethical, and their reasons to support were related to advancement and humanity. Studies of high-school students' understandings and attitudes toward modern biotechnology (Chen and Rafffen, 1999; Dawson and Schibeci, 2003a; Wood-Robinson et al., 1997) found that numerous English and Australian high-school students (age: 16–19 years) did not understand the process of modern biotechnology applications. Most students seemed unable to distinguish between genetically modified (GM) foods and selectively bred foods. Moreover, some students seemed confused by the difference between cloning and genetic engineering in that they gave Dolly the sheep as an example of both cloning and genetic engineering.

Schuitema et al. (2008) found that a solid research domain on curriculum-oriented moral education remains lacking, despite the growing attention to the prosocial and moral development of students. Furthermore, most studies did not evaluate the effectiveness of moral-education curricula in terms of either students' learning experiences or their learning results. (Sadler et al., 2016; Schuitema et al., 2008).

Moral decision-making can facilitate in establishing appropriate standards for conducting scientific research and in using ethical approaches for implementing scientific knowledge in society. Many science educators and researchers have advocated enhancing moral reasoning in science classrooms through the discussion of socioscientific issues (SSI), especially genetics-related dilemmas (Andrew & Robottom, 2001; Demiral & Çepni, 2018; Evans, 2002; Sadler & Zeidler, 2002; Stock & Campbell, 2002; Zeidler, 1984; Zeidler et al., 2002; Zeidler & Schafer, 1984; Zohar & Nemet, 2002). SSI are complex and real problems for which solutions remain underdetermined (Kolstø, 2001; Zeidler & Sadler, 2008). SSI-based teaching can stimulate the consideration of moral issues and implications in students of various age groups, including middle-school, high-school, and university levels (Friedrichsen et al., 2016; Grace & Ratcliffe, 2002; Karakaş, 2022; Sadler, 2004a; Sadler & Zeidler, 2004;).

SSI-based science teaching is concerned with how students learn to engage in scientific issues that have significant associations with societal problems and issues. Social issues with conceptual and procedural connections to science provide ideal foci for science education as framed by the situated learning theory (Sadler, 2009; Sadler at al., 2017). In the context of SSI, real-life situations that are scientific in nature but are also influenced by other factors such as social, political and ethical issues, will challenge many individuals to exercise their scientific literacy and engage in scientific practices. SSI-based teaching empowers science learning and the development of scientific literacy, and it emphasizes the decision-making and negotiation of scientific issues for all citizens and not just those who will enter a scientific career. The learners will have the opportunity to engage in experiences such

as argumentations. Further, they could gain an awareness of the interrelationships among social, political, and scientific perspectives as they learn the importance of science content and practices such as argumentation, reasoning, and decision-making

The following aspects must be considered in the framework of SSI-based teaching (Presley et al., 2013).

(1) Design elements required for building instruction around a compelling issue, presenting the issue, providing scaffolds to engage in higher-order thinking practices and providing a meaningful conclusion.

(2) Learner experiences required to confront scientific ideas and theories related to the issue, collect and/or analyze scientific data related to the issue and negotiate the social dimensions of the issue.

(3) The familiarity that teachers must have with the issue being considered, such as knowledge about the science content related to the issue and awareness of the social considerations associated with the issue. To address controversial issues in the science classroom, teachers must have knowledge of a broad range of topics, including economics, politics, ethics, technology, health and environment (Ekborg et al., 2009; Yakob et al., 2015). Further, teachers may have to rethink their roles in the classroom. Specifically, teachers may shift from being the sole authority in the classroom to being a facilitator or a knowledge contributor (Presley et al., 2013).

In this study, we applied SSI-based teaching, specifically, situated learning and dialogic learning, for addressing bioethical issues. Underlying these strategies is the assumption that learning must be made meaningful to students. We used this framework to design a series of learning modules in which students were introduced to the moral dimensions of science and the complexity of issues so that they could engage in argument-driven inquiry in a democratic learning environment that provided settings for them to identify and research issues and to engage in ethical and critical inquiry in an authentic manner. The essential features of teaching bioethics were synthesized and incorporated into the well-established SSI approach are the theoretical underpinning of our intervention. This study developed the intervention using the SSI-based, bioethics enriched module named; Bioethics for Informed Decision (BID). The aim of this study was to examine the effect of an intervention on the improvement of students' moral reasoning scores on modern biotechnology applications. The means of moral reasoning scores across the semester before and after implementing an intervention was compared. In this light, this study seeks to answer the following research questions: how do the mean moral reasoning scores change over the course of an intervention? and compared to ordinary group (IPST), is it more effective in developing moral reasoning in high school students?

Literature Review

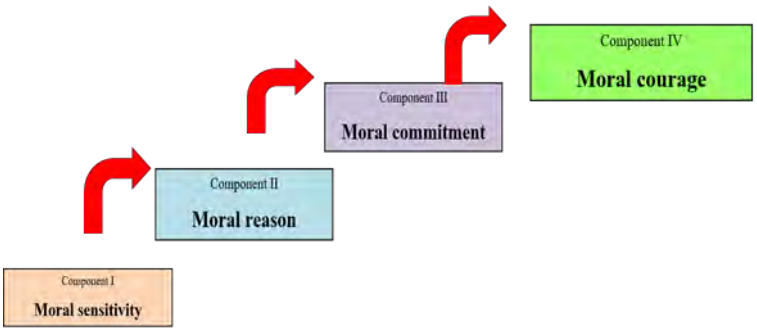
Morality and ethics are two key terms that need to be defined. The public may question the difference between the two. Morality and ethics are used interchangeably in most modern contexts, including those relevant to science education. Colloquially, "moral" tends to be used in more personal contexts whereas "ethics" is frequently invoked in professional settings. These are just linguistic conventions and do not represent ontologically disparate constructs (Zeidler and Sadler 2008). This paper uses "moral" and "morality" over "ethical" and "ethics," respectively, because these terms are compatible with the linguistic choices made by much of the literature that supports our arguments. However, the term "ethics" will be used when necessary to accurately represent the work and linguistic choices of other authors.

Theoretical Framework of Psychological Process in Moral

Rest's (1986) psychological process in moral provides a useful framework for moral development. Rest postulated a Four-Component Model of Moral Behavior (as shown in Figure 1) for the psychological process that contributes to moral decisions and behavior.

Figure 1

Four Components of Psychological Process in Moral



Note. Rest, 1986

This model considers the psychological processes that are involved when people behave morally, and it consists of four major psychological processes that must occur in order for moral behavior to take place. The first component is called moral sensitivity; there must be some sort of interpretation of the particular situation. It includes the consideration of actions that are possible in the situation, who are the concerned parties, and how they would be affected by the consequences of each action. The second component is called moral reason; one must be able to make a judgment about which course of action is morally right or fair and accordingly choose one possible line of action for what one ought to do in that situation. The third component is called moral commitment; one ought to prioritize moral values above other personal values such that an intention to do what is morally right is formed. Values motivate individuals to achieve goals and guide their behavior. The fourth component is called moral courage; it involves having courage and implementing skills to carry out a line of action even under pressure (Myyry, 2003).

In this study, we focus only on the second component, moral reasoning, owing to the difficulty in measuring the two subsequent components. These two components measure the intention and performance of an individual when facing a realistic dilemma that has many unpredictable conditions. A person will perform the latter two components when they face real situations in their daily life. It will be better for further studies to authentically measure and enhance them.

Although this study measured only the second component, moral reasoning we did not ignore the first component, moral sensitivity. According to the psychological process of morals, moral sensitivity is a prerequisite for moral reasoning (Figure 1). We incorporated moral sensitivity in teaching. Moral sensitivity was merged into teaching bioethics. We aim to encourage students to realize and be concerned about the consequence of the use of DNA technology, the moral dilemmas, and take different moral viewpoints of stakeholders in that scenario before making any decision

Essential Features of Teaching Bioethics

As we wish to enhance students' moral reasoning, we synthesized the essential features of teaching bioethics and incorporated them into a well-established SSI approach (Zeidler & Sadler, 2008). Underlying these strategies are the assumptions that learning must be made situated and

dialogic for it to be meaningful to students. We reviewed many interventions targeting bioethics and moral reasoning in school science contexts. We found that most of these interventions relied on the studies by Kohlberg (1969), Rest (1986), Sadler (2004b, 2009), and Sadler and Fowler (2006). We use the following five essential features of teaching biotechnology to guide the design and construction of our instructional modules.

Selection of a Provocative Issue That Connects the Student's Experience and Science Content

The teacher should search for and address a current moral dilemma that links to scientific contents and that the students can somehow connect with (Lazarowitz, 2014). The teacher needs to ensure that technical and scientific background information is presented concisely but with adequate detail to provide a suitable understanding for informing the ethical debate and to incorporate relevant scientific facts and content (Bryant & Velle, 2003).

Have Students Encounter Different Views and Engage in a Critical Discourse

The teacher should provide the students with an opportunity to consider, understand, and feel all stakeholders' perspectives and values through approaches such as role plays, public hearings, classroom debates and science dramas. Students need to deal with other students' different moral viewpoints (Bryant & Velle, 2003; Schuitema et al., 2008). Students need to conduct transactive discussions, defined as reasoning that operates on the reasoning of others, that help raise both moral and scientific reasoning (Schuitema et al., 2008; Turner & Chamber, 2006). Furthermore, students need a chance to critically examine all views presented and thereby argue and formulate a coherent, reflective, and well-justified response to the moral situations, both verbally and in written form (Johnson, 2010).

Encourage Students to Express and Justify Their Standpoint in a Respectful and Supportive Environment

A teacher should encourage students to develop, express and justify their own views to the public and learn from different perspectives. Further, they should discourage wrong ideas. All students can learn and benefit from each other's different viewpoints. Diversity in opinions is considered a crucial part of healthy skepticism. The teacher needs to create a sense of freedom and a respectful and democratic atmosphere in the classroom.

Train Students to Monitor and Regulate Their Moral Learning

Teachers should teach students how to think rather than what to think and to understand how they arrived at their decision (Bryant & Velle, 2003). Students need a chance to revisit their initial point of view and make a correction, if any, after exchanging views with others. Teacher should ask them to be reflective on their moral reasoning to reflect on their logical and moral thoughts (Schuitema et al., 2008; Turner & Chamber, 2006).

Teachers as Facilitators

Teachers are present throughout a discussion. However, apart from initiating and ending a group discussion, they should remain neutral and not ask biased questions. They should teach students how to deal with cultural diversity, and students should be able to contrast their different views (Bryant & Velle, 2003; Clarkeburn, 2002; Turner & Chamber, 2006).

Research Design and Methods

This study employed a quasi-experimental research design. The study involved two groups: control and experimental groups. The mean moral reasoning scores of these two groups before and after implementing an intervention were compared to examine the effect of the intervention.

Subjects

The subjects were 206 Grade 12 students from three high schools in the central part of Thailand. Before our intervention, all of them had learned fundamental and prerequisite genetics concepts on topics such as molecular genetics and DNA technology. These students were taught by three biology teachers who volunteered to participate in this study. Each teacher taught two intact biology classes. One class had a bioethics-focused module named Bioethics for Informed Decision (BID); it served as the experimental group (i.e., BID group). The other classroom used the standard curriculum developed by the Institute for the Promotion of Teaching Science and Technology (IPST), Ministry of Education of Thailand; it served as the ordinary group (i.e., control group). The control group employed case-based discussion as a main teaching approach; in this approach, a case was an issue that concerned the application of DNA technology. After introducing the case, the students engaged in either a whole-class discussion or were divided into pro and con groups based on their opinions for a discussion. In total, we had six classes (n = 206 students) that were assigned to the experimental group (three classes, n_1 = 87 students) and the control group (three classes, n_2 = 119 students).

The BID and the IPST group were taught under the framework of dialogic learning with the SSI approach but are different in details. The IPST group employed case-based discussion as the main teaching approach with a whole class debate on the advantages and disadvantages in an issue. While the BID provided students the opportunity to consider multiple perspectives from stakeholders related to that issue using a role play activity. The aim of BID focused not only the debating on the pros and cons of that issue but also focus on making decisions and how they reach their own standpoints using ethical inquiry. The teacher needed to ensure that students get enough the scientific background of that issue before making a decision. The teacher's role was neutral, not asking biased questions, and creating a sense of open-mindedness for different viewpoints.

Interventional Bioethics Modules

BID consists of five high-school biology modules on the topics of molecular genetics and DNA technology, as shown in Table 1. It was implemented in the experimental group.

Table 1

Science Content and Brief Description of Moral Dilemmas

	Bioethics for Informed-Decision Modules				
	XYY syndrome born to be bad	Gene therapy and Huntington's disease	GM mosquito	Alzheimer's disease and the secret letter	Thyroid cancer and genetic diagnosis
Science Contents	Chromosome mutation	Gene therapy	Gene insertion method	-Multiple allele -Genetic testing	- Inherited mutation - Pedigree

Moral dilemma in the application of DNA technology	Murderer who claims he has a genetic disorder	Your close friend who has a problem with a genetic disease	GM mosquito for resistance to malaria	Genetic testing for predicting chance of Alzheimer's disease	Genetic diagnosis for child who has a family history of cancer

The BID modules integrated SSI-based teaching and the synthesized essential features of teaching bioethics. We wished to enable students to develop moral reasoning skills so they could move beyond a "gut reaction" to more informed and critical positions. The goals of BID were to encourage students to ask moral questions, understand moral principles, and apply them and scientific understanding to make informed decisions considering various stakeholders' perspectives. We tried to cultivate critical reasoning skills, moral values and leadership in this "hard" biology topic. The implementation of the modules can be flexible depending on school contexts. We designed classroom activities, worksheets, materials and instructional guidelines, and trained the teachers. In each module, we provided scenarios related to the application of DNA technology that would create a moral dilemma. These scenarios included both fictional and realistic ones, and they were only introduced after teaching the corresponding science content. The students engaged in ethical inquiry through role-playing activities and structured discussions in a safe learning environment.

Instruments and Measures

The instruments and measures for moral reasoning were adapted from the studies by Clarkeburn (2002) and Fowler et al. (2009). We also created some additional scenarios related to the Thai context, such as "Golden Rice" and "BT cotton." Golden rice and BT cotton are transgenic crops. Golden rice is genetically modified to produce beta-carotene, which is not normally present in rice. Beta-carotene is converted into vitamin A when metabolized by the human body. We need vitamin A for healthier skin, immune systems and vision. But millions of people in Asia and Africa can not get enough vital nutritious food, thus this GM rice could be a better choice in countries whose populations are dependent on rice. BT cotton has been the insertion of one or more genes from a common soil bacterium, *Bacillus thuringiensis*. These genes encode for the production of insecticidal proteins as they grow. The genes that have been inserted into cotton produce toxins to caterpillar pests (Lepidoptera). BT cotton reduces farmers' use of insecticide and it helps them save cost. Moreover, a reduction in insecticide use may be beneficial for farmers' health and the environment by reducing pollutants. On the other hand, growing genetically modified crops would be concerned about the effect they would have in a long run. Could the crops negatively impact biodiversity? A possible threat to biodiversity may arise when genetically modified crops breed with wild species.

The test comprised four open-ended questions covering the application of DNA technology to health, the economy, society and the environment. The instrument began with a short paragraph introducing a complex, multifaceted dilemma that involved balance and trade-offs. To measure moral reasoning, students were asked to state their position and a justification for their choice. Their responses were interpreted and classified into one of the predetermined ordered categories according to a scoring rubric.

The content of the instruments was validated by experts and was pilot tested. After the pilot test, interviews were conducted with some students to gauge whether and how they understood the dilemma and the questions and to identify the items that caused them the most trouble. The instruments were revised based on the results of this pilot test.

Scoring Guide

The moral reasoning had a total score of 20 points; each of the four scenarios had five points. We adapted a five-level scoring rubric based on the study by Črne-Hladnik et al. (2012). Table 2 shows the scoring rubric used to measure the moral reasoning.

Table 2

Scoring Rubric for Measuring Moral reasoning, Along with Sample Responses

Score (point)	Levels	Sample responses
	Rationalistic moral reasoning	
5	Decision-making by considering reasons based on the intent of multidimensional moral principles or tradeoff between two or more options (mature/multidimensional moral reasoning)	"Even though worms will adapt to the resistance of BT cotton, at least we can reduce the use of chemicals or pesticides that are harmful to consumers and other living things" (Student ID 71)
4	Decision-making based on unidimensional moral principle or by considering only one dimension of moral consequence (immature/unidimensional moral reasoning)	"Amniotic fluid penetration is very risky because the child may get injury among other risks" (Student ID 124)
	No position / non-rationalistic moral reasoning	
3	Decision-making based on emotions or personal preference (moral emotion-based reasoning)	"For the peace of mind of the pregnant mother" (Student ID 173)
2	Decision-making based on intuition or vague or overly general reasons (moral intuitive-based reasoning)	"I think it should be better" and "Should be better than BT cotton" (Student IDs 41 and 42, respectively)
1	No answer or knowing that many options exist, both positive and negative, without making any decisions.	"I have no idea" (Student IDs 137 and 170)

Although, scoring students' responses by using the scoring guide is subjective, depending on the raters' perspective. In this study, we realize this credibility issue. First, we organized the rater training, for 3 raters in this study who all had a degree in Biological Science so the raters' educational backgrounds are not different. Second, each rater needs to be consistent with scoring students' responses in themselves to ensure that the scoring has intra-rater reliability. Lastly, inter-rater reliability, before analyzing students' responses, we have a focus-group meeting with 3 raters to clarify and make them understand predetermined categories. After analyzing students' responses, if one of the raters have a different result, we set up a meeting to ask them to justify their decisions and have discussion. If they could not reach consensus, we used 2 of 3 agreements from all raters to reach a decision.

Data Collection and Data Analysis

This study was conducted in the first semester of the 2017 academic year. The moral reasoning of all students across both groups was assessed before and after the implementation of the interventions. We described the data using descriptive statistics and then compared the means of the moral reasoning scores between the two groups before and after the implementation using

independent t-tests. In order to conduct t-test to compare means between two independent group will check assumption of t-test by conducting a normality test.

Findings

The mean moral reasoning scores of both groups were increased at the end of semester. Table 3 shows the descriptive statistics of students' moral reasoning in both instructional approaches before and after the implementation of the interventions. After the implementation of the intervention, the means of the moral reasoning score of the experimental group (Bioethics enrichment) were found to be higher than those of the control group (Ordinary case-based). The mean of the scores of the intervention group increased from 3.44 to 3.83 while mean scores of the control group increased from 3.42 to 3.51.

Table 3

Descriptive Statistics of Moral Reasoning Score Between Experimental and Control Groups Before and After the Implementation of the Intervention

Occasion of measurement	Instructional approach (modules)	N	Min	Max	Mean	Std. Deviation
Pretest	Bioethics enrichment	78	2	5	3.44	.665
	Ordinary case-based	100	2	5	3.42	.742
Posttest	Bioethics enrichment	79	2	5	3.83	.699
	Ordinary case-based	108	2	5	3.51	.702
Valid N (listwise)	Bioethics enrichment	63				
	Ordinary case-based	89				

Importantly, when we compared the means of the moral reasoning scores between the two groups before and after the implementation using independent t-tests because the normality test indicated normal distribution in the data as you can see in the table 4. The results showed before the implementation, the mean of moral reasoning scores of both groups were not statistically different while at the end of semester, the means of the intervention group were higher than that of the control group statically at $p < 0.01$ level. The students in the intervention group have increased their mean moral reasoning score than the control group.

Table 4

Independent t-test Results Comparing the Means of Moral Reasoning Score Between the Experimental and the Control Groups Before and After Implementing the Interventions.

Occasion of measurement	Instructional approach (modules)	N	Mean	SD	Independent sample test			
					Levene's test for equality of variance		t-test for equality of means	
					F	Sig	df	Sig (two-tailed)
Pretest	Bioethics enrichment	78	3.44	.655	.744	.390	176	.822
	Ordinary case-based	100	3.42	.742				
Posttest	Bioethics enrichment	79	3.83	.699	.053	.818	185	.002**
	Ordinary case-based	108	3.51	.702				

Note. **p<.01

Discussion

At the pretest, there is no statistically difference in the means of the moral reasoning scores between BID and IPST groups. The means of the moral reasoning scores of BID group is higher than IPST group statistically at the end of the implementation.

The IPST (control group), employed case-based discussion as the main teaching approach. In this approach, a case was an issue that concerned the application of DNA technology. After introducing the case, the students engaged in either a whole-class discussion or were divided into pro and con groups based on their opinions for a discussion. The IPST did not emphasize on moral questions, neither addressed moral principles and applied them to make a decision, nor take into account multiple perspectives from stakeholders. They mainly focused on the scientific understanding of the issue to make a decisions. An intriguing finding is that scientific content knowledge alone cannot enhance moral sensitivity (Clarkeburn, 2002). Consistent with Zeidler and Sadler (2008), moral reasoning that ignores real-world evidence is fundamentally flawed. Science classrooms that denied emotive venues of discourse in the discussion of social-science issues curtail student's moral development (Hancock et al., 2019; Herman et al., 2018; Zeidler & Sadler, 2008).

Our BID module made meaningful learning experience to students and enable them to develop moral reasoning skills so they could move beyond a "gut reaction" to more informed and critical positions. We tried to cultivate critical reasoning skills, moral values and leadership in this "hard" topics in Biology. Many science educators (Sadler, 2004a; Sadler and Zadler, 2005a,b) suggested a framework that highlighted three unique patterns of informal reasoning displayed in the argumentation elicited by genetic engineering issues; being rational, emotive and intuitive (Sadler and Zadler, 2005a). Morality contributed to the informal reasoning and argumentation of students who participated in socioscientific scenarios related to modern biotechnology applications, especially gene therapy and human cloning. According to this framework, students were introduced to the moral dimension of science from the complexity of the issues. They could then engage in argument-driven inquiry in a democratic learning environment that provides settings for them to identify and research the issues and to engage in ethical and critical inquiries in an authentic manner, for example, how students would make a decision in the case of a murderer who claims he has a genetic disorder if they were members of the courtroom. Levinson (2004) pointed out that exploring moral perspectives in biological studies would stimulate the interest of students and enable them to become socially responsible. The implementation of the BID modules can be flexible depending on school contexts. We only designed classroom activities, worksheets and materials, and gave teachers instructional guidelines. In each module, we provided scenarios about moral dilemmas of the application of DNA technology. These were both fictional or realistic and were conducted after teaching science content. The students engaged in ethical inquiry through role-playing activities and structured discussions in a safe learning environment.

Conclusion

The means of moral reasoning scores of students in the experimental group (BID module) were higher than those of students in the control group (IPST module) at the end of the semester. The BID modules include structured discussions and ethical inquiry activities based on situated learning and dialogic learning. These activities emphasized the ethical deliberations that lead students to face the implications of modern biotechnology applications from multiple perspectives, including human health, environment or ecosystem, and economics. Notably, BID module which integrated not only SSI-based teaching but also synthesized essential features of teaching bioethics explicitly can improve students' moral reasoning score. BID provided a more authentic way for the students to learn and respond to their peers who had opposing views. Some activities let them "in" a stakeholder so they would feel and think deeply on an issue through dramas, role plays, or debates. Ethics aims to instill good values in the minds of students, heighten their sensitivity to make better sense of social aspects of science education and increase scientific knowledge underpinning an issue, improve moral

reasoning, and become better people by making them more virtuous and more likely to implement normatively right choices (Reiss, 2006).

Implication

After the implementation of the intervention, the means of the moral reasoning score of the experimental group were found to be higher than those of the control group. We confirmed that classroom assessment should be ongoing and reflective and should inform teachers' teaching practice. Even though this moral reasoning does not occur "instantly," science teachers should not ignore it in their science classroom. Time and continuous practice are required for achieving better results for students. Science teachers need to move students beyond their initial reactions, not as a means of necessarily changing those views, but as a means for encouraging critical reflection. Students are expected not just to make judgments of scientific data; the real-world challenges them to consider what is right and what "ought" and "should" be done from the viewpoint of normative ethics. Finally, policymakers or stakeholders should consider the design of and provide professional development for enhancing bioethics education for science teachers so that they can effectively foster the moral dimension of science in their science classrooms.

Suggestions

In the present study, although the effect of BID module explicitly improves students' moral reasoning score over the course of one semester. More time is required to develop the ability of moral reasoning (Kohlberk 1969; National Research Council of Thailand 2013; Piaget 1932). Therefore, the change in students' moral reasoning over time needs to be systematically captured using a longitudinal data analysis framework.

Methodologically, we suggested the use of a longitudinal study with multiple repeated measurements over a longer period because moral reasoning is a psychological construct that needs time to nurture. It could help science teachers capture a holistic picture of the growth in students' moral reasoning, such as variations in initial status and rates of change among students. Future studies could use advanced statistical analyses, such as latent growth curve modelling, to explore the growth in learning and factors that might have an impact on students' growth of moral reasoning.

Importantly, we studied only the growth of students' moral reasoning while we omitted other factors such as teachers' experiences or school contexts that might impact students' moral growth. Researchers should explore these factors and examine their effect on the growth and development of students' moral reasoning, for example, beliefs, religion, the law, or students' economic status.

Acknowledgements

This research was supported by The Capacity Building of KU Students on Internationalization Program Scholarship from Kasetsart Universtiy and the Institute for the Promotion Teaching Science Technology (IPST), Thailand. Any opinions, findings, discussion, and suggestions or implication expressed in this material are those of the author(s) and do not necessarily reflect the views of universities and institute.

References

American Association for the Advancement of Science (AAAS). (1990). *Science for All Americans.* Oxford University Press.

Andrew, J., & Robottom, I. (2001). *Science and ethics: Some issues for education. Science Education, 85,* 769–780.

Antonio & Prudente. (2021). Metacognitive argument-driven inquiry in teaching antimicrobial Resistance: Effects on Students' Conceptual Understanding and Argumentation Skills. *Journal of Turkish Science Education*. *18*(2), 192-217.

Bryant, J., & Velle, L. B. (2003). A bioethics course for biology and science education students. *Journal of Biological Education, 37*(2), 91–95.

Chen, S. Y., & Raffan, J. (1999). 'Science for citizenship' for decision making and the social construction of scientific knowledge. *Science Education, 78,* 185-201.

Clarkeburn, H. (2002). A test for ethical sensitivity in science. *Journal of Moral Education, 31*(4), 439–453.

Črne-Hladnik, H., Hladnik, A., Javornik, B., Košmelj, K., & Peklaj, C. (2012). "Is judgment of biotechnological ethical aspects related to high school students' knowledge?" *International Journal of Science Education, 34*(8), 1277–1296.

Dawson, V. M., & Schibeci R. A. (2003). West Australian school students' understanding of biotechnology. *International Journal of Science Education, 25,* 57–69.

Dawson, V. M., & Taylor, P. C. (1999). Teaching bioethics in science: Does it make a difference? *Australian Science Teachers' Journal, 45,* 59–64.

Demiral, Ü., & Çepni, S. (2018). Examining argumentation skills of preservice science teachers in terms of their critical thinking and content knowledge levels: An example using GMOs. *Journal of Turkish Science Education, 15*(3), 128-151.

Ekborg, M., Ideland, M., & Malmberg, C. (2009). Science for life—A conceptual framework for construction and analysis of socio-scientific cases. *Nordic Studies in Science Education*, 5(1), 35–46.

Evans, J. H. (2002). *Playing God?: Human genetic engineering and the rationalization of public bioethical debate*. Chicago, IL: University of Chicago Press.

Fowler, S. R., Zeidler, D. L., & Sadler, T. D. (2009). Moral sensitivity in the context of socioscientific issues in high school science students. *International Journal of Science Education 31*(2), 279–296.

Friedrichsen, P. J., Sadler, T. D., Graham, K., & Brown, P. (2016). Design of a socio-scientific issue curriculum unit: Antibiotic resistance, natural selection, and modeling. *International Journal of Designs for Learning, 7*, 1–18.

Grace, M. M., & Ratcliffe, M. (2002). The science and values that young people draw upon to make decisions about biological conservation issues. *International Journal of Science Education, 24*, 1157–1169.

Hancock, T.S., Friedrichsen, P.J., Kinslow, A.T., Sadler, T. D. (2109). Selecting Socio-scientific Issues for Teaching. *Science & Education, 28*, 639–667.

Herman, B. C., Zeidler, D. L. & Newton, M. (2018). Students' Emotive Reasoning Through Place-Based Environmental Socioscientific Issues. *Research in Science Education. 50*, 2081-2109.

Hill, R., Stanistreet, M., Boyes, E., & O'Sullivan, H. (1998). Reactions to a new technology: Students' ideas about genetically engineered foodstuffs. *Research in Science and Technology Education, 16,* 203–216.

Hoffman, L. W., & Hoffman, M. L. (1964). *Review of Child Development Research*. New York: Russell Sage Foundation.

Johnson J. (2010). *Teaching Ethics to Science Students: Challenges and a Strategy. Education and Ethics in the Life Sciences.* ANU E Press.

Kahn, S., & Zeidler, D. L. (2016). Using our heads and HARTSS*: developing perspective-taking skills for socioscientific reasoning (*Humanities, ARTs, and Social Sciences). *Journal of Science Teacher Education, 27*, 261–281.

Karakaş. (2022). The effect of socioscientific issues-based discussion activities on the attitudes of primary school teacher candidates to the life science teaching. *Journal of Turkish Science Education. 19*(1), 17-36.

Kohlberg, L. (1964). *Development of Moral Character and Moral Ideology*. Univ. of Chicago.

Kohlberg, L. (1969). Stage and Sequence: The Cognitive Developmental Approach to Socialization. In D. Goslin (Ed.), Handbook of Socialization Theory and Research (pp. 347-480). IL: Rand McNally.

Kohlberg, L. (1984). *Essays on Moral Development Vol. II: The Psychology of Moral Development*. Harper & Row.

Kolstø, S. D. (2001). 'To trust or not to trust, ... '-pupils' ways of judging information encountered in a socio-scientific issue. *International Journal of Science Education, 23*, 877–901.

Lazarowitz, R. (2014). Moral, Ethics, and Human Values in Biology Education. High School Biology Curricula Development: Implementation, Teaching, and Evaluation from the 20th to the 21st Century. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education Volume II*.

Levinson, R. (2004). Teaching bioethics in science: Crossing a bridge too far?. *Canadian Journal of Science, Mathematics and Technology Education, 4*(3), 353–369.

Levinson, R., & Reiss, M. (2003). *Key Issues in Bioethics.* Routledge Falmer.

McComas, W. F. (2014). *The Language of Science Education.* Sense Publishers.

Myyry, L. (2003). *Components of Morality: A Professional Ethics Perspective on Moral Motivation, Moral Sensitivity, Moral reasoning and Related Constructs Among University Students*. Academic dissertation to be presented with the permission of the Faculty of Social Sciences of The University of Hellsinki.

National Research Council of Thailand. (2013). *Teachers and strengthening ethics to students.* Bangkok. (in Thai)

Nuffield Council on Bioethics. (1993). *Genetic screening ethical issues*. London: Author.

Owens, D. C., Sadler, T. D., & Zeidler, D. L. (2017). Controversial issues in the science classroom. *Phi Delta Kappan, 99*(4), 45-49.

Piaget, J. (1932). *The Moral Judgment of the Child.* London: Harcourt, Brace.

Pedretti, E. (1999). Decision making and STS education: Exploring science knowledge and social responsibility in schools and science centers through an issues-based approach. *School Science and Mathematics,* 99, 174–181.

Presley, M. L., Sickel, A. J., Muslu, N., Johnson, D. M., Witzig, A. B., Izci, K, & Salder, T. D. (2013). A framework for socio-scientific issues based education. *Science Education, 22*(1), 26–32.

Reiss, M. (2006). Teacher education and the new biology. *Teaching Education* 17, 121–131.

Rest, J. R. (1986). *Moral development: Advances in research and theory.* Praeger.

Sadler, T.D. (2004a). Informal reasoning regarding socioscientific issue: A critical review of research. *Journal of Research in Science Teaching*. *41*, 513–536.

Sadler, T. D. (2004b). Moral sensitivity and its contribution to the resolution of socio-scientific issues. *Journal of Moral Education 33*(3), 339–358.

Sadler, T. D. (2009). Situation learning in science education: Socio-scientific issue as contexts for practice. *Studies in Science Education, 45*(1), 1–42.

Sadler, T. D., Foulk, J. A., & Friedrichsen, P. J. (2017). Evolution of a model for socio-scientific issue teaching and learning. *International Journal of Education in Mathematics, Science and Technology*, *5*(2), 75–87.

Sadler, T. D., & Fowler, S. (2006). A threshold model of content knowledge transfer for socioscientific argumentation. *Science Education, 90*, 986–1004.

Sadler, T. D., Romine,W. L., & Topcu, M. S. (2016). Learning science content through socio-scientific issues based instruction: a multi-level assessment study. *International Journal of Science Education, 38*(10), 1622 – 1635.

Sadler, T. D., & Zeidler, D. L. (2004). The morality of socio-scientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education, 88*, 4–27.

Sadler, T. D., & Zeidler, D. L. (2005a). Patterns of informal reasoning in the context of socio-scientific decision-making. *Journal of Research in Science Teaching, 42*(1), 112–138.

Sadler, T. D., & Zeidler, D. L. (2005b). The significant of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education, 89*(1), 71–93.

Saunders, J. K., & Rennie J. L. (2011). A pedagogical model for ethical inquiry into socioscientific issue in science. *Research in Science Education, 43*, 253–274.

Schuitema, J., ten Geert, D., & Veugelers, W. (2008). Teaching strategies for moral education: A review. *Journal of Curriculum Studies, 40*(1), 69–89.

Stock, G., & Campbell, J. (2000). *Engineering the human germline: An exploration of the science and ethics of altering the genes we pass to our children.* Oxford University Press.

Tidemand, S., & Nielsen, J. A. (2016). The role of socioscientific issues in biology teaching: From the perspective of teachers. *International Journal of Science Education, 39*(1), 44–61.

Turner, D. V., & Chamber A. E. (2006). The social mediation of a moral dilemma: Appropriating the moral tools of others. *Journal of Moral Education, 35*(3), 353–368.

Wood-Robinson, C., Lewis, J., Leach, J., & Driver, R. (1997). Genetics and scientific literacy: The results of a research project and their implications for the school curriculum and for teaching. Paper presented at *V Congreso Internacional sobre Investigacion en la* Didactica de las Ciencias, Universidad de Murcis.

Yakob, N., Yunus, H. M., & May, C. Y. (2015). Knowledge and practices in teaching socio-scientific issues among Malaysian primary school science teachers. *US-China Education Review A, 5*(9), 634–640.

Zeidler. D. L. (1984). Moral issues and social policy in science education: Closing the literacy gap. *Science Education, 68*, 411–419.

Zeidler, D. L., & Schafer, L. E. (1984). Identifying mediating factors of moral reasoning in science education. *Journal of Research in Science Teaching, 21*, 1–15.

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education, 86*, 343–367.

Zeidler, D. L., & Sadler, T. D. (2008). The role of moral reasoning in argumentation: Conscience, character, and care. In S. Erduran and M. Aleixandre (Eds.), *Argumentation in Science Education* (pp. 201-216). Springer.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching,* 39, 35–62.