Supporting decision-making about SynBio-related SSIs in biology education

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Abstract

An important aim in science education is scientific literacy, in which students can negotiate science-related issues often including possible societal components. This means it is necessary for students to be able to negotiate and make informed decisions about socioscientific issues (SSIs). Synthetic biology (SynBio) is a new field between biology and engineering. Due to vast innovations and their potential impacts on society SynBio is a field were SSIs are expected to arise. Therefore, science education should prepare students to make informed decisions about SynBio-related SSIs. To do this student need to be able to use scientific knowledge, self-knowledge and societal knowledge to weigh their actions. To this avail a lesson module (*Synthetic biology - towards a critical perspective*) was developed by Fonseca Azevedo & Knippels (2017). The aim of this thesis was to contribute to SSI-based education by evaluating and further developing this lesson module on its potential to foster the decision-making and opinion-forming process of secondary biology students. To achieve this a design-based research approach was used to further develop the lesson module. In three case studies on two Dutch secondary schools, data was collected in three classes (n=85) of varying levels. The results showed that after the lesson module the students had gained personal, - and social knowledge, some knowledge of the concept and the consequences of SynBio and showed that in formulating an opinion almost all students substantiate their position with arguments, use arguments (pro and contra) and use rationality, sometimes in consortium with intuitions and/or care-based considerations.

Keywords: Design-based research; Opinion-forming; Socioscientific issues; Synthetic biology; Lesson module evaluation.

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Scientific literacy has become an important aim in science education internationally (DeBoer, 2000; Sadler, 2004). In the Netherlands, this is being done in biology education through the inclusion of "*Valuing and Judging*" (subdomain A9 exam program biology, College voor Examens, 2014) in the central examination programs and the emphasis on fostering active citizenship within Dutch policy nota's like: Onsonderwijs2032 (2016). Scientific literacy as defined by PISA (2015, p. 7) states "*The ability to engage with science-related issues, and with the ideas of science, as a reflective citizen*". Besides knowledge of science, nowadays the definitions of scientific literacy often include a societal factor (Sadler, Barab, & Scott, 2007). For example, Bron, Veugelers, & Vliet (2009) emphasize that students should be able to participate in public discussions on scientific issues and make informed decisions about problems using scientific knowledge. These definitions of scientific literacy infer the necessity for students to be able to negotiate certain socioscientific issues (SSIs). SSIs are issues with a scientific and a societal component that do not offer simple solutions. These issues are an expression of the developments in science and technology that are inseparably linked to the present-day socio-political landscape in industrialized countries (Levinson, 2006). Those scientific issues that need public input naturally have a societal component (Sadler, 2004). The argumentation and reasoning needed to make decisions in scientific issues differs from socioscientific issues. This is far more complicated in SSIs and decisions are affected not only by the scientific considerations, but also by culture, moral and ethical reflections (Braund, Lubben, Scholtz, Sadeck, & Hodges, 2007). The international want for scientific literacy in the curriculum is compelling when we consider our fast-changing society, which, due to the knowledge leaps being taken in scientific fields and engineering, is having greater (potential) effects on our society as a whole. So, to comply with demands from politics, policy and as a purpose in itself, educators are faced with the task to teach our students to become responsible citizens. Therefore, they should strive for students to become scientifically literate. SSI-based education can be a good way to support scientific literacy of students, as negotiating SSIs is crucial for the development of this scientific literacy (Sadler, 2004).

One of the fields on the fringe of science and engineering is synthetic biology (SynBio). SynBio is an interdisciplinary field where there is potential for SSIs to arise (Anderson et al., 2012; Tucker & Zilinskas, 2006). As SynBio is a relatively young field, it is defined in lots of different ways, but the overall concept in most SynBio definitions is the 'creation of new biological systems' (new as in: not found in nature). As such, SynBio is developing new and potentially very useful applications for society such as: sustainable fuels, new and cheaper medicine. However, potentially SynBio could also hold enormous risks, for the biological balance of our biosphere (through the introduction of bioengineered organisms) and because of its possible application in biological warfare. Besides this, the development of SynBio probably will raise ethical questions, as it already comes close to the creation of artificial life and raise social issues because of the possible soft impacts of applications like bioluminescent plants (see appendix 2 p. 48). This shows SynBio is a field with various potential socioscientific issues which students might encounter in their future. Therefore, SynBio is an important subject for science education to address, and potentially a good way to introduce SSI-based education into the classroom. Learning to negotiate SSIs thoughtfully is a way that science education can help students to improve their scientific literacy.

Learning to negotiate SSIs, has two important aspects: the forming of opinions and making informed decisions (Sadler, 2002; Waarlo, 2014). These two things - opinion-forming and making informed-decisions - in themselves have some requirements. Students should possess some scientific knowledge, self-knowledge and societal knowledge to be able to form an opinion and make an informed decision on SSI's. Knippels, Severiens, & Klop (2009) summarized different studies on opinion-forming and informed decision-making on moral issues and formulated five commonalities that are of importance in opinion-forming and informed decisions-making. These five can be seen as learning goals for students. Furthermore, in the development of lesson modules on opinion-forming Knippels & de Bakker (2016) described six didactical phases to guide lesson-design that fosters student's opinion-forming and informed decision-making process (descriptions of these and the five commonalities can be found on page 8). With these principles as a rough guideline a lesson module on SynBio (*Synthetic biology - towards a critical perspective,* Fonseca Azevedo & Knippels, 2017) has been developed.

'Synthetic biology - towards a critical perspective' was developed around SSIs that stem from actual developments in the field of SynBio, its potential implications for society and makes use of future scenarios developed by the Rathenau Institute. However, the lesson module has not been tested in classroom practice yet. To test the adequacy of the design it must be evaluated to see if it can foster the opinion-forming and informed decision-making process in secondary biology students in a classroom setting. Therefore, the lesson module will be evaluated through a designed-based research approach using several test situations in different classroom settings. As such, the purpose of this lesson module is to foster the opinion-forming and decision-making process through the development of scientific knowledge, self-knowledge and societal knowledge. The design aim of this research is to adjust the lesson module to withstand the rigors of the classroom, to see if the six didactical phases of Knippels & de Bakker (2016) can inform the design and to adjust the design accordingly. The overall aim of this study is to contribute to SSI-based education by evaluating and further developing the lesson module '*Synthetic biology - towards a critical perspective*' on its potential to foster the decision-making and opinion-forming process of secondary biology students.

Theoretical background

Scientific literacy and Socioscientific issues

Internationally, scientific literacy is a sought-after outcome of science education. To underline this Laugksch (2000) says that the progress of science depends for a large portion on public understanding and the support of a sustained program of science education and research and that this is of crucial importance to a nation's economic well-being. Also, Sadler (2004) states that science pervades in nearly all of modern society, and in order for such a democratic society to function its citizens must be able to consider and resolve scientific issues. Intuitively this points to the importance of scientific literacy. However, many different definitions of scientific literacy exist and as DeBoer (2000) states: without a clear definition of scientific literacy, it is not clear what science education has as its goal. In this study we use the National Science Education Standards definition. It defines a person to be scientifically literate when this person is able to "*use appropriate scientific processes and principles in making personal decisions*" and "*engage intelligently in public discourse and debate about matters of scientific and technological concern*" (National Research Council, 1996, p. 13). This definition of scientific literacy implies that scientific literacy is for everyone and not only for the academic elite. These ideas have permeated through to policy makers and thus scientific literacy has also appeared on the political agenda.

In 2005 in the Netherlands steps were taken to incorporate active citizenship into the curriculum. Scientific literacy can be seen as a part of active citizenship, as active citizenship is most valuable if citizens are involved with, and have a critical attitude towards society (Boerwinkel, Veugelers, & Waarlo, 2010). The competences for active citizenship, among others, are: being able to take a position on issues and to discuss this position and being able to accept other viewpoints (Bron & van Vliet, 2010). Now these components of active citizenship show a social factor in scientific literacy. This is affirmed by Sadler (2004) who argues that those scientific issues in need of public input (not those pertaining to professional science and scientists) always involve a societal factor. Also, Levinson (2006) argues that these issues (scientific issues in need of public input) refer to the difference between the nature and content of science such as: "*the perception of risk, interpretation of empirical data and scientific theories, as well as the social impact of science and technology*." These issues with both a scientific and a social factor are termed socioscientific issues (SSIs).

SSIs are open ended, complex and controversial issues with no easy answers (Sadler, 2004; Zeidler, Sadler, Simmons, & Howes, 2005). These issues can concern well-established science and deal with the implications of scientific evidence itself (type A), or concern with science-in-the-making and the nature of the scientific evidence (type B) (Ratcliffe & Grace, 2003). Because of the social factor in these issues they are laden with soft impacts (soft impacts are mostly considered to be subjective, emotional, one-sided and value-laden).

As the scientific problems that a citizen is likely to encounter are socioscientific issues. So, to be scientifically literate, people should be able to discuss and make informed decisions about SSIs (Kolstø, 2001; Sadler 2002; 2004). Sadler (2004) goes on to argue that SSIs even are an inextricable part of scientific literacy. And Zeidler and Nichols (2009) state that by studying SSIs, scientific literacy can be fostered. So, SSI-based education could be a good way to foster scientific literacy. Besides this, SSIs have some other advantages when using them in the classroom, as Knippels & de Bakker (2016, p. 13) explain: "*Discussing socioscientific issues in the classroom helps students to see the relevance of science in school, it makes students familiar with current issues and helps students create a realistic image of knowledge development, and the possibilities and the restrictions of science and technology*" thus creating interest and knowledge of the nature of science, which can be seen as lesson goals in themselves. Therefore, an important aim of science education is to foster students' ability to negotiate SSIs, and moreover, students should be able to use scientific processes and habits of mind to solve these kinds of problems they might encounter in their everyday life (Sadler, 2004).

Synthetic biology

Synthetic biology (SynBio) is an emerging field of biology where engineering principles are applied in the formation of new biological systems. SynBio was developed by building on old biotechnology and the development of new technology, for example the synthetic sequencing of DNA. With the help of these new technologies SynBio is designing standard components of cells (bio bricks). These components are then used in an effort to "engineer" biology and construct new biological systems or redesign existing biological systems for our purposes. SynBio has the long-term goal to convert bioengineered cells into programmable computers as to direct their operations (Tucker & Zilinskas, 2006). Some of the possible uses for these bioengineered cells are, the production of pharmaceuticals (efficient and cheap), the detection of toxic chemicals, the breakdown of pollution, the repair of damaged genes and the specific destruction of cancerous cells (Tucker & Zilinskas, 2006). The novelty of this field and its goals makes SynBio an area with the possibility to create a multitude of SSIs with enormous consequences for society. SynBio could have great potential benefits for our society but could also hold great dangers. Potential dangers are an escape of engineered organisms and their unknown or at least uncertain impact on our biosphere, organisms that are released for applied purposes that can cause dangerous side effects, and there is a chance that people will purposefully create harmful organisms (Tucker & Zilinskas, 2006). Besides this there are two more points of concern. The first is that evolution and mutation are still of influence on these organisms. The second is that there are legitimate ethical questions to be raised with the creation of synthetic organisms (Anderson et al., 2012). Because of how these risks and possible benefits of SynBio can impact our society it is imperative that the public is involved in the discussion on SynBio (Anderson et al., 2012). For now, SynBio-related SSIs deal with 'science-in-the-making' (type B SSIs, Ratcliffe & Grace, 2003).

The introduction of SynBio into a classroom can be difficult. A promising way to introduce SynBio-related SSIs is the use of techno-moral vignettes. Techno-moral vignettes (TMV) are future scenarios that tempt students to think about how science and technology will impact our society in the future. They were developed by the Rathenau Institute to inform the public debate about SSIs. Because they are situated in the future these scenarios are relevant for the students as they will be adults in the time the scenarios are situated (Boerwinkel, Swierstra & Waarlo, 2014) and they make students consider the concrete applications SynBio may have in the future. So, SynBio-related TMVs can be a good way to introduce SSIs to students in the classroom.

Opinion-forming and emotions

Opinion- forming and informed decisions-making is central to SSI-based education (Waarlo, 2014). Therefore, one of the aims of science education should be to teach students to use relevant information to weigh possible advantages and disadvantages of potential actions. In SSIs relevant information can be scientific, - societal, - and personal information. Scientific information is crucial to understand the precise nature of an SSI. One example of the importance of social information pertains to the fact that our society is messy and that issues within the social domain are often ambiguous, sensitive and laden with bad arguments. Therefore, learning activities that expose students to other perspectives on an issue besides their own can help students to become better at making logical and scientific decisions on SSIs (Zeidler et al., 2002). Personal information is important as the opinion-forming and informed decisions-making process starts here and it is crucial to know the implications of one's personal feelings and values.

The scientific debate about opinion-forming and informed decisions- making has been dominated by rationalists (Haidt, 2001). In the rationalist's models on moral judgement, emotions are discarded because they are irrational. However, Roeser (2006) argues that we need emotions to make rational decisions as people rely on emotions in making judgments concerning risks and that "*emotions are an indispensable normative guide in judging the moral acceptability of technological risks*" (Roeser, 2006, p. 690). Also, Haidt (2001) claims that emotions and intuitions directly influence moral judgements. He introduced the social intuitionist model (SIM) and argues that an emotion is formed first and is later supported by arguments. This underlines the importance of emotions in the opinion-forming and informed decisions-making process as emotions are at the very beginning of personal knowledge. Emotions are the first step in the opinion-forming process which is followed naturally by the decision-making process, when called for. The importance of emotions in the opinion-forming process when dealing with SSIs has been well supported by several authors (Zeidler, Sadler, Simmons, & Howes, 2005; Roeser, 2011; van der Zande, 2011). Therefore, emotions should be incorporated into learning activities to help support the opinion-forming process. Besides that, learning activities that help investigate the values behind emotions and reflect on other's values and perspectives, help students to negotiate future moral dilemmas (Van der Zande, 2011). So, it seems fruitful to take emotions as a starting point in learning activities that expose students to relevant scientific, - societal, - and personal information as to form an opinion and create awareness of the opinion-forming process with students.

Five commonalities and six didactical phases

Levinson (2006) says that despite measures to promote the teaching of SSIs there is limited consensus on how this should be conceptualized and addressed. Knippels et al. (2009) looked at several studies on opinion-forming and decision-making on moral issues such as SSIs and formulated basic commonalities that are necessary for a lesson to support the opinion-forming and informed decision-making process. The commonalities describe what students should be able to do, to form an opinion and make an informed decision. The commonalities are:

A. Students need to be capable of recognizing and extracting the, or a, moral question of the dilemma,
B. Students have to develop an awareness of the arguments and values that they and others use,
C. Students should be able to think through the consequences of a potential decision,
D. Students should be able to assess where to find and how to use the information needed to guide this process,
E. Students should be aware of all the steps that need to be taken in order to arrive at a well-informed opinion.

As these commonalities are more or less learning goals for students, they in their turn inspired the didactical phases of Knippels & de Bakker (2016) to inform how to reach the commonalities. Knippels & de Bakker (2016) described these six didactical phases for the teaching of SSIs, during the development of learning materials on opinion-forming.

1. The introduction of the dilemma (relating to the daily life of students and their interests),
2. Formulate initial opinion individually (or in small groups),
3. Creating a "need to know" by raising factual, - personal, - and/or social questions,
4. Opening a dialogue for the clarification and communication of personal values and those of others,
5. Forming of opinions and making informed decisions (scientific-, social, - and personal knowledge should inform the decision-making process, formulating conclusions and considering possible actions),

6. Reflection on the previous steps and the learning outcome.

These phases will be used to further develop and inform the design of '*Synthetic biology - towards a critical perspective*'. The learning and teaching activities (LTA's) of the overall design of '*Synthetic biology - towards a critical perspective*' should reflect the six didactical phases. Not explicitly mentioned in this phasing above (but part of the rationale behind the phasing, Knippels et al., 2016) is that the questions raised in the 'need to know' phase are subsequently explored by the students in different (more or less inquiry-based) learning and teaching activities. This is to explore their own questions and in doing so facilitate answering not only the students' factual questions but also personal, - and social questions and letting them thus explore the scientific concepts of the dilemma, as well as personal and societal values and beliefs.

The introduction of a highly complicated and developing scientific subject (like SynBio) can be difficult, because of the complexity of the scientific knowledge and the relation it should have to the possible soft impacts on society. The first phase of the didactical phasing is concerned with this introduction. As has been said techno-moral vignettes (TMVs) are a good way to introduce SynBio-related SSIs into the classroom. Besides this, TMVs have been proven to be successful in raising emotions and creating a "need to know" (Knippels & de Bakker, 2016; Ripken, 2015) as they raise factual and normative questions with students (Ripken, 2015; Slegers, 2014; De Ruijter, 2013). De Ruijter (2013) studied which of the TMV's developed by the Rathenau Institute were suitable for use in biology education, by looking at what kind of emotions and questions the TMV raised and what kind of underlying values and moral reasoning could be invoked by the TMV. It was concluded that TMV's are a good way to introduce moral dilemmas as it evoked "*emotions and a broad range of questions, values and reasoning types*" (de Ruijter, 2013, p. 18). One of those vignettes was used in the development of the lesson module '*Synthetic biology - towards a critical perspective*'. Furthermore, Slegers (2014) concluded that TMV-related learning and teaching activities were able to support students in attaining commonality A and partly in B (recognizing the dilemma and awareness of the arguments and values). Building further, Ripken (2015) designed and evaluated the first lesson of the lesson module '*Synthetic biology - towards a critical perspective*' on TMV-related learning and teaching activities. She also was successful in showing that these TMV-related LTA's supported attainment of commonality A. She was only partially successful in proving that reframing activities supported the students in attainment of commonality B. Reframing activities are activities that through the negotiation of issues familiarize students with interests, beliefs and values of others (Ripken, 2015).

The use of TMV's, TMV-related learning activities and reframing activities all have proven to help students reach the aims of phase 1, to a certain extent those of phase 2 and to create "need to know" (phase 3). But as the phases are interdependent, this research will focus on the evaluation of the

result of all six didactical phases. To evaluate the potential of the lesson module to foster the opinion-forming and informed decisions-making through the attainment of scientific knowledge, self-knowledge and societal knowledge by students. Therefore, the research question is:
To what extent does the lesson module '*Synthetic biology - towards a critical perspective*' foster secondary biology students' informed decisions-making process about SSIs?

To address this research question the following sub questions were formulated:

- To what extent does the lesson module evoke factual, - personal, - and social questions?
- To what extent is the lesson module able to support the student' conceptual development of SynBio?
- To what extent can students use arguments (pro and against), different argumentation types, scientific concepts and perspectives (other than their own) to formulate an informed-opinion?

Besides these sub questions the student's appreciation of the lesson module was assessed.

Methodology

To answer the research question a design-based research approach was used. In design-based research, the design of educational materials is combined with the development and/or testing of theory in the classroom (Bakker & Van Eerde, 2014). Design-based research (DBR) consists of roughly three phases: (1) an exploration and design phase (2) a test phase and (3) an analysis phase. These phases are cyclic in nature: the process of designing, testing it in practice, analyses of the tests, fine tuning the LTAs based on indications from classroom practice, and testing the adapted design again in a new case study or in classroom practice.

In this study, the first design phase was conducted by Karina Fonseca Azevedo as part of her internship for the Master SEC at Utrecht University. She designed the lesson module: '*Synthetic biology - towards a critical perspective'*. The first version of the module was used in the first cycle of this study and tested in two case studies. In total seven case studies were conducted in three schools in the Netherlands, Christelijk Gymnasium Utrecht, Leidsche rijn College Utrecht, and Jac. P. Thijsse College, Castricum (see table 1). The lesson module was taught by the regular biology teacher and all lessons were observed by a researcher. The teachers ranged in between 7 and 14 years of experience as teachers. After the first test phase, a hypothetical learning trajectory (HLT) was described (in retrospect) based on the learning and teaching activities of the lesson module of Azevedo & Knippels (2016). From the HLT it was extrapolated to what extent the six didactical phases were incorporated into the design. In the HLT the didactical phasing present in the design is described. Furthermore,

Table 1 General information on test schools and classes

n=number of students in the class

Test cycle	School	Stream	Grade	Subject	Abbreviation used	Age of students (years)	Number of students n= (female; male)
1	1	Pre-university education (VWO)	6	Biology	V6.2 V6.3	17-18 16-19	n=15 (3;12) n=19 (11;8)
2	2	Pre-university education (VWO)	5	Biology	V5E V5L	16-19 15-18	n=12 (2;10) n=29 (18;11)
-	3	Senior General Secondary Education (VWO)	4	Biology	H4.1 H4.4	15-17 16-17	n=20 (10;10) n=17 (13;4)
3	2	Pre-university education (VWO)	4	Natuur Leven en Technologie (NLT)	V4NLT	15-16	n=10 (5;5)

between test cycles the student's questionnaires (filled out at the end of the lesson module by the students) were analysed. Thereafter the design was adjusted to further incorporate the six didactical phases and to counteract problems or incorporate ideas based on the classroom observations and the student' questionnaires. The new version of the design was reviewed by the supervisor of this thesis and a biology education researcher. This whole process was repeated another three times. What should have been the third test cycle (school 3) has been excluded from this study, since the HLT was not implemented as intended, due to a miscommunication with the teacher regarding the level of the students and their prior knowledge.

Rationale for adjustments to the design

After the HLT was established, the original design was redesigned to better incorporate the didactical phases and to negotiate any problems that surfaced in the first test cycle (design phase 1). A PowerPoint presentation (PPT) was designed that could be used by the teachers while teaching the lessons with the hope it would keep teachers closer to the lesson design. The PPT was used by all subsequent teachers.

We will now describe the main changes to the learning and teaching activities (LTA's) after the different test cycles. For the initial HLT and the whole design see respectively appendix 1 and 2. For the final HLT with all LTA's see table 2.

Design phase 1. For LTA 0 (table 2) instructions were added to the teacher's guide as to introduce the concept of an SSI or dilemma (dilemma was the word used in the student material) and to discuss the learning goals at the start of the lessons, in order to make sure that SSI or dilemma as a concept was clear to the students. Discussing the learning goals was added as this is an effective way to inform the students of what they are expected to know or do after the lessons module and why. Besides, adding the discussion to the learning goals, enabled the teacher to link back to this at the end of the lesson module in the reflection phase (incorporating phase 6, reflection, more explicitly into the design).

LTA 6 ‘Making a decision’ was added to the design, to make the students explicitly formulate a decision on the case of “*Bioluminescent plants and DIY biohacker*” and its desirability. Besides making a decision on the given case the students were asked to consider the consequences, good and bad, and to evaluate their own competency in making a decision (assignment 4). This LTA was added to integrate didactical phase 5 (forming opinions and informed decisions) into the design and to set up didactical phase 6 (reflection) in the later LTA’s.

LTA 11, ‘Opinion-forming and values’ was adapted, firstly, a text was added on the importance of opinion forming and the role that personal values play. This was done to make the students aware of the current ideas about opinion forming and to further set up phase 6 (reflection) in order to use this further on in the design. Secondly, in order to strengthen phase 4 and 5 (dialogue of personal and other values and forming opinions and informed decisions) in the design, assignment 7 was changed to let students practise linking values to the ideas, opinions and emotions they formulated in the first lesson (see appendix 2 for full assignment). Then assignment 8 (students explain their answers on assignment 7 to each other) was added to practice the clarification of the student’s own ideas and to further explore those of others, and thus, strengthening phase 2 and 4 (formulate initial opinion and dialogue of personal and other values) into the design.

LTA 12, ‘Classical Reflection’ was added to reflect on assignments 7 and 8 and to further explore the student’s opinions, feelings and values. This supports the didactical phases 2, 4, 5 and 6 (see page 8 and 9). Besides that, from the students’ questionnaires, it could be concluded that group discussions are a popular element of these lessons for the students.

To LTA 15, the ‘disaster case’, an element was added to assignment 9 (see page 58), a value element was added. This addition made the students formulate possible values that could accompany the stakeholder’s motives. This was implemented to let the students consider and clarify the values of others (phase 4) in preparation of the open dialogue.

LTA 16 was added to the HLT to get the students to weigh ‘their’ stakeholder’s point of view against those of others and to come to a mutual decision. By adding this element awareness is raised about the power and the difficulties of compromise. This was as to incorporate phase 2, 4 and 5 (see page 8) further into the design.

Added to the ‘open dialogue’ (LTA 17), were instructions for the teacher to ask about the groups eventual decision and the compromises they made. This was to compare the decisions that were made throughout the class (to reinforce phase 2, 4 and 5 into the design).

Table 2 Final Hypothetical Learning Trajectory implemented in test cycle 3

Learning and teaching activity (LTA) Lesson 1	**Activity**		**Hypothesized learning results**	**Phase and data source**
	Teacher	**Students**		
LTA0: Introduction General introduction to the lesson and the video.	The teacher introduces the video (TMV) and explains what is expected of students. Provides the worksheets. Introduces the learning goals and explains in general what socioscientific issues/dilemmas are.	Listen to the explanation of the teacher. They can ask questions.	Students become aware of the nature of the video and the lesson.	1 Interview teacher, observation sheet
LTA1: **Video** Projection of the video in the classroom.	Starts the video	Watch the video	Students get engaged in the subject. Emotions and questions are raised. A "need to know" is created for students	1 and 3 Interview teacher, Workbook, amount and sort of questions raised Questionnaire
LTA2: **Identify questions, emotions and moral dilemmas** Articulation of personal questions, emotions and moral dilemmas. Students are asked to write down their initial thoughts, emotions and questions they had during the video	Is available for questions on the assignment and provides examples of emotions questions and moral dilemmas, if asked.	Answer assignment 1 individually on the students' worksheet.	Students articulate moral dilemmas they see with the TMV. Students articulate their initial questions and feelings on the dilemma.	2 3 and 4 Workbook
LTA3: New perspectives Developing awareness of other perspectives on a moral dilemma. Students explain their answers to the first questions to each other in duo's	Instructs students question their partner and to take notes of partner's answers and his or her explanation.	Ask questions Explain their own answers to their partner. Take notes on partner's explanations	Students see questions and emotions on the dilemma of their partners and by clarifying and discussing their own initial thoughts and emotions, students have to consider the underlying values. Students also gain insight to that someone else can deduce a different dilemma from the same TMV.	2, 4 and 5 Film, - and sound clips

LTA4: Classroom reflection Whole classroom reflection	Asks students about questions, emotions and dilemmas that were raised. Asks what information is missing? Makes notes of the answers on the board.	Share and discuss the raised questions, emotions and dilemmas.	Students become familiar with other perspectives through the questions and emotions on the dilemma of the whole class.	2, 3 and 4 Film, - and sound clips
LTA5: Article on Biohackers Articulation of questions, emotions and moral dilemmas raised by new information	Instructs students to read the article and formulate questions, feelings and moral dilemmas (assignment 3). Is available for questions.	Read the article and write down their questions, feelings and moral dilemmas (assignment 3).	Students recognize another perspective on SynBio and if this influences them to new questions, feelings and moral dilemmas.	2 and 3 Workbook
LTA6: Making a decision Deciding what or if to do anything about biohacking or glowing plants. Considering the consequences of their decision and their competence to make it and articulating their opinion	Instructs students make assignment 4 (decide on the regulation of the case and describe consequences of decision and the important arguments, articulate own opinion). Is available for questions.	Make a decision on the regulation of biohacking and glowing plants and describe the consequences of their decision and the most important arguments. Articulate their own opinion on SynBio	Students practice deciding on regulation, articulate why they take this course of action and consider pos. and neg. consequences of the decision. Consider if they have enough information to make this decision	5 Workbook
LTA6: Classroom reflection Has there been a change after reading the article in the student's emotions, questions and moral dilemmas? What kind of decisions have been made and what are their consequences	Asks if student's feelings and opinions have changed and why (not). Asks what decisions have been made and their consequences Makes notes on the board.	Answer the questions of the teacher. Give their own opinion	Through the discussion of the opinions of the class students see other perspectives on the dilemma. Become aware of any changes in their own or other perspectives.	2, 4 and 5 Film, - and sound clips

Learning and teaching activity (LTA) Lesson 2	**Activity**		**Hypothesized learning results**	**Phase and data source**
	Teacher	**Students**		
LTA7: Introduction General introduction to the lesson and the video.	The teacher introduces the video (SynBio) and explains what is expected of students. Provides the worksheets. Instructs students to read assignment 5 (what is according to the video SynBio?).	Listen to the explanation of the teacher. Read assignment 5 (what is according to the video SynBio?). They can ask questions.	Students become aware of the nature of the video, the lesson and assignment 5 (what is according to the video SynBio?).	Interview teacher, questionnaire and workbooks
LTA8: **Video** Projection of the video in the classroom	Starts the video, stops after 2.50 minutes to let students fill in first part of assignment 5. Then continues the video	Watch the video. Answer first part of assignment 5. Watch rest video. Finish assignment 5.	Students get engaged in the subject. Students reproduce the videos definition of SynBio and several applications and techniques of SynBio as to be able to recall them.	3 Interview teacher, Workbooks
LTA9: **Classical Reflection** Sharing and refining the answers. Recall questions of previous lesson. Small discussion	Asks students for their answers and makes corrections. Recalls questions on the scientific nature of SynBio of previous lesson and starts discussion with some questions.	State their answers and listen to other answers. Voice their thoughts and opinions.	Students refine the definition of SynBio, the techniques and applications and discuss these to facilitate their comprehension.	3 and 4 Film, - and sound clips and workbooks
LTA10: History, techniques and applications Assignment for comprehension of scientific concepts.	Instructs students to read the information and define SynBio and the difference with recombinant-DNA-techniques (assignment 6). Is available for questions on the text and the assignment.	Read the text. Define SynBio and the difference with recombinant-DNA-techniques (assignment 6).	Students must recall the definition of SynBio and compare it to recombinant DNA-techniques for better comprehension.	2 Workbooks

LTA11: Opinion-forming and values Text and assignment for comprehension of the opinion-forming process and underlying values	Instructs students to read the text and make assignment 7 (link values to the feelings, opinions and arguments formulated in lesson 1) and 8 (in pairs; explain answers to assignment 7). Is available for questions on the text and the assignment.	Link values to the feelings, opinions and arguments formulated in lesson 1(assignment 7) alone. And make assignment 8 in pairs (explain answers to assignment 7, discuss and question the values they hold with their peer).	Students read about opinion-forming and values. Students try to articulate their own values behind the opinions and emotions of previous lesson and question and answer their partner about their values.	2, 4, 5 and 6 Workbooks
LTA 12: Classical reflection Sharing and refining answers. Asking questions on opinion-forming and values. Small discussion	Asks students for their answers and makes corrections. Answers questions of the students. Initiate discussion.	State their answers and listen to other answers. Voice their thoughts and opinions.	Students refine the definition of opinion-forming and values to facilitate their comprehension.	2, 4, 5 and 6 Film, - and sound clips

Learning and teaching activity (LTA) Lesson 3	**Activity**		**Hypothesized learning results**	**Phase and data source**
	Teacher	**Students**		
LTA13: Introduction General introduction to the lesson and the video.	The teacher introduces the video (SynBio crisis) and explains what is expected of students. Provides the worksheets. Instructs the students to work in groups of 3.	Listen to the explanation of the teacher. They can ask questions.	Students become aware of the nature of the video and the lesson.	Questionnaire Interview teacher, Film, - and sound clips
LTA14: **Video** Projection of the video in the classroom	Starts the video	Watch the video.	Students get engaged in the subject.	1 and 3 Questionnaire Interview teacher, Film, - and sound clips
LTA15: **Stakeholders** Investigations of the stakeholders in a hypothetical case study	Instructs the students to make assignment 9 (reflect on the possible motives of the stakeholders of the case and the underlying values) in the groups. Is available for questions.	Reflect on the possible motives of the stakeholders of the case and the underlying values (assignment 9).	Students reflect on the relationship of different stakeholder before the crisis and their underlying values as to prepare them for the open dialogue and to imagine other's points of view. Practice critical thinking.	2, 4 and 5 Film, - and sound clips and workbooks
LTA16: Open dialogue Classroom dialogue with central question: Is SynBio desirable?	Puts perspective-table on the board. Asks students about their compromise and to reflect on the consequences of their decision. Starts the dialogue with the central question.	Have an open dialogue were no positions have to be defended. Listen to each other.	Students will become more aware of the differences between opinions. Become aware of the values behind the opinions. Practice critical thinking.	2, 4 and 5 Film, - and sound clips

LTA17: Form a well-considered opinion	Askes students to make assignment 10 (formulate their own opinions on the desirability of SynBio.).	Formulate down their opinions on the desirability of SynBio (assignment 10).	Students articulate a well-considered opinion	5 and 6 Workbooks
LTA 18: Module closing	Then close the lesson with a small recap of the lesson module. Highlighting the opinion forming steps that are important in this module and the learning goals.	Listen and answer questions of the teacher	Students become aware of opinion forming steps that are important in this module.	6 Film, - and sound clips Interviews teacher and students.

Design phase 2. After a superficial analysis of the students' workbooks and the students' questionnaires no major changes were made in the HLT. The learning activities were well understood by the students. In the questionnaires students complained of vague questions but the students' written answers in the booklets did not support this. Some minor changes, predominantly in the construction of questions and the layout were made for the benefit of clarity. For example: assignment 4 part 3 (appendix 2, page 50) was rewritten as it did not illicit the kind of answers that were wanted. Assignment 7 and 8 were put in the same (table-) format as assignments 1 and 3 for continuity. Furthermore, classroom observations revealed several deviations from the design by the teacher. For example: LTA 17 the 'open dialogue' was mostly performed as either a Q and A sessions with students or as a form of debate, although the importance of the openness of this element was extensively discussed in the teacher's guide. So, more effort should be put into the preparation of the teachers by the researcher.

Design phase 3. As the test phase (school 3, see table 1) preluding this design phase was considered to have failed the changes in this design phase were mostly build upon earlier concluded problems.

In LTA 6, assignment 4 part 3 was altered (to ask students their opinion on SynBio, their view of SynBio on a whole and the desirability of the techniques used). The previously question asked students to judge their ability to make a decision on the dilemma. This was found to be steering the answers, for research purposes it was thought desirable to ask a question akin to assignment 10 (asking students to formulate an own opinion on the developments of SynBio) as to track the opinion of the students on synthetic biology throughout the lessons.

Wording of assignment 2 and 8 (both asking students to discuss previous answers with a classmate, see appendix 2 page 47 and 57) were changed in order to clarify what it was that the students had to do in the small groups and get them to actually question their peers on each other's feelings, opinions, fears and accompanying values of the subject.

LTA 16 was left out of the design. This assignment was found to be unclear to most of the students and teachers. This assignment was not replaced with another because of a lack of time and because the students did like the conversational elements in the design and these were the elements that tended to be cut because of the lack of time.

LTA 18 was added to the design as a reflection element (phase 6) on the lesson module. So, the teacher can solidify the important elements of the lesson and recap the steps useful for opinion forming.

Some small changes to the teacher's guide were made to get them to check the student's comprehension of the video's and emphasize the importance of values in the opinion forming process.

Data sources and collection

To assess the effectiveness of the designed LTA's and to answer the research question several types of data were collected (see table 3 for all collected data). Data collection was guided by the curriculum levels of van den Akker, Kuiper & Hameyer (2003), the intended, - implemented, - and attained curriculum levels and were assessed by the following data sources:

- During the implementation of the lesson module in practice, classroom-observations were made on how the teacher and the students carried out the teaching and learning activities, to assess if the lesson was implemented as intended
- After the lessons, a questionnaire (see appendix 3) was administered to all students to assess how the students perceived the learning activities, their opinion, their idea of the learning outcomes and to get some background information about the students
- All lessons were videotaped, and audio-recordings were made of smaller groups off students during the lessons, these were not used in this research
- Semi-structured interviews (for protocol see appendix 4) of about 10-15 min were held and audio-taped with both the teacher (individual) and students (in pairs) after the lesson module to assess how the lesson was perceived, to see if the learning goals were reached and for the students to elaborate on their answers in the questionnaire
- The worksheets were collected and analysed to assess the attained curriculum (see appendix 2)

Table 3 Lesson attendance and collected data

hw=homework, A= assignment

Test cycle	class	# work-books collected	A 1	A 3	A 6	A 10	Questionnaires	Inter-view students	Inter-view teacher
1	V6.2	4	0	0	2	0	15	0	1
1	V6.3	17	0	0	6	14	19	0	1
2	V5E	12	0	0	12	0	12	1	1
2	V5L	27	24	24	24	26	29	1	0
3	V4NLT	10	6	6	9	10	10	1	1

Data analysis

All data that was used in the data analyses was transcribed verbatim. A second independent-researcher coded all the students‘ answers as a measure of an interrater reliability.

Workbooks. To determine what questions were raised by the SSI, answers on assignment 1 and 3 were analysed. This was done for test cycle 2 class V5L and test cycle 3 class V4NLT. Assignment 1 and 3 askes students to write down their feelings, questions and the moral dilemmas concerning two cases, the TMV (Bioluminescent trees) and "*Bioluminescent plants and DIY* *biohacker*" (for both cases see appendix 2) The questions posed by the students in these assignments were sorted into two categories: 'factual questions' and 'normative questions'. The latest category was subdivided based on the nature of the questions into: personal and social questions.

To determine to what extent the students developed a conceptual understanding of SynBio, the students' answers on assignment 6 of the workbook were analysed. Assignment 6 stated: "*Write down the definition of Synthetic biology and explain how synthetic biology differs with traditional recombinant-DNA-technology*." (for definition see appendix 5). A coding model (see appendix 5) was used to analyse all the students answers and given a score (-, + or ++) depending on the number of correct elements in their answer (0 to 2 elements). The analyses of assignment 6 had a 74% intercoder-agreement.

To determine to what extent students could use different elements to formulate an informed-opinion, the students' answers on assignment 10 of the workbook were analysed. Assignment 10 asked the students to: "*Give your opinion on: which course we should take concerning the development of synthetic biology at this time*", students' answers were analysed to determine several elements in their opinion:

- their position (pro, pro under conditions or against),
    - the intercoder-agreement for the student's position was a 100%.
- the number of arguments they used (including the number of argument in favour and opposed).
    - the intercoder-agreement for the arguments the students used was 83%.
- the type of reasoning that the students used in their opinion were determined: rationalistic, -intuitive, - and emotive reasoning (Sadler & Zeidler, 2005)
    - the intercoder-agreement for the type of reasoning of the students was 63%.
- if the students used any scientific concepts in the articulation of their answers
    - the intercoder-agreement for the use of scientific content was 66%.
- the number of perspective they used in their answers (see appendix 6 for the analytical guidelines)
    - the intercoder-agreement for the use of perspectives was 83%.

Questionnaires. To determine how the students valued the lesson module a 5-point Likert-scale analyses was done of the questionnaire item: "*How do you value the lesson module?*" students answered in two different scales: very difficult – very easy and very enjoyable – not enjoyable at all (see table 7). Furthermore, it was determined if there were any overall trends found in the answer to the open questions: What did you find to be the most fun, no fun at all, the hardest and the easiest?

Interviews. The audio-recorded interviews with teachers and students, were transcribed verbatim and were searched as to find quotes that have barring on the results of this research.
In table 3 the lesson attendance and all the data sources that were used in the analyses are shown.

Results

The result will pertain to class V5 L of test cycle 2 (now referred to as test cycle 2) and test cycle 3 because test cycle 3 had only ten or less student answers to contribute to the data. Besides this, the changes to the HLT between the second and third test cycle were minimal. The results will look at the development of scientific, - social, - and personal knowledge of the students as to determine to what measure the lesson module fosters the informed-decision making process on SSIs.

Intended curriculum

The lesson module was not always implemented as was intended. The deviations from the HLT were observed in class by a researcher during the implementation of the lesson. The main problems were: the open dialogue, phase 6 and time management. The open dialogue, as can be seen in the final HLT (table 2), features heavily in the design. The problem was that most teachers and, for that matter, the students are not used to this activity. In test cycle 2 this LTA was not implemented as intended, it was more a closed dialogue with the teacher as she wanted to make sense of the module for the students. In round 3 the dialogue was implemented as intended. Phase 6 (reflection on the previous steps and the learning outcome) was passed over in both cycle 2 and 3. This was due to time constraints, but it also had to do with the preparation of the teachers as they did not exactly know the steps of opinion-forming used in the lesson module they could not reflect upon them.

Questions raised

The two SSI-cases in the module on average raised 3.0 and 2.7 (respectively test cycle 2 and 3) questions on assignment 1 (LTA 2: *Fill out the table below with the feelings, moral dilemmas and questions occur to you when seeing the video Bioluminescent trees*) and 2.8 and 2.0 questions on assignment 3 (LTA 5: *Fill out the table below with the feelings, moral dilemmas and questions occur to you after reading the article ‘Bioluminescent plants and DIY biohacker*). The measure of factual questions far outweighs the measure of normative questions (see table 4). Of the normative questions a little more social-questions were formulated by the students than personal questions. Most factual questions, besides a couple of questions that concerned general biology or SynBio knowledge, were directed at the content of the case, such as the technical details of bioluminescent trees and the biological facts around bioluminescent trees and society. Most of the normative questions concerned why we should use the products highlighted in the cases and the ethical question of how far we will or

Table 4 Analyses of assignments 1 (Fill out the table below with the feelings, moral dilemmas and questions occur to you when seeing the video Bioluminescent trees) and 3 (Fill out the table below with the feelings, moral dilemmas and questions occur to you after reading the article 'Bioluminescent plants and DIY biohacker') of the workbooks

a=assignment, n= number of students' answers

		2nd test cycle 5V L n=24		**3rd test cycle** V4NLT n=6		**Examples**
		A 1	A 3	A 1	A 3	
Factual questions		68	50	11	6	LRC5VLQ1L1: *How do you create trees that give light?*
						LRC V4NLTQ1L3: *What if people get infected and start giving light?*
						LRC5VQ1L26: *How much does it cost to make a luminescent tree?*
						LRC 4VNLTQ1L7: *Why is it necessary for plant to give light instead of lampposts?*
						LRC V4NLTQ1L8: *How do you feed light to plants?*
Normative questions	Social	3	15	4	4	LRC5VLQ3L5: *How far will we take this?*
	Personal	2	8	3	3	LRC V4NLTQ3L8: *Can you still sleep with a luminating plant?*

may take this (SynBio). Furthermore, it is noteworthy that assignment 3 evoked a larger percentage of normative questions then assignment 1, in both test cycles. And that in test cycle 3 the percentage of normative questions was higher than in test cycle 2, although on average the students in test cycle 2 formulated less questions than those in test cycle 2.

Conceptual development

Students' understanding of SynBio was determined by analysing assignment 6 (LTA 10, '*Formulate the definition of synthetic biology and explain how it differs from traditional recombinant-DNA-technology*' appendix 2, table 5). In terms of percentage both test cycle 2 and 3 just about scored the same on this assignment, with test cycle 2 scoring marginally better. Notable is that it seems that none of the students, in any of the test cycles, exactly copied the definition from the workbook, which they should have read just before answering assignment 6. This could prompt the question if the students read the text at all. In the subsequent interviews (n=2) at least one of the students showed she could retain the information when asked "*What is SynBio?*", stating: "*Sort of making new DNA instead of cutting and pasting. So, you make the DNA yourself and only what you think is best, or what is the best.*" (Interview students LRC 5V, line:89-90).

Table 5 Analyses assignment 6 (Formulate the definition of synthetic biology and explain how it differs from traditional recombinant-DNA-technology)

n=number of students' answers

Test cycle	**2**	**3**		
Score	n=36	n=9	Total	Example students' answers
++	10	2	12	*"Converting DNA to have a specific function. When you have for example a yeast cell and you want it to have a specific function, you add the desirable DNA to the yeast cells. In the past you would have to cut the desirable DNA from other DNA, now you can make it yourself with a computer."* (assignment 6, V4NLT student 1)
+	25	6	31	*"Synthetic biology is making pieces of DNA yourself. This differs from recombinant-DNA-technology, for that you need existing pieces of DNA."* (assignment 6, V4NLT student 7)
-	1	1	2	*"With synthetic biology something alive is literally created from inorganic compounds. The difference with recombinant is that you still use the function of the cell and with synthetic a machine does that."* (assignment 6, V4NLT student 6)

Opinion-forming development

The development of the students' opinion-forming was determined by analysing assignment 10 (LTA 17, *Give your own opinion on which course of action we should take considering the development of synthetic biology right now*). This analysis consists of several elements: the position of the student, the number of argument they used (for and against), the type of reasoning students, the use of scientific concepts and the use of perspectives. See table 6 for the whole analyse. For the analyses guidelines see appendix 6.

Position in opinion. The analyses of assignment 10 showed that not very many students held outright position (pro or against) without any substantiation in their opinions on the development of SynBio. In test cycle 2, 88% and in test cycle 3, 90% of the students were pro but expressed some form of conditions under which the development of synthetic biology could or should continue. Most students considered that although SynBio has some serious risks it can also have at least equally great benefits. Most conditions that were set were not very specific, they mostly pertained to some form of control, such as: "good" or "strict" rules to rein in the risks of SynBio, for example: "*I think as long as there are good rules SynBio can continue*" (assignment 10, V4NLT student 7). A lot of the students seem to think that science can determine what the risks of SynBio, or a specific technique, will be so after this is deemed save we can move forward with SynBio.

Arguments. The average number of arguments that students used in their written opinion in test cycle 2 was 2.8 and in test cycle 3 it was 2.2. Per test cycle there was one student that did not use any arguments as opposed to respectively 25 and 9 students that did. The students that did not use

Table 6 Analyses of assignment 10 (Give your own opinion on which course of action we should take considering the development of synthetic biology right now)

	Test cycle 2	Test cycle 3		Examples from the students' workbooks
Class	V5 L	V4 NLT	Total	
n (number of students' answers)	26/27	10/10	36	
Position				
Pro	1	0	1	*"I think we should support SynBio and encourage new developments like these"* (assignment 10, V5 L student 6)
Against	2	1	3	*"By weighing the pros and cons I would conclude that under harsh rules we could use SynBio. But this could also get out of hand so in the end I would totally forbid it."* (assignment 10, V4NLT student 1)
Pro under conditions	23	9	32	*"Because it's new it's scary but I think we should give it a chance. And if anything goes wrong we adjust and try again."* (assignment 10, V5 L student 17)
Undecided	0	0	0	
Arguments				
Total # of arguments	73	22	95	
# arguments for	40	13	53	*"There are enormous advantages, like: cheap medicine, sustainable fuel and agrarian stimulation"* (assignment 10, V5 L student 1)
# arguments against	33	9	42	*"I think we should let nature be otherwise things could get a bit out of hand,"* (assignment 10, V5 L student 26)
Average # used	2.81	2.20	2.64	
# students that did not use arguments	1	1	2	
# students that used arguments	25	9	34	
Reasoning type (more than one type can be used by one student)				
Rationalistic reasoning	26	9	35	*"I am of the opinion that SynBio can only be used (out in the open) if this has an advantage for the health of people."* (assignment 10, V4NLT student 3)
Emotive reasoning	4	3	7	*"Another disadvantage is that people could be intimidated by the unnatural of it"* (assignment 10, V4NLT student 1)
Intuitive reasoning	6	1	7	*"I think it best for everyone if we use SynBio as much as possible to make new things."* (assignment 10, V5 L student 15)
Use of scientific concepts				
Yes	21	6	27	*"Also, I think that they should not sell DNA via the internet cause then millions of people get their hands on these techniques and then things could go amiss very badly, and they would not be able to restore them."* (assignment 10, V4NLT student 4)
No	5	4	9	
Perspectives (other than own)				
Average # used	0.31	0.30		
# students that used perspectives	8	3	11	*"I understand for example that farmers would want to use it because of the improved results they could get."* (assignment 10, V5 L student 11)
# students that did not use perspectives	18	7	25	

arguments just stated what they thought would be the best way to proceed with SynBio. For example: "*Controlled research/applications in heavily secured research laboratories.*" (assignment 10, LRC V4NLT student 5). The students that did make use of arguments had, in test cycle 2, 40 arguments and in test cycle 3, 13 arguments in favour of the development SynBio to respectively 33 and 9 arguments against. Most pro arguments highlighting the benefits for society like: cheaper medicine and better crop yields. For example: '*It* (SynBio) *can offer sustainable solutions for the good of the earth… And also, solutions for food shortage are desirable*" (assignment 10, LRC V5 student 5). The against arguments were less specific as they spoke often of "the risks of SynBio" to people and/or nature, making weapons and questioned the general 'usefulness' of these techniques. For example: "*SynBio should not be used because it is fun, like creating luminescent trees but for things that have some social benefit*" (assignment 10, LRC V5 student 3). As most students held a 'pro under conditions' position one might have expected a larger difference in 'pro' to 'against' arguments, but this was not the case. The ratio of 'pro' to 'against' arguments was approximately the same for both test cycles, about 6:4.

Types of reasoning. All students except one used rationalistic reasoning, sometimes in conjunction with emotive or intuitive reasoning. Most emotive reasoning was used by the students to emphasize that they thought the well-being of others was important factor and for some even the feelings of others was an important factor. For example: "*More drawbacks are that some people might be intimidated by the 'unnatural' it is.*" (assignment 10, V4NLT student 1). In terms of percentage test cycle 3 had a higher use of emotive reasoning than test cycle 2. Test cycle 2 had a higher percentage of students using intuitive reasoning, 23%. While in test cycle 1 only 1 student used intuitive reasoning (10%). Students used intuitive reasoning to express the feeling they had about the development of SynBio, these were mostly positive. For example: "*I think the developments of synthetic biology is not bad*." (assignment 10, LRC V5 student 27).

Use of scientific concepts. In test cycle 2, 81% of students used scientific concepts in their own opinion and in test cycle 3, 60%. Scientific concepts was used in a broad sense of the word, so not only pertaining to the scientific workings of SynBio but also its consequences. For example: "*Like this SynBio can offer sustainable solutions what could be good for the earth."* (assignment 10, LRC V5 student 6).

Use of perspectives. In test cycle 2, 31% of the students used in their opinion a perspective that was not their own (such as: people in poor countries that could benefit greatly from the development of SynBio), either to underpin their argument or to investigate it from another angle. In test cycle 3 this was 30%. Mostly the students sought to see the risks of SynBio might be more acceptable because it might help people in other countries that do not have the food surety or access to affordable medicine that we have in western countries. For example: "*I think it should be implemented in poor countries especially. Maybe people there can then buy medicine as it becomes affordable.*" (assignment 10, V4NLT student 2). Furthermore, some students could see that the development of new techniques could scare people. For example: "*People should be confronted with synthetic biology in daily life, so they get the time to get used to these new developments.*" (assignment 10, LRC V5 student 6).

Experiential curriculum

To assess the students' opinion of the lesson module an analysis of the student questionnaire was made. On the questionnaire item: "*How do you value the lesson module?*" students answered on the two different scales, form very easy to very difficult and from not enjoyable at all to very enjoyable (for numerical scale see table 7). A Likert-scale analyses (see table 8) yielded an overall enjoyability of 3.5, somewhat above neutral on the enjoyable side of the scale. The overall difficulty was found 2.8, somewhat towards the easy side of the scale. The scores per test cycle can be found in table 8. The classes in their 5th year found the lesson module to be slightly easier than the classes in their fourth year.

Table 7 Numerical scale of questionnaires items

Scale	Enjoyability	Difficulty
1	Not enjoyable at all	Too easy
2	Not enjoyable	Easy
3	Neutral	Neutral
4	Enjoyable	Difficult
5	Very enjoyable	Too difficult

Table 8 Likert-scale analyses of questionnaire

Test cycle	Class	Enjoyability	Difficulty
2	V 5 L	3.4	3.1
3	V 4 NLT	3.3	2.7
	Total	3.5	2.8

The open questions: "*What did you find to be: the most fun, no fun at all, the hardest and the easiest?*" of the questionnaire got very mixed responses. Moreover, quite a few students did not (entirely) fill out this part of the questionnaire. Still some elements were mentioned more than others. The students thought the most fun of the module was: the open dialogues (or as they called them: discussions) with the class and watching the videos. The least fun was had with: the amount of writing, "constantly" writing about emotions and 'vague' assignments. Students considered working with values, the use of English in the videos and working with opinions and emotions the hardest. Easy was thought to be: working with your own opinions (because they are always correct) and the discussions with the class.

Conclusion

The aim of this study was to contribute to SSI-based education by evaluating and further developing the lesson module '*Synthetic biology - towards a critical perspective*' on its potential to foster the decision-making and opinion-forming process of secondary biology students. It has already been proven that the use of TMV's, TMV-related learning activities and reframing activities help students reach the aims of didactical phase 1 (see page 8), to a certain extent those of phase 2 and to create "need to know" (phase 3). This thesis focussed on implementing all six didactical phases in the lesson design and evaluated the potential of the lesson module to foster the opinion- forming and informed decision-making through the development and use of scientific knowledge, self-knowledge and societal knowledge by students. So, the research question was:

To what extent does the lesson module '*Synthetic biology - towards a critical perspective*' foster secondary biology students' informed decisions-making process about SSIs?
The research question was answered by means of three sub questions:

- To what extent does the lesson module evoke factual, - personal, - and social questions?
- To what extent is the lesson module able to support the student' conceptual development of SynBio?
- To what extent can students use arguments (pro and con), different argumentation types, scientific concepts and perspectives (other than their own) to formulate an informed-opinion?

Questions raised

To see what kind of questions were raised (sub-question 1) by the students on the two cases (see pages 47 and 48) were analysed. The first case, bioluminescent trees, was the TMV (techno-moral vignette) and discussed a hypothetical situation concerning SynBio made bioluminescent trees, the second case discussed the situation here and now were do-it-your-self bio-hack packets and bioluminescent plants are already for sale. The results from this analysis show that factual, - personal, - and social questions were raised by the two cases. The difference in the percentage between normative, - and factual questions (only assignment 3, test cycle 3 was 50-50 the rest was heavily in favour of factual questions) can be explained by the fact that this was a biology class, so the students are focussed on the factual side of things and by the certitude that students are rarely asked about normative cases, let alone in a science class. This does however show that a "need to know" was created with the students. Furthermore, this is underpinned by the rise of normative questions from assignment 1 to 3. Suggesting that once accustomed (practiced and discussed), the students find it easier to negotiate their own and other emotions and think of and formulate normative questions. Showing that the didactical phases (1 through 4, see page 8) work here to develop students' personal and social knowledge.

Conceptual development

As a measure of the student's conceptual development (sub-question 2) students were asked to formulate the definition of SynBio and to note the difference with traditional recombinant DNA-techniques (assignment 6). Most students could formulate one or two elements of the definition of synthetic biology, but these were not always very precise. Only 2 students (1 each test cycle) could not reproduce any of the elements of synthetic biology and 12 students could formulate all elements (out of a total of 45 students in test cycle 2 and 3). As there were no changes in this part of the design it seems logical that test cycle 2 and test cycle 3 in terms of percentages scored almost the same. In assignment 10, 72% of the students used scientific concepts in the formulation of their opinion. Only the use of the concepts was reported, not if they were correctly used. These scientific concepts mostly consisted of the benefits and risks of SynBio. This shows that some conceptual development has taken place with the concept of SynBio itself and with the adjacent concepts (in so far as the students can use them in argumentation) concerning the risks and benefits of SynBio like: ecological risks of releasing genetically modified organisms.

Opinion-forming development

To what extent can students use different elements to formulate an informed-opinion? (sub-question 3) was answered by looking at several elements of the opinion formulated by the students on assignment 10 (*Give your own opinion on which course of action we should take considering the development of synthetic biology right now*.). By far the most students held the position ‘pro, under conditions’ and so they could see different benefits and risks to synthetic biology. This was supported by the finding that almost all students used ‘pro’ as well as ‘against’ arguments in assignment 10, showing that they could incorporate both sides when forming their opinion. On average the students used 2.6 arguments in the formulation of their opinion and all but one student used rationalistic reasoning in their opinion. 9 students in test cycle 2 and 4 students in test cycle 3 used emotive, -and/or intuitive reasoning, always in combination with at least rationalistic reasoning. Students thus substantiated their opinion with logical arguments and did not, for the most part, just take a position. Some students used immediate reactions, feelings and showed that their argumentation started from intuition. A little more students used care-based arguments and 30% of the students referenced a perspective (that was not their own) in their opinion and so we can see that the student’s considerations were enriched. The use of perspectives also shows that the students become aware of their own values and those of other people in dilemma’s (reframing, see page 9). Framing (see page 9) helps us to make sense of complex situation, so as students are using different perspectives in their opinion we can see that they can see and negotiate a higher degree of complexity in the dilemma. The fact that 72% of the students used scientific concepts in formulating their opinions shows that students find rational arguments important. This all shows, that the students opinion-forming has developed and consists of several facets working together to come to better informed decisions and the measure of success of phase 5 (forming of opinions and making informed decisions).

Experiential curriculum

Overall the lesson module was liked a little more than disliked. The students thought it was a little easy, as they considered things that cannot be ‘wrong’ (in the school-sense of right and wrong) easy. The students especially liked the novelty of the module and a chance to have a dialogue (they say: discussion) with each other. They did however find considering their own emotions and working with values, difficult. This was also found to be least fun, maybe because it was difficult and relatively new to the students. Furthermore, students did not like writing as much and protested the "vagueness" of the questions. As far as the writing part, from the tone of the answers in the questionnaires this seems to be not that serious of a problem. Also, the problem with vagueness did not overtly present itself in the observations and in the workbooks, it was found they could answer these questions very well.

On the interview question whether the module reached the learning goals all four of the teachers that were interviewed thought it did. One remarking: "*I think in any case that they noticed that at a certain point their opinion is developing as you obtain more knowledge… they are, together, very focused on formulating such an opinion with each other, so in how far other people influence their opinion. I don't know if they notice that*" (Interview teacher LRC V4 NLT line: 84-88). Another teacher remarked that students probably had no opinions (about related issues) to begin with or knew that they could have opinions about this sort of subject.

Some of the interviewed student remarks hinted at some knowledge and understanding of the opinion-forming process. One of the students remarked on being asked what she learned from the module: "*Mainly, forming my opinion well I think, just all the steps you take and listening to each other's opinion.*" (Interview student LRC V4 NLT line 116-117). Another student responded to the question: "*Why is it useful to hear other people's opinions?*": "*So maybe you adjust yourself a little bit, you can think, oh maybe that's a good point as well*" (Interview students, V4 NLT line: 56-57). Both pointing at possible success of the reflection phase (phase 6, see page 9) of the design.

Overall can be concluded that the students developed some self-knowledge and some of society in practicing and listening to each other. They developed some understanding of the concept of SynBio, but also of the concepts surrounding the risks and benefits (consequences) of SynBio. And so, the students' scientific knowledge is further developed. In forming a well-informed opinion, we see that almost all students can substantiate their position with arguments, using arguments from both sides. The students show they mostly use rationality (often only rationality) in their opinion, often supported by scientific concepts. To a lesser extent, intuition and care-based consideration are used in their opinion. But when intuition, care-based considerations are used in the formulation of an opinion they are accompanied by rational considerations. Almost a third of the students considered others in their opinions. As such can be concluded that the students' opinions were enriched. To this extent the students' informed decision-making process was fostered. Although this study did not explicitly look at the individual success of the didactical phases it can be concluded that thus far they were successful in informing this design. Besides all that, students liked the module and found it a not too difficult.

Discussion

As scientific literacy is an important aim of science education so is fostering students' informed decision-making on SynBio-related SSIs. Using design-based research this thesis evaluated '*Synthetic biology* - *towards a critical perspective'* on its potential to foster students' informed decision-making, By, improving students' scientific knowledge, self-knowledge and societal knowledge. It can be said that '*Synthetic biology* - *towards a critical perspective*' has been successful, to a certain extent, in doing this. This research builds on research by De Ruijter (2013), Slegers (2014) and Ripken (2015) who have shown that use of TMV's, TMV-related learning activities and reframing activities help students reach the aims of didactical phase 1 (see page 8), to a certain extent those of phase 2 and to create "need to know" (phase 3). The results of this research show that the lesson module (and the incorporated the didactical phases) support the development of students' scientific, -self, - and societal knowledge and that in turn enriched the students' decision-making.

Methodological reflection

The prior knowledge of students on forming an informed-opinion and on SynBio was not objectively determined before the start of the lesson module. During the interviews students were asked if they had any experience with education on opinion-forming or something alike. Most students reported to have had some experience with opinion-forming in subjects as Dutch, Philosophy or Social science (Maatschappijleer). Ideally this study would have liked to make a comparison of an opinion expressed by the students before the lesson module, in the beginning of the lesson module with the one expressed at the end of the lesson module (assignment 10). To accomplish this in the last test phase assignment 4.3 was changed in the design to assess the opinion of the students during the first lesson. But after consulting with the supervisor of this thesis it was decided that the assignments (4.3 and 10) were too dissimilar (in formulation and in lay-out) to make a comparison between the assignments valid. As the prior knowledge was not determined and the incorporation of assignment 4.3 was not adequate this failed.

The quotes from student and teacher interviews in this thesis were selected by the first author only and although selected with care, the selection could be exposed to a bias of the main researcher. One quite influential problem, the first researcher had, was with the preparation of the teachers. A lot of time was wasted in the lessons because of a lack of preparation of the teachers. This was one of the main reasons that the open dialogue was not always implemented as was intended, and often changed into discussions, closed dialogues or was not done at all. This was mostly due to the fact that most teachers did not (entirely) read the teachers-guide. Several things were tried but to no avail. When asked about this most teachers responded by pointing out that they did not have enough of time to do this. One teacher, who gave the module twice when asked if something could have been done to prepare her better responded by saying: "*I think the best preparation is when you already did it… and* *as long as you haven't done the module you look at the material like: oh, that will teach itself and they will understand all of it*." (Interview teacher V5 E, line 34-38).

As the students on average thought the module was a little easy the question could be raised: is the module not too easy? As can be seen in the results of the questionnaires the students of the lower classes did find the module marginally more difficult. But. besides that, the students do not rate something like forming an opinion difficult. The perceived difficulty for the students lies more in the answers you can get right or wrong and not in soft skills, like articulating your own emotions, giving an opinion, listening to each other and respecting their point of view, which are of great importance to this lesson module. So, then the difficulty of the module is not so much in its scientific content which on itself is appropriate because it is meant for students at different school levels. So, some will find it easier than others, but the difficulty is in the softer skills. To illustrate this, in the questionnaire some students did identify "opinions" as one of the more difficult things but also as an easy one because as one student points out: "*Opinions, they are always correct*" (Analysis questionnaire, V5 E, student 7).

Limitations of the study

The eventual results of this study were based on students (test cycle 2 and 3) from the same school. This means that the validity is somewhat diminished because all students were from more or less the same student-population.

As there is no direct comparison of the student's opinions on SynBio between the beginning of the module to one in the end of the module it cannot be seen what progress the students have made in forming an informed-opinion. Which renders that this research can only comment on what the students can do after the module, with less surety on the effect of the module.

As the analyses of the development of personal, - and social knowledge was limited to the questions that the students formulated, this does not seem complete. To get a fuller picture the dialogues in the classroom might have been analysed to see the development of personal, - and social knowledge in conversation. The same can be said for the development of opinion forming development since this analysis also only uses written data from the students.

With regards to the conceptual development, this study is limited in the sense that only the definition of SynBio and the use of scientific knowledge in the student's opinion was analysed. The analyses of the definition of SynBio should have been broader to include the concepts surrounding SynBio. Besides that, the use of scientific concepts in the students' opinions should have been checked for correct use and accuracy.

With regard to the didactical phases this study is limited in that it did not look at the success of the individual phases. This was a conscious decision but in hindsight we think this would have made this studies contribution to SSI-based education more formidable.

Recommendations for further research/development

As has been said above we would recommend further research to make analyses of more than just written sources to determine the development of personal, - and social knowledge and opinion forming.

In the development of further lesson materials this research would like to recommend that more can be done with the "need to know" of the students as there is now not a real opportunity for the students themselves to explore their own questions, search for answers and resolve their 'need to know'. As the results of the development of scientific knowledge were not that good this could be something to consider adding to the lesson module '*Synthetic biology - towards a critical perspective*'. Besides this, maybe SynBio should be integrated with the "DNA" subjects in the curriculum so that the scientific concepts fall on a more fertile ground and does not get lost in the personal, - and social aspects of this module.

This research would like to stress the importance of the open-dialogue for both the design and the enjoyment that the students experience. As has been said before, the open-dialogue did not always reach its full potential in the test cycles. In further development of this module it should be considered to free up more time in the design and to prepare the teachers specifically for the dialogue so that the open-dialogue has a better chance to succeed.

It would be very interesting to try to make a SynBio based opinion-forming lesson module like this but for the lower levels (VMBO in the Netherlands). Most lesson modules based on this kind of cutting edge science are made for the higher levels of the educational system. Quite logical of course when you look at the level of difficulty of some of the scientific content. But, as has been said in the introduction and theoretical background, all students should become scientifically literate, so they can become responsible citizens. Besides this, it would be very interesting to see what level of scientific information they could handle and to see if the role of emotions in the opinion-forming process is more prominent than in other grades.

As we see the difference between formulated factual questions and normative questions. Also, the difference between the use of scientific knowledge and the use of perspectives plus the fact that of the reasoning types only rationalistic reasoning was used on its own. This research shows that the emotive considerations still need to catch up with the rational considerations in terms of their considered importance in opinion forming. Thus, this research wonders if making a module focussed on this discrepancy would be of use for the development of responsible citizens.

As all teachers remarked that opinion-forming or lessons alike to that are barely represented in the lessons they gave, and these are the first things removed from the lesson program as time gets tight. This research would like to stress that as scientific literacy and opinion-forming are part of the curriculum in the Netherlands something should be done to give this the time in the curriculum it deserves. These skills and experiences are not only of importance for the individual students to successfully navigate a technological society moving at a fast pace, but also for our society as a whole were differences between people might become increasingly unnoticeable in our personalized social-media driven world.

This study shows that there are ways available to teach about SSIs in the (science) classroom and that the didactical phases of Knippels & de Bakker (2016) inform such a design. Teachers should use this and as they do so students will benefit, as does society.

To illustrate that this lesson module and probably lessons like this work for the students, a quote from one student remarked in the interview on being asked what she liked most about the module replied: "*... it is not per se only what for example school wants you to know, but just what 'you' think*." (Interview student V4 NLT, line 37-38).

References

Anderson, J., Strelkowa, N., StanGuy-Bart, Douglas, T., Savulescu, J., Barahona, M., & Papachristodoulou, A. (2012). Engineering and ethical perspectives in synthetic biology. *Science & Society*, *13*(7), 584–590. doi:10.1038/embor.2012.81

Azevedo, K. F. (2016). *Synthetic biology - Towards a critical perspective* (Master science education and communication internship)

Bakker, A., & van Eerde, D. (2014). An introduction to design-based research with an example from statistics education. In *Approaches to Qualitative Research in Mathematics Education* (pp. 429–466). doi:10.1007/978-94-017-9181-6_16

Boerwinkel, D. J., Veugelers, W., & Waarlo, A. J. (2010). Burgerschapsvorming, duurzaamheid en natuurwetenschappelijk onderwijs. *Pedagogiek*, *29*(2), 155–172.

Boerwinkel, D. J., Swierstra, T., & Waarlo, A. J. (2014). Reframing and articulating socioscientific classroom discourses on genetic testing from an STS perspective. *Science & Education*, *23*(2), 485-507.

Braund, M., Lubben, F., Scholtz, Z., Sadeck, M., & Hodges, M. (2007). Comparing the effect of scientific and socioscientific argumentation tasks: Lessons from South Africa. *School Science Review*, *88*(324).

Bron, J., Veugelers, W., & Vliet, E. (2009). Leerplanverkenning actief burgerschap. Retrieved from http://www.slo.nl/downloads/2009/Leerplanverkenning-actief-burgerschap.pdf

Bureau Platvorm Onderwijs2032 (2016). Onsonderwijs2032 Eindadvies. Retrieved from http://www.onsonderwijs2032.nl/wp-content/uploads/2016/01/Ons-Onderwijs2032-Eindadvies-januari-2016.pdf

de Ruijter, C. (2013). *Techno-moral vignettes: A useful tool to introduce synthetic biology related socioscientific issues?* (MSc thesis).

College voor Examens (2014). SYLLABUS CENTRAAL EXAMEN 2016. Retrieved from https://www.examenblad.nl/examenstof/syllabus-2016-biologie-vwo-nader/2016/f=/biologie_vwo_2016_def_voor_hervaststelling.pdf

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, *37*(6), 582–601. doi:10.1002/1098-2736(200008)37.

Haidt, J. (2001). The emotional dog and its rational tail: A social intuitionist approach to moral judgment. *Psychological Review*, *108*(4), 814–834. doi:10.1037/0033-295x.108.4.814

Knippels, M. C. P. J., & de Bakker, L. (2016, December 8). Dialoog in de bèta-les. *Didactief*. Retrieved from https://didactiefonline.nl/artikel/dialoog-in-de-beta-les

Knippels, M. C. P. J., Severiens, S. E., & Klop, T. (2009). Education through fiction: Acquiring opinion-forming skills in the context of genomics. *International Journal of Science Education*, *31*(15), 2057–2083. doi:10.1080/09500690802345888

Kolstø, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education*, *85*(3), 291–310. doi:10.1002/sce.1011

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education*, *84*(1), 71–94. doi:10.1002/(sici)1098-237x(200001)84:1<71: aid-sce6>3.0.co;2-c

Levinson, R. (2006). Towards a theoretical framework for teaching controversial socio-scientific issues. *International Journal of Science Education*, *28*(10), 1201-1224.

National Research Council (1996). National science education standards. *National Academies Press* Washington DC, (pp. 13).

Pisa, O. E. C. D. (2015). Draft Science Framework. 2014-07-17. Retrieved from http://www.oecd. org/pisa/pisaproducts/Draft PISA 2015 Science Framework. pdf.

Ratcliffe, M., & Grace, M. (2003). *Science education for citizenship: Teaching socioscientific issues*. McGraw-Hill Education (UK).

Ripken, G. C. (2015). *Supporting opinion-forming of secondary biology students on SynBio-related SSIs* (MSC Thesis thesis).

Roeser, S. (2006). The role of emotions in judging the moral acceptability of risks. *Safety Science, 44*(8), 689–700. doi: 10.1016/j.ssci.2006.02.001

Sadler, T. D. (2002). Socioscientific issues and the Affective domain: Scientific literacy's missing link. 35p.; *Paper presented at the Annual Meeting of the Southeastern Association for the Education of Teachers in Science*, Kennesaw, GA. Retrieved from https://eric.ed.gov/?id=ED472041

Sadler, T. D. (2004). Moral and ethical dimensions of socioscientific decision-making as integral components of scientific literacy. *Science Educator*, *13*(1), 39. Sadler, T. D. (2011). *Socioscientific issues in the classroom: Teaching, learning and research*. Netherlands: Springer.

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in Socioscientific inquiry? *Research in Science Education, 37*(4), 371–391. doi:10.1007/s11165-006-9030-9

Sadler, T.D., & Zeidler, D.L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of research in science teaching, 42,* 112-138. doi: 10.1002/tea.20042

Sadler, T. D., & Zeidler, D. L. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching*, *46*(8), 909–921. doi:10.1002/tea.20327

Settelmaier, E. (2003). Dilemmas with dilemmas...Exploring the suitability of dilemma stories as a way of addressing ethical issues in science education. Retrieved from https://eric.ed.gov/?id=ED476253

Slegers, A. M. (2014). *Techno-moral vignettes in socioscientific issues-based education on synthetic biology* (MSC Thesis thesis). Retrieved from Utrecht University Repository

Tucker, J. B., & Zilinskas, R. A. (2006). The promise and perils of synthetic biology. *The new atlantis*. Retrieved from http://www.thenewatlantis.com/docLib/TNA12-TuckerZilinskas.pdf

van den Akker, J., Kuiper, W., & Hameyer, U. (2003). *Curriculum landscapes and trends*. doi:10.1007/978-94-017-1205-7

van der Zande, P., Brekelmans, M., Vermunt, J. D., & Waarlo, A. J. (2009). Moral reasoning in genetics education. *Journal of Biological Education*, *44*(1), 31–36. doi:10.1080/00219266.2009.9656189

Waarlo, A.J., (2014*). Enhancing Socioscientific Issues-based Learning in Schools*, D2.1 SYN-ENERGENE, co-funded by the European Commission under the 7th Framework Programme, Karlsruhe, Germany / Utrecht University, Freudenthal Institute for science and mathematics education (NL).

Zeidler, D. L., & Nichols, B. H. (2009). Socioscientific issues: Theory and practice. *Journal of Elementary Science Education*, *21*(2), 49–58. doi:10.1007/bf03173684

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education*, *89*(3), 357–377. doi:10.1002/sce.20048

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*(3), 343–367. doi:10.1002/sce.10025

Appendix 1 – Initial HLT

Lesson 1 **Learning and teaching activity (LTA)**	**Activity**		**Hypothesized learning results**	**Phase and analyses**
	Teacher	**Students**		
LTA0: Introduction General introduction to the lesson and the video.	The teacher introduces the video (TMV) and explains what is expected of students. Provides the worksheets.	Listen to the explanation of the teacher. They can ask questions.	Students become aware of the nature of the video and the lesson.	1 Interview teacher,
LTA1: **Video** Projection of the video in the classroom.	Starts the video	Watch the video	Students get engaged in the subject. Emotions and questions are raised. A "need to know" is created for students	1 and 3 Interview teacher, Workbook, amount and sort of questions raised
LTA2: **Identify questions, emotions and moral dilemmas** Articulation of personal questions, emotions and moral dilemmas. Students are asked to write down their initial thoughts, emotions and questions they had during the video	Is available for questions on the assignment and provides examples of emotions questions and moral dilemmas, if asked.	Answer question 1 individually on the students' worksheet.	Students articulate moral dilemmas they see with the TMV. Students articulate their initial questions and feelings on the dilemma.	2 3 or 4 Workbook
LTA3: New perspectives Developing awareness of other perspectives on a moral dilemma. Students explain their answers to the first questions to each other in duo's	Instructs students to take notes of partner's answers and his or her explanation.	Explain their answers to their partner. Take notes on partner's explanations	Students see questions and emotions on the dilemma of their partners and by clarifying and discussing their own initial thoughts and emotions, students have to consider the underlying values. Students also gain insight to that someone else can deduce a different dilemma from the same TMV.	2, 4 and 5 Film, - and sound clips

LTA4: Classroom reflection Whole classroom reflection	Asks questions on the questions, emotions and dilemmas that were raised. Asks what information is missing? Makes notes of the answers on the board.	Discuss the raised questions, emotions and dilemmas.	Students become familiar with other perspectives through the questions and emotions on the dilemma of the whole class.	2, 3 and 4 Film, - and sound clips
LTA5: Article on Biohackers Articulation of questions, emotions and moral dilemmas raised by the text	Instructs students to read the article and make assignment 3 and 4	Read the article and write down their questions, emotions and moral dilemmas.	Students recognize another perspective on SynBio and articulate questions, emotions and moral dilemmas with another perspective in mind.	2, 3 and 6(q 3 last part) Workbook
LTA6: Classroom reflection Has there been a change after reading the article in the student's emotions? What kind of questions and moral dilemmas have been raised?	Asks if student's feelings and opinions have changed and why (not). Asks what kind of questions and moral dilemmas were raised. Makes notes on the board.	Answer the questions of the teacher	Through the discussion of the opinions of the class students see other perspectives on the dilemma. Become aware of any changes in their own or other perspectives.	2, 4 and 5 Film, - and sound clips

Lesson 2 **Learning and teaching activity (LTA)**	Activity Teacher	 Students	Hypothesized learning results	Phase and analyses
LTA0: Introduction General introduction to the lesson and the video.	The teacher introduces the video (SynBio) and explains what is expected of students. Provides the worksheets. Instructs students to read assignment 5.	Listen to the explanation of the teacher. Read assignment 5. They can ask questions.	Students become aware of the nature of the video, the lesson and assignment 5.	2 Interview teacher, questionnaire and workbooks
LTA1: **Video** Projection of the video in the classroom	Starts the video, stops after 2.50 minutes to let students fill in first part of assignment 5. Then continues the video	Watch the video. Answer first part of assignment 5. Watch rest video. Finish assignment 5.	Students get engaged in the subject. Students reproduce the videos definition of SynBio and several applications and techniques of SynBio as to be able to recall them.	Interview teacher, Workbooks
LTA2: **Classical Reflection** Sharing and refining the answers. Recall questions of previous lesson. Small discussion	Asks students for their answers and makes corrections. Recalls questions on the scientific nature of SynBio of previous lesson and starts discussion with some questions.	State their answers and listen to other answers. Voice their thoughts and opinions.	Students refine the definition of SynBio, the techniques and applications and discuss these to facilitate their comprehension.	3 and 4 Film, - and sound clips and workbooks
LTA3: History, techniques and applications Assignment for comprehension of scientific concepts.	Instructs students to read the information and make assignment 6. Is available for questions on the text and the assignment.	Read the text. Make assignment 6.	Students must recall the definition of SynBio and compare it to recombinant DNA-techniques for better comprehension.	2 Workbooks

LTA4: History, techniques and applications Assignment for incorporating applications of SynBio in opinion	Instructs students to exchange points of view on assignment 7 and to understand each other's points. Is available for questions on the assignment.	Make assignment 7. Discuss the opinions of assignment 7 with a peer and try to understand their point of view.	Students define what they think about the production of organisms and products by SynBio techniques and exchange these thoughts to become more aware of their own ideas and those of others.	2 and 3 Workbooks

Lesson 3 **Learning and teaching activity (LTA)**	**Activity**		**Hypothesized learning results**	**Phase and analyses**
	Teacher	**Students**		
LTA0: Introduction General introduction to the lesson and the video.	The teacher introduces the video (SynBio crisis) and explains what is expected of students. Provides the worksheets. Instructs the students to work in groups of 3.	Listen to the explanation of the teacher. They can ask questions.	Students become aware of the nature of the video and the lesson.	1 and 3 Interview teacher, Film, - and sound clips
LTA1: **Video** Projection of the video in the classroom	Starts the video	Watch the video.	Students get engaged in the subject.	1 and 3 Interview teacher, Film, - and sound clips
LTA2: **Stakeholders** Investigations of the stakeholders in a hypothetical case study	Instructs the students to make assignment 8 in the groups. Is available for questions.	Answer the questions in assignment 8.	Students reflect on the relationship of different stakeholder before the crisis as to prepare them for the open dialogue and to imagine other's points of view. Practice critical thinking.	2, 4 and 5 Film, - and sound clips and workbooks
LTA3: Open dialogue Classroom dialogue with central question: Is SynBio desirable?	Puts perspective-table (assignment 9) on the board. Starts the dialogue with the central question.	Have an open dialogue were no positions have to be defended. Listen to each other.	Students will become more aware of the differences between opinions. Become aware of the values behind the opinions. Practice critical thinking.	2, 4 and 5 Film, - and sound clips
LTA4: Form a well-considered opinion	Askes students to make assignment 9 a d 10. Then close the lesson with a small recap of the lesson module	Write down their opinions on the desirability of SynBio.	Students articulate a well-considered opinion	5 and 6 Workbooks

Appendix 2 – Student materials

Naam:

Klas:

Synthetische biologie

Naar een kritisch perspectief

Colofon

Freudenthal Instituut
voor Didactiek van Wiskunde en Natuurwetenschappen

Responsible Research and Innovation in Synthetic Biology

V3.0

Deze lesmodule is ontwikkeld door het Freudenthal Instituut in het kader van het Europese project SYNENERGENE.

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Delen van deze lesmodule zijn gebaseerd op en/of geïnspireerd door de eerste lesmodule *"Synthetic biologie: what is posisble and advisable?"*
http://www.fi.uu.nl/toepassingen/28400

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Bij vragen of opmerkingen kunt u contact opnemen met het Freudenthal Instituut (fisme@science.uu.nl).

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Inhoud

ONDERDEEL 1
Synthetische biologie: Gevoelens, morele kwesties en vragen

Video
Je krijgt een video te zien over een fictief toekomstscenario waarin planten licht kunnen geven. Lees eerst de opgave en vul hem in na het zien van de video.

https://www.youtube.com/watch?v=xGQ6Cp1dC4c

Opdracht 1
Schrijf in onderstaande tabel op welke gevoelens, morele kwesties en/of dilemma's, en vragen bij je opkomen bij het zien van de video.

Gevoelens	**Morele kwesties en dilemma's**	**Vragen**
	Bijvoorbeeld: Willen we het leefgebied van andere soorten verwoesten?	

Het is mogelijk om de inhoud van de video nogmaals door te nemen door onderstaande (naar het Nederlandse vertaalde) tekstversie te lezen.

Bioluminescerende straatlantaarns

Haar man vond de lichtgevende bomen eng. Die vreselijke kerstdagen leken de hele zomer te duren en het was alleen een kwestie van tijd voor ze de verdomde bomen Jingle Bells zouden leren zingen. En waar was de uitknop op deze dingen, klaagde hij. Wat moet iemand doen om wat degelijke duisternis te krijgen in deze wereld vol licht?

Maar zijzelf vindt ze mooi, terwijl ze opkijkt naar het ingewikkelde netwerk van blauw licht dat zachtjes boven haar hoofd meewaait op de zachte wind. Oh, kon het niet altijd zomer zijn, zodat de bomen zouden blijven stralen. Ze haatte het harde en genadeloze mechanische licht van de ouderwetse straatlantaarns, die natuurlijk nog steeds gebruikt werden in de winter, als de bomen het niet deden. Vooral de lente was vreselijk, als het twijfelende licht van de bomen concurreerde met de straatlantaarns die nog steeds aan stonden.

Haar man was gewoon chagrijnig en ouderwets. Bioluminescerende planten waren de rage en elke dag waren er creatieve doe-het-zelf-synthetische biologen die trots een nieuwe huisgemaakte bioluminescerende tuinsoort presenteerden. Er zijn wedstrijden, waar juryleden een bezoekje brachten aan prachtig verlichte tuinen. Natuurlijk, tijdens het grijze seizoen moest je je planten licht 'voeren' met enorme elektrische lampen, maar het resultaat was zoveel beter.

Om eerlijk te zijn, als je 'lumis' wilde zien was je niet langer beperkt tot de straten en de tuinen. Steeds vaker doken er wilde soorten op in de bossen en weides. Maar goed, wat verwachtte je dan? Het is nu eenmaal onmogelijk om te zorgen dat alle enthousiaste amateurfokkers zich houden aan de industriële veiligheidsmaatregelen. Ach, wie kan het schelen! Er is nog niemand vergiftigd en dat sommige nachtdieren moesten verplaatsen naar de donkere delen van de wereld… wat maakt dat uit. Het is moeilijk verdrietig te zijn voor dieren die je normaal gesproken toch nooit ziet.

Opdracht 2

Werk in tweetallen. Leg je antwoord bij opdracht 1 uit aan je klasgenoot en andersom. Bevraag elkaar en probeer de ander te begrijpen. Stel vragen zoals: Wat bedoel je daar mee? Wat is voor jou belangrijk en Waar maak je je zorgen om. Maak hieronder aantekeningen van zijn/haar antwoorden en uitleg.

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ONDERDEEL 2

Al realiteit: bioluminescerende planten en doe-het-zelf biohackers

Artikel

Lees onderstaand artikel over een bestaand ''doe-het-zelf-biohackpakketten'' waarmee mensen zelf thuis lichtgevende planten kunnen maken.

Bioluminescerende planten en doe-het-zelf biohackers in de realiteit: bedreigingen voor het leven? [1]

Met de verkoop van doe-het-zelf-biohackpakketten zijn synthetische biologietechnieken voor iedereen beschikbaar. Straks kan iedereen thuis gistcellen rood laten kleuren. Ondertussen hebben ondernemers al plannen om glow-in-the-darkplanten te versturen naar enthousiastelingen overal in de VS. Alhoewel de levensvormen die gemaakt zijn met de biohackpakketten onschuldig lijken, zijn ze potentieel gevaarlijk, moeilijk te reguleren en kunnen ze vermoedelijk zelfstandig vermenigvuldigen.
Dit ODIN-project heeft als doel om nieuwe technieken voor genetische modificatie toegankelijk te maken voor iedereen die er $130 of $160 voor over heeft. Deze pakketten komen met alle benodigde informatie over DNA-sequenties en kloneren zodat elke klant zijn eigen genoom kan bouwen.

"Glowing Plants: Natural light with no electricity" haalde bijna een half miljoen dollar bij elkaar met Kickstarter voor het produceren van diverse lichtgevende planten. Volgroeide planten of 50-100 vruchtbare zaden kunnen op voorhand besteld worden bij Glowing Plant. Het bedrijf adviseert klanten om de planten als nachtlampje te gebruiken of om ermee te pronken. James Clapper, directeur nationale inlichtingendienst van de VS, zei dat hij genetische modificatie als één van de zes potentiele massavernietigingswapens ziet en dat zowel opzettelijk als onopzettelijk misbruik van genetische modifactietechnologie kan leiden tot verstrekkende gevolgen voor de economie en nationale veiligheid. Tot dusver is er onvoldoende onderzoek gedaan naar de potentiele consequenties voor het milieu van ontsnapte of vrijgelaten genetisch gemodificeerde organismen. Hoe kan het dat dergelijke schoolpakketten en doe-het-zelf-biohackpakketten volledig genegeerd worden in het debat over de veiligheid van genetische modificatie?

[1] Artikel is aangepast van "Rogue scientists to DIY biohackers: Real threats to ecosystems are not being taken seriously" | SynBioWatch. (N.d.). Geraadpleegd op 25 juli, 2016, op http://www.synbiowatch.org/2016/04/rogue-scientists-to-diy-biohackers/

Opdracht 3

Elk stukje nieuwe informatie beïnvloedt je mening. Misschien niet genoeg om je mening te veranderen maar je mening wordt hierdoor wel steeds beter onderbouwd. Schrijf nieuwe gevoelens, vragen en morele kwesties/dilemma's op die bij je opkomen na het lezen van het artikel.

Gevoelens	Morele kwesties en dilemma's	Vragen

Opdracht 4

Wat zou jij doen als je mocht beslissen over de regels rond Bioluminescerende planten, doe-het-zelf biohackers en synthetische biologie? Beschrijf hoe jouw beslissing eruitziet (verbieden, reguleren, toestaan of anders) Schrijf op waarom je tot deze beslissing gekomen bent.

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Wat zijn de mogelijke gevolgen van jouw beslissing? Noem een positief en een negatief gevolg.

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Wat is jouw mening? Hoe denk je over synthetische biologie in het algemeen? Vind je het wenselijk dat met dit soort technieken geëxperimenteerd wordt?

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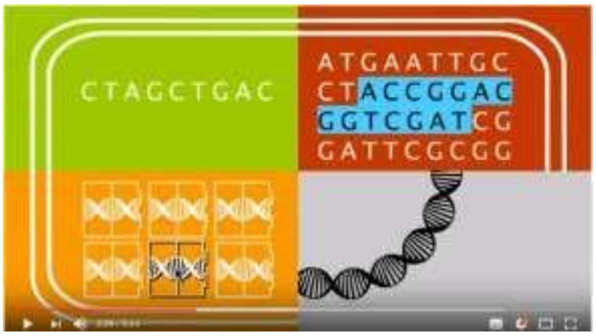
ONDERDEEL 3
Synthetische biologie: Wat is het en wat kan je ermee?

Video
Je krijgt een filmpje over synthetische biologie te zien. Lees eerst de volgende opdrachten.



https://youtu.be/UHBdEwNbXI0

Opdracht 5
Na 2.50 wordt het filmpje stopgezet. Wat is, volgens het filmpje, synthetische biologie?

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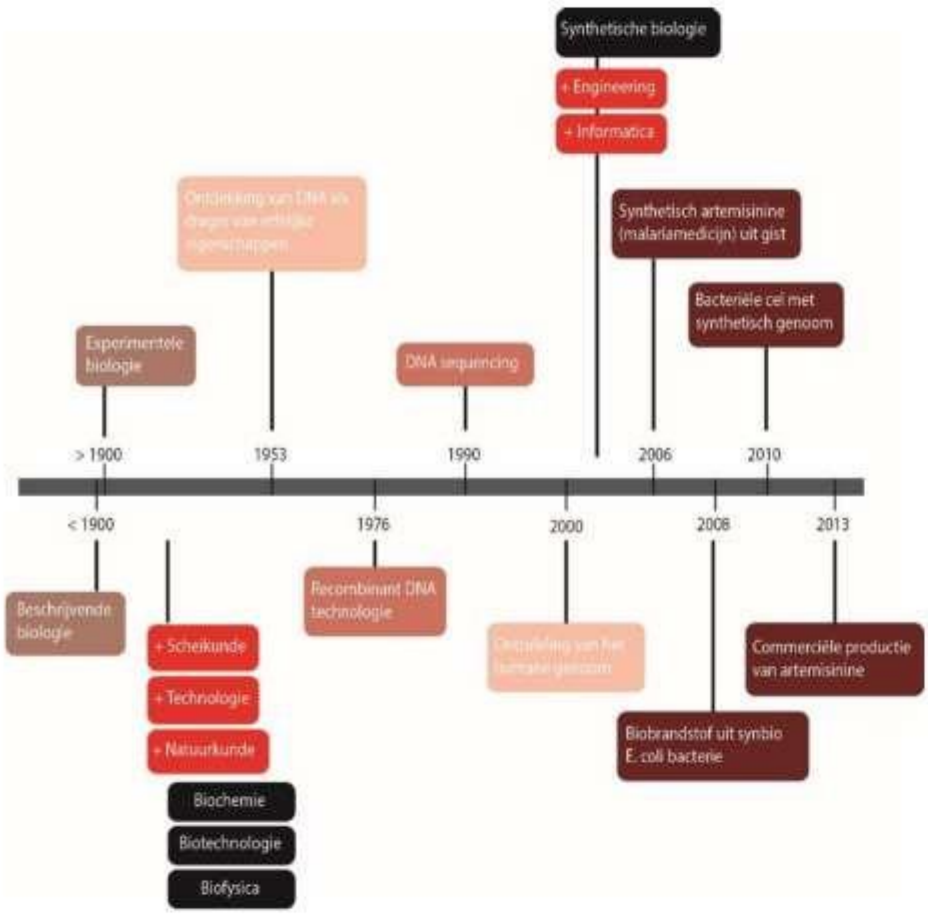
In het tweede deel van het filmpje wordt een aantal technieken en toepassingen van synthetische biologie besproken. Vul de tabel hieronder verder in.

Technieken	Toepassingen
DNA knippen en plakken/ recombinant DNA-technologie	*Bacterie*: detecteert verschillende concentraties van een giftige stof

Geschiedenis

Toen biologen aan het begin van de 20e eeuw gingen samenwerken met natuurkundigen, scheikundigen en technologen leidde dit tot grote ontwikkelingen. Voorbeelden hiervan zijn de opkomst van de biotechnologie en de ontwikkeling van nieuwe technieken, zoals de recombinante DNA-technologie en DNA-sequensen. Toen biologen aan het begin van de 21e eeuw ook gingen samenwerken met informatici en engineers (ontwerpers/bouwers), leidde dit tot de opkomst van de synthetische biologie (zie figuur 1).

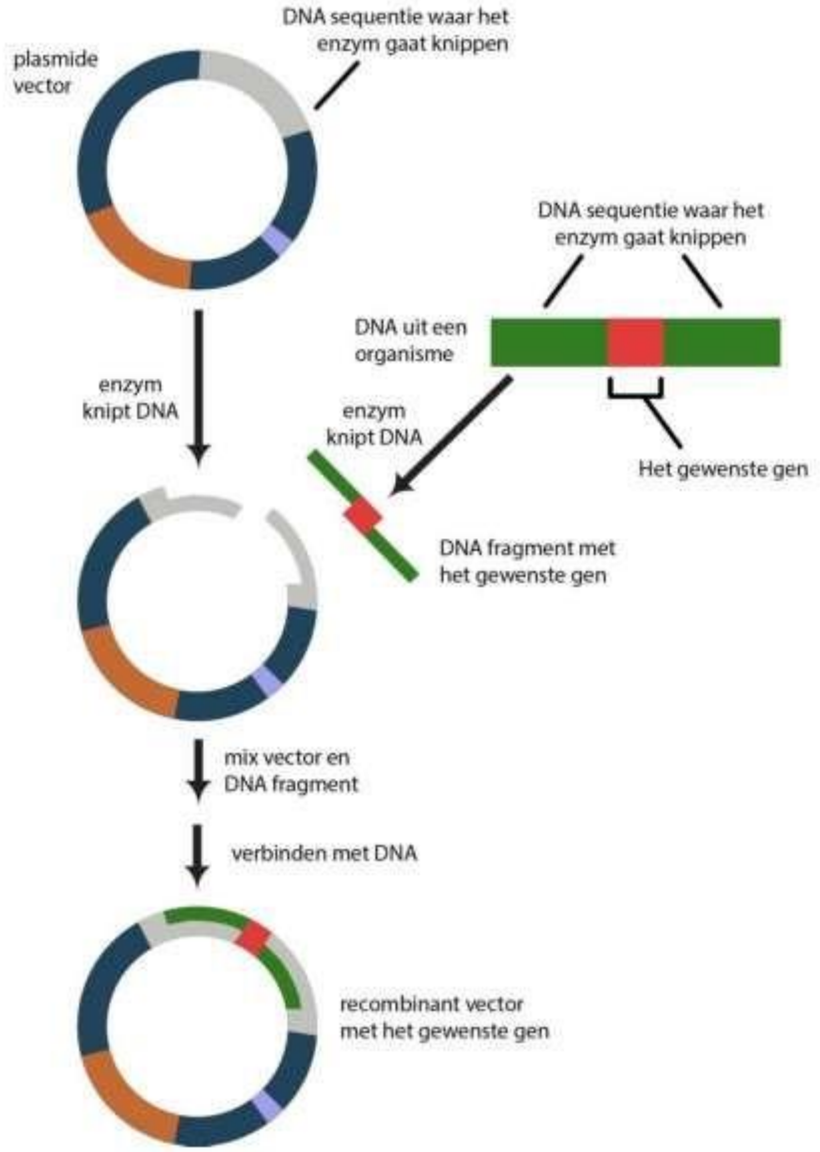
Synthetische biologie is dus een wetenschapsgebied waarin verschillende specialismes samenwerken. In de synthetische biologie worden bestaande technieken, zoals de recombinante DNA-technologie en DNA-sequensen, verder ontwikkeld. Met deze vernieuwde technieken kunnen onderzoekers nieuwe biologische systemen ontwerpen en bouwen. Ze kunnen bijvoorbeeld nieuwe functies in een cel, weefsel of organisme brengen, of zelf nieuwe cellen creëren met synthetische biologie.



Figuur 1: Geschiedenis van synthetische biologie

Technieken

Synthetische biologie is gebaseerd op de **recombinant-DNA-technologie**. In figuur 2 kun je nog eens bekijken hoe dit werkt.

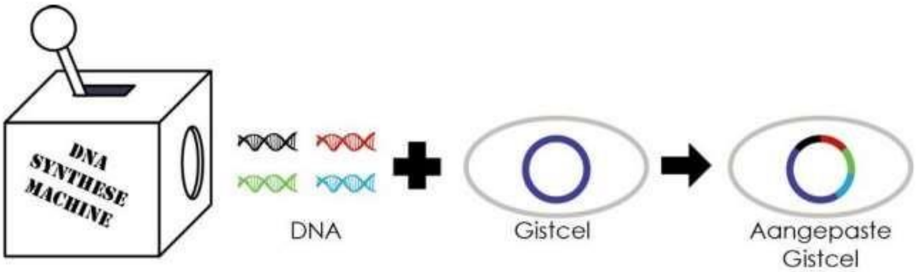


Figuur 2: Recombinante DNA-technologie

Met synthetische biologie hoeven onderzoekers de gewenste stukken DNA niet meer te knippen uit bestaand DNA: ze kunnen het gewenste DNA zelf ontwerpen en maken of zelfs bestellen via internet. Het DNA wordt dan gemaakt door een machine, met suiker als grondstof. Ook kunnen onderzoekers via een onlinedatabase **BioBricks** bestellen. Dit zijn stukken DNA met een bepaalde functie (ze coderen bijvoorbeeld voor een bepaald eiwit), die zo ontworpen zijn dat je ze gemakkelijk met elkaar kunt combineren. BioBricks worden daarom ook wel 'plug-and-play DNA' genoemd. Er zijn verschillende soorten BioBricks, bijvoorbeeld:

- BioBricks met alleen een coderend gen of een onderdeel van het DNA dat een gen kan reguleren.
- BioBricks die het coderende gen bevatten en ook alle onderdelen die dit gen reguleren.
- BioBricks van meerdere genen die samen een functie uitvoeren.

Onderzoekers kunnen BioBricks gebruiken om een bestaand organisme, een gistcel bijvoorbeeld, aan te passen. Dit gaat dan als volgt (figuur 3):



Figuur 3: Een gastheer aanpassen met synthetische biologie technieken. In dit geval is de gastheer een gistcel.

Onderzoekers proberen ook om **minimale cellen** te creëren. Dit zijn cellen die allen de genen bevatten die nodig zijn om te overleven. In de toekomst kunnen onderzoekers mogelijk BioBricks toevoegen aan deze minimale cellen, om de cellen een bepaalde functie te laten uitvoeren, zoals het produceren van een medicijn.

Toepassingen

Synthetische biologie wordt pas sinds een tiental jaren gebruikt, maar er is al een aantal indrukwekkende toepassingen ontwikkeld.

Duurzame brandstof

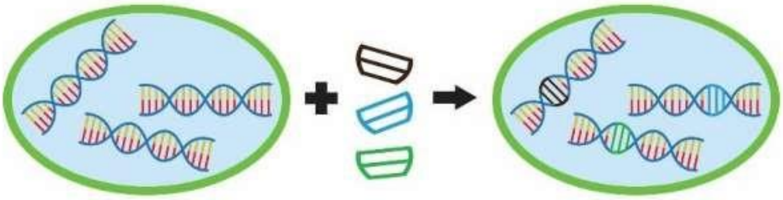
Bio-ethanol is een alcohol die gebruikt kan worden als duurzame autobrandstof. Bio-ethanol wordt gemaakt met behulp van bakkersgist, dat suikers uit maïs in bio-ethanol om kan zetten. Dit kan tot gevolg hebben dat maïs als voedingsproduct te duur wordt. Met synthetische biologie is het mogelijk om in plaats van maïs restproducten van landbouwgewassen, zoals stro en maïsloof, als grondstof voor bio-ethanol te gebruiken. Dit is gerealiseerd door genen aan bakkersgist toe te voegen die de suikers uit restproducten in bio-ethanol om kunnen zetten. De eerste fabriek die op deze manier bio-ethanol maakt, is in 2014 geopend.

Lab waar gisten rest-suikers omzetten in bio-ethanol (op de sectie Industriële Microbiologie van de TU Delft).

Goedkoop medicijn tegen malaria

Het malariamedicijn **artemisinine** werd oorspronkelijk gewonnen uit het plantje zomeralsem. Deze productiewijze zorgde voor een duur medicijn, en er was niet altijd voldoende beschikbaar. Door met synthetische biologie de genen voor artemisinineproductie te synthetiseren en in gist in te brengen (figuur 6), kunnen gisten het medicijn nu snel en goedkoop produceren in een reactorvat. Een farmaceutisch bedrijf maakt op deze manier artemisinine, dit levert zo'n 100 miljoen malariabehandelingen per jaar op.

Zomeralsem



Figuur 6: De gesynthetiseerde genen voor de productie van artemisinine worden in het DNA van gist ingebouwd. De gist kan nu artemisinine produceren.

Opdracht 6

Schrijf de definitie van synthetische biologie op en leg uit hoe synthetische biologie verschilt van de traditionele recombinant-DNA-technologie.

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Meningsvorming en waarden

Dilemma's zoals jullie de vorige les hebben gezien bij synthetische biologie komen wel vaker voor in onze samenleving. Dit soort dilemma's, sociaalwetenschappelijke dilemma's, worden door nieuwe ontdekkingen in de wetenschap opgeroepen. Deze nieuwe ontdekkingen kunnen grote veranderingen in onze samenleving veroorzaken en daar willen we over nadenken, bijvoorbeeld om te bepalen of we wel het risico willen lopen dat de samenleving op een bepaalde manier verandert. Stel je eens voor hoe onze samenleving er nu zou uitzien zonder de smartphone en apps zoals Instagram en WhatsApp? Hoe anders zou ons leven zijn als we niet altijd bereikbaar waren via onze telefoon? Nieuwe wetenschappelijke en technische ontwikkelingen kunnen enorme invloed op onze samenleving hebben. Deze invloeden zijn moeilijk te voorspellen. Maar er moeten wel beslissingen over genomen worden. Daarom is het van groot belang dat iedereen weet wat hij of zij moet doen om tot een weldoordachte mening te komen.

Bij het vormen van een mening zijn een paar dingen van groot belang zoals kennis over het onderwerp en een kritische houding. Niet alleen feitelijke kennis is hier van belang. Ook is het belangrijk dat je iets weet over de samenleving en over jezelf. Uit onderzoek blijkt dat wij mensen beslissingen nemen door eerst naar onze emoties te luisteren en daar argumenten bij te bedenken. Dit heb je zelf niet altijd door maar het lijkt wel zo te werken. Emoties worden op hun beurt opgewekt door de waardes die wij als persoon hebben (denk aan: eerlijkheid, gezondheid, macht hebben, zorgzaamheid, enzovoorts). Om in een samenleving goed met elkaar beslissingen te kunnen nemen is het dus van belang dat je weet wat voor waardes jij belangrijk vindt en waar je emoties en meningen dus vandaan komen. Daarnaast is het ook handig als je een idee hebt over hoe andere mensen zich voelen en wat voor waardes achter hun meningen en argumenten schuilgaan.

Opdracht 7

Kijk terug naar je eigen mening, gevoelens en argumenten die je hebt opgeschreven in les 1 Bedenk wat voor waarden daaraan ten grondslag kunnen liggen en schrijf deze op. Noteer eerst de mening, het gevoel of de argumenten en daarnaast de bijpassende waarde.

Mening, gevoelens en argumenten	**Bijpassende waarde**

z.o.z.

Opdracht 8

Werk in tweetallen. Leg je antwoord bij opdracht 7 uit aan je klasgenoot en andersom. Bevraag elkaar en probeer de ander te begrijpen. Stel vragen zoals: Wat bedoel je daar mee? Wat is voor jou belangrijk en Waar maak je je zorgen om. Maak hieronder aantekeningen van zijn/haar antwoorden en uitleg. Bedenk met zijn tweeën of jullie nog waarden kunnen toevoegen.

Mening, gevoelens en argumenten	**Bijpassende waarde**

ONDERDEEL 4
De beste handelswijze: Een open dialoog

Video

Je krijgt een video te zien over een fictief toekomstscenario van een synthetische biologiecrisis. Werk samen met twee klasgenoten aan de volgende opdracht, na het zien van het filmpje.

SynBio Scenarios: The FertiBac Crisis

https://www.youtube.com/watch?v=GhjOQCk8E_k

Opdracht 9

De video presenteert een voorbeeld van een fictieve synthetische biologiecrisis veroorzaakt door een genetische mutatie. In het filmpje komen de volgende betrokkenen naar voren:

1. *Boeren*
2. *Synthetische biologie-industrie*
3. *Wetenschappers*
4. *Wereld Gezondheidsorganisatie*
5. *De getroffen bevolking*

Reflecteer met 2 klasgenoten op de mogelijke drijfveren van elke groep betreffend het gebruik van de mogelijkheden en risico's van synthetische biologie ***voordat*** *de crisis ontstond.*
Bedenk bij elke groep ook een onderliggende waarde.
Bijvoorbeeld:

1. *Boeren*

- ❖ *Boeren waren alleen bezorgd over hun gewassen en verkoop*
- ❖ *Boeren waren op de hoogte van de risico's maar waren alleen geïnteresseerd in rijk worden*
- ❖ *Boeren hebben de risico's van synthetische biologie nooit begrepen*
- ❖ *Boeren dachten dat de wetenschappers veiligheid waarborgden*
- ❖ *Er waren maar enkele boeren die synthetische biologie niet vertrouwden*

Waarden: Financiële stabiliteit, vertrouwen in de wetenschap en risico's nemen

2. *Synthetische biologie-industrie*

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Waarden:………
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3. *Wetenschappers*

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Waarden:………
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4. *Wereldgezondheidsorganisatie*

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Waarden:………
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5. *De getroffen bevolking*

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Waarden:………
…

Open dialoog

Tijdens deze module heb je geleerd over de mogelijkheden van synthetische biologie, maar ook over de nadelen en de morele kwesties van de techniek. Tijdens de klassikale dialoog zal je vanuit verschillende perspectieven de afweging maken of sommige synthetisch biologische toepassingen en reglementen raadzaam zijn of niet.

	Wenselijkheid
Vooruitgang Wat kan synthetische biologie betekenen in het kader van vooruitgang? Zitten er voordelen aan deze vooruitgang? En nadelen?	
Economie Wat kan synthetische biologie betekenen in het kader van economische groei? Beïnvloedt het de verdeling van winst? Of kan het negatieve economische effecten hebben en/of positieve? En wie zullen hierdoor worden beïnvloed?	
Risico's Wat zijn de potentiële risico's van synthetische biologie? Wat zijn de risico's voor de mens en de natuur?	
Ethiek Is synthetische biologie ethisch verantwoord? Mogen wij mensen leven creëren? Wat willen we wel en wat willen we niet? Kan de wetenschap zijn gang gaan?	

Opdracht 10

Geef nu je eigen mening over: welke handelswijze kunnen we het beste ondernemen bij de ontwikkeling van synthetische biologie op dit moment.

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Waar is dit nou allemaal goed voor?

Tijdens deze module heb je geleerd over de mogelijkheden van synthetische biologie, maar ook over de nadelen en de morele kwesties van de techniek. Tijdens dit laatste stukje uitleg zal de leraar vertellen waar zo'n les als deze goed voor is en welke stappen uit deze lessen handig kunnen zijn bij het vormen van een mening over sociaalwetenschappelijke dilemma's.

Appendix 3 – Student questionnaire

Enquête 'Synthetische biologie: Naar een kritisch perspectief'

5hE

Om de les over synthetische biologie te kunnen onderzoeken en verbeteren, vragen we je deze enquête in te vullen. De gegevens zullen anoniem verwerkt worden. Alvast bedankt voor het invullen.

Algemeen

1) Naam (voor- en achternaam): ……………………………………………………………………………

2) Hoe oud ben je? ……… **3)** Wat is je geslacht? ○ Vrouw ○ Man

4) Profiel: …………… met als keuzevak(ken) ……………………………………………………………………

De lessenserie

5) Wat vond je van de lessenserie (kruis aan)?

Heel leuk	*Leuk*	*Neutraal*	*Niet leuk*	*Helemaal niet leuk*
○	○	○	○	○
Te moeilijk	*Moeilijk*	*Neutraal*	*Makkelijk*	*Te makkelijk*
○	○	○	○	○

Eventuele toelichting:

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6) Geef hieronder aan welk lesonderdeel uit de serie je het leukst, het minst leuk, het moeilijkst en het makkelijkst vond, en motiveer je keuze.

Het **leukst** vond ik ………………………………., omdat ……………………………………………………………

……………………………………………………………………………………………………

Het **minst leuk** vond ik ………………………………., omdat ……………………………………………………………

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Het **moeilijkst** vond ik ………………………………., omdat ……………………………………………………………

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Het **makkelijkst** vond ik ………………………………., omdat ……………………………………………………………

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Z.O.Z

7) Heb je iets geleerd van deze lessenserie? Zo ja, probeer dan zo goed mogelijk uit te leggen wat je hebt geleerd. Zo nee, waarom denk je van niet?

- O Ja, dit heb ik geleerd:

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- O Nee, want:

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8) Omschrijf in eigen woorden wat synthetische biologie is:

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9) Is je mening ten opzichte van synthetische biologie veranderd door de lessenserie?

- O Ja, en dat komt denk ik door:

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- O Nee, en dat komt denk ik door:

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10) Wat vind je van synthetische biologie?

- O Ik ben er **voor**, omdat:

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- O Ik ben er **tegen**, omdat:

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11) Ruimte voor overige opmerkingen

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Bedankt voor het invullen van de enquête. Lever hem in bij je docent of de onderzoeker van de Universiteit Utrecht.

Universiteit Utrecht

Freudenthal Instituut
voor Didactiek van Wiskunde en Natuurwetenschappen

Appendix 4 - • Protocol semi-structured interviews students and teachers

Interview leerlingen Naar een kritisch perspectief

- Datum:
- Klas:

- Voicerecorder akkoord?
- Anonieme verwerking gegevens
- Er zijn geen goede of foute antwoorden

1. Naam:

2. Wat vond je van de lessenserie? Waarom?
    - Leuk/niet leuk, en waarom? Welke onderdelen?
    - (Te) moeilijk/makkelijk, en waarom? Welke onderdelen?
    - Interessant
    - Zinvol

3. Wat vond je ervan om over een biologisch vraagstuk/synbio na te denken vanuit verschillende perspectieven (industrie, wetenschappers, WHO, burgers)?

4. Begrepen jullie de filmpjes?
    - Konden jullie de dilemma's uit het 1e filmpje halen?

5. Hoe vond je het om waarden aan je eigen emoties te koppelen?
    - Moeilijk/makkelijk
    - Nuttig
    - Verhelderend

6. Hoe was het om de meningen van je klasgenoten te horen?
    - Nuttig
    - Leuk
    - Confronterend

7. Zou je dingen aan de lessenserie willen veranderen? Waarom wel/niet?
    - Wat zou je willen veranderen?

8. Zou je in eigen woorden uit kunnen leggen wat je geleerd hebt van de lessenserie?
    - Kun je omschrijven wat synthetische biologie is? (*het ontwerpen en vervolgens aanpassen of bouwen van respectievelijk bestaande of nieuwe biologische systemen, en het interdisciplinaire karakter van synbio*)
    - Hebben de perspectieven je geholpen bij het nadenken over de wenselijkheid van synbio? Waarom wel/niet?
    - Vind je synthetische biologie wenselijk? Waarom?
        - Ben je je door deze lessenserie meer bewust geworden van normen en waarden die voor jou van belang zijn? Waarom wel/niet?
        - Ben je je door de klassikale dialoog meer bewust geworden van de verschillen in meningen en persoonlijke belangrijke waarden van anderen? Waarom wel/niet?

9. Heb je al eerder les gehad over het vormen van een mening?
    - Bij welk vak?
    - Ging dat anders dan bij deze lessenserie?
    - Waar gaat je voorkeur naar uit (welke aanpak)? Waarom?

10. Zou je wat je tijdens deze les hebt gedaan kunnen gebruiken bij een volgende keer dat je een mening moet vormen over een dilemma? Waarom wel/niet?
    - Zou je het dilemma dan vanuit verschillende perspectieven bekijken?
    - Is er een stap in de meningsvorming die je zou gebruiken?
    - Welke stap in de meningsvorming is voor hou van belang?

11. Heb je nog vragen of opmerkingen?

Interview docent: Naar een kritisch perspectief

- Datum:
- Klas:

- Voicerecorder akkoord?
- Anonieme verwerking gegevens

Algemeen
1. Jaren ervaring
2. Leeftijd

De lessen
3. Wat vond je van de lessenserie?
4. Liep het zoals verwacht?
    - Zijn er dingen die je liever anders gezien/gedaan had?
5. Denk je dat de lessenserie zijn doelen behaald heeft? Waarom wel/niet?
6. Heb je suggesties voor verbetering van de lessenserie?
7. Denk je dat leerlingen wat ze tijdens deze les gedaan hebben (dilemma doordenken vanuit verschillende perspectieven, een beslissing nemen en daar consequenties aan verbinden) een volgende keer (kunnen) gebruiken wanneer ze een mening moeten vormen over een dilemma? Waarom wel/niet?
8. Andere vragen/opmerkingen?

De docentenhandleiding
9. Gaf de docentenhandleiding voldoende ondersteuning bij de lessenserie?
10. Vond je de docententool behulpzaam voor het begeleiden van de dialoog? Waarom wel/niet?
11. Was de PPT goed voor de ondersteuning?
12. Moeten daar nog veranderingen aangemaakt worden?

Achtergrond
13. Heb je al eerder aan meningsvorming gedaan in de les? Ja, wanneer(dit schooljaar)? Waarom wel/niet?

- Vind je het belangrijk dat er aandacht aan meningsvorming besteed wordt in de biologieles?
- Hoe doe je dat in het algemeen en waarom?
    i. Waar gaat je voorkeur naar uit (welke aanpak)? Waarom?
- Hoe zie je jouw rol tijdens discussies?
    i. Heb je bewust voor een bepaalde rol uit de docententool gekozen?
- Was je bekend met frames (voor het lezen van de docententool)?

Inhoud

14. Wat vond je van het eerste filmpje?
    - Goeie intro?
    - Kunnen lln de dilemma's daaruit halen?
15. Lukte het de leerlingen om waarden aan hun emoties en meningen te koppelen?
    - Wat vond je van de stappen t.b.v. de meningsvorming?

Appendix 5 – Coding model assignment 6

Antwoordmodel
Opdracht 6: Schrijf de definitie van synthetische biologie op en leg uit hoe dit verschilt van de traditionele recombinante DNA-technologie.
(1) Synthetische biologie is het modificeren (of manipuleren) van DNA. Optioneel: Het ontwikkelt door op al bestaande technieken zoals: recombinant DNA-technologie en DNA-sequensen. Of : In synthetische biologie hoeven wetenschappers niet langer de gewenste stukken DNA uit bestaand DNA te knippen: ze kunnen het gewenste DNA zelf ontwerpen. Of: het DNA wordt dan gesynthetiseerd door een machine (of besteld via het internet).
(2) Wetenschappers bouwen en ontwerpen nieuwe biologische systemen (bijvoorbeeld: nieuwe functies in een bestaande cel, weefsels of organismes bouwen, of nieuwe cellen creëren).
+ + Twee van de elementen of soortgelijke elementen
+ Een van de elementen of een soortgelijk element
-- Geen van de elementen

Appendix 6 - The analytical guidelines of assignment 10

Position	Pro/Against/Pro under Conditions/Undecided about the development of SynBio
# Arguments	Arguments consist of an supplied point pro or or against the position held. Summations are seen as seperate if they consist of different arguments
# Arguments Pro	Arguments used to plead for the use of Synbio
# Arguments Against	Arguments used to plead against the use of Synbio
Argumentation type (more then one type can be used by one student): Rationalistic/Intuitive/Emotive reasoning	Rationalistic reasoning o Reason and logic o No influence of emotions o Two types of arguments Hypothetical, under assumption, but still logically reasoned o Empirical proven facts
	Emotive reasoning o A care perspective in which empathy and concern for the well-being of others guided decisions or courses of action o Care based considerations o Both cognitive and affective o Involve moral emotions: sympathy and empathy.1 (Eisenberg, 2000 as cited in Sadler & Zeidler, 2005) o Sympathy and empathy entail feelings of concern for other individuals' needs o Sympathy/empathy allow students to identify with the characters in the SSI scenarios1 (Sadler & Zeidler, 2004 as cited in Sadler & Zeidler, 2005) o Sense of care toward individuals o Empathic toward well-being of others Directed toward real people or fictitious characters
	Intuitive reasoning o Considerations based on immediate reactions to the context of the scenario o Affective o Immediate feelings or reactions o Immediate positive or negative reaction to a scenario that contributed to their negotiation and eventual resolution of the issue o Result of gut-level reaction or feeling that could not necessarily be explained in rational terms o Directed toward specific aspects of the scenario (instead of real people or fictitious characters) o Always before one of the other two types of reasoning o Prima facie duties, intuitively known and self-evident (being evident without need of proof) obligations (Audi, 2004 as cited in Van der Zande 2009)
Use of scientic content	Use of any scientific content in the formulated opinion
# perspectives	Direct mention of the perspective of someone other then the student's as an consideration.