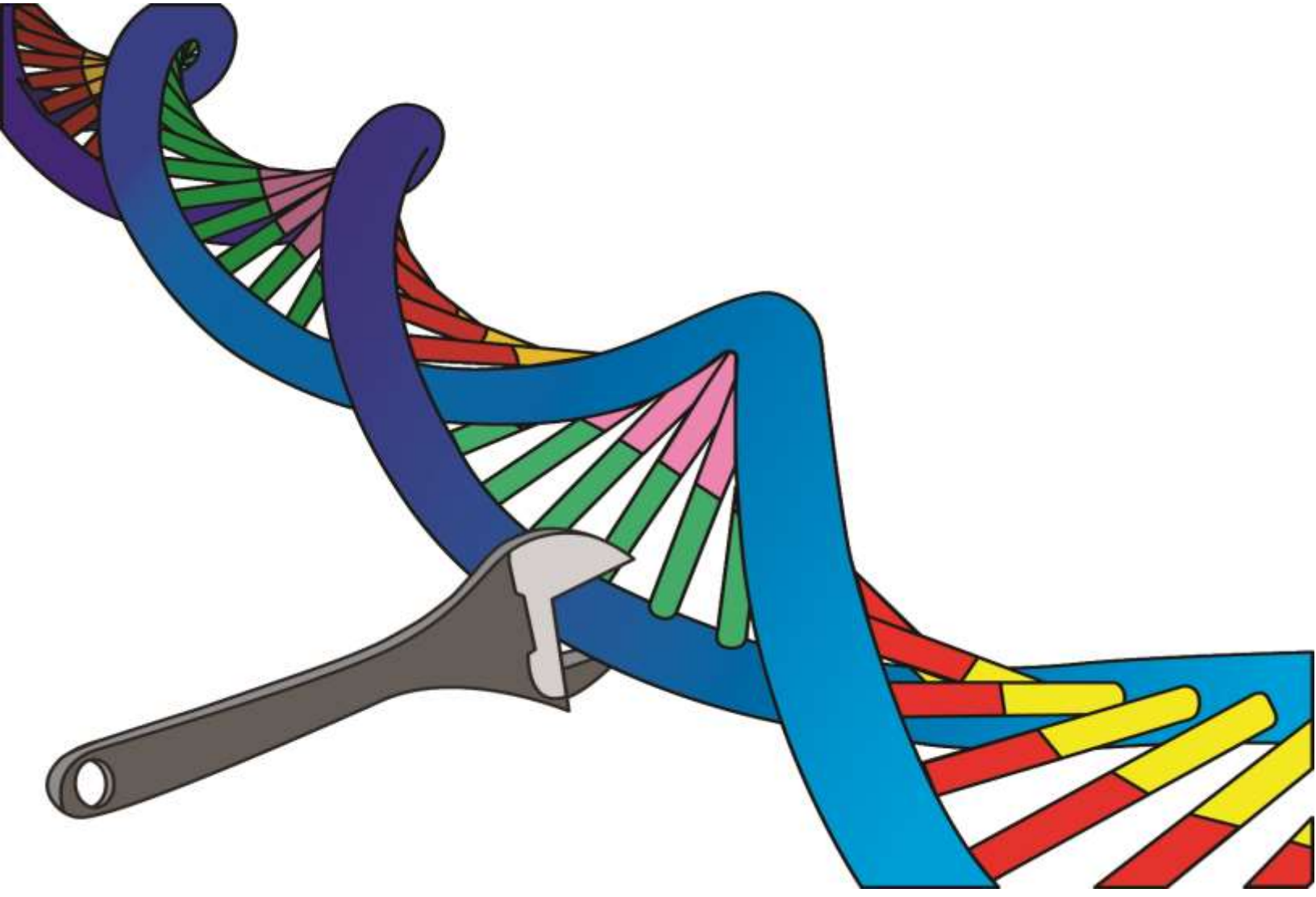
Teacher Guide

Synthetic biology

Towards a critical perspective



Colophon

Universiteit Utrecht

Freudenthal Instituut
voor Didactiek van Wiskunde en Natuurwetenschappen

synenergene
Responsible Research and Innovation in Synthetic Biology

v1.0

This teaching module was developed by the Freudenthal Institute for Science and Mathematics Education, within the framework of the European SYNENERGENE project.

Authors
Karina Fonseca Azevedo, Marie-Christine Knippels
Adapted by Michiel van Harskamp

Parts of this module are based on and inspired by the first lesson module *Synthetic Biology: What is possible and advisable?* http://www.fi.uu.nl/toepassingen/28400/

Illustrations
Jenty Heijstek

Design
Miranda Overbeek

Please contact the Freudenthal Institute at fisme@science.uu.nl if you have any questions or comments.

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Content

Level and learning goals

Level	Upper Secondary Education - students between 15 and 18 years old
Subject	Biology
Required prior knowledge	Before this lesson module students should have completed the following themes: • Genetics • DNA replication • Protein synthesis • Bio technology (such as recombinant DNA technology)
Learning goals	After completing the module, students should be able to: • Identify moral (socio-scientific) issues and dilemmas, and to explain their personal opinion. • Describe the main scientific concepts of synthetic biology and use this information in new situations (e.g. in combination to an analysis of moral issues). • Elaborate a meaningful opinion about synthetic biology developments (i.e. by thinking critically about the positive gains against the risks and moral issues).
End terms	This lesson module supports the international aim of promoting Scientific Literacy and Attitudes Toward Science and Technology. • Communicate clearly about the science. • Make informed decisions about these issues. • Understand the science relevant to environmental and social issues.
Duration	3 x 50 minutes

Introduction

Synthetic biology (synbio) is a new interdisciplinary field that is experiencing rapid growth. Synbio has a lot of potential to solve problems that relate for example to health, food and energy, but there are also potential risks. In this module students are first presented to a possible future scenario in which a specific application of synbio technology, *bioluminescent streetplants*, is imagined with the consequences this may have. This future scenario (called a 'vignette') stimulates students in formulating emotions, arguments and questions. Next, students are confronted with the current reality of bioluminescent plants and the do-it-yourself synbio venture. A need-to-know regarding what synthetic biology actually is is generated and in lesson two students learn about synbio history, techniques and applications. The module ends with a *synbio crisis* vignette and open dialogue on the advisability of certain synbio applications and regulations.

Background information for the teacher

The interdisciplinary scientific field of synbio has emerged over the last ten years or so, through cooperation between biologists, engineers and information scientists. Synbio further develops existing techniques from bio technology, such as recombinant DNA technology and DNA sequencing, so that existing and new biological systems can be adapted, designed and constructed. This is also referred to as engineering biological systems. While in classic recombinant DNA technology the necessary DNA sequence had to be cut from existing DNA, now DNA sequences can be synthetized, and DNA can be ordered online. The DNA can be selected from a database, or be designed. Another option is BioBricks, standardized DNA parts with a specific function. These allow fast and easy modification of existing systems as well as creation new ones.

To learn more about synthetic biology, you can check the following links:

- Virtual learning platform about synbio of the Freudenthal Institute, containing background information and materials: http://www.fi.uu.nl/synenergene/
- SYNENERGENE project platform: https://www.synenergene.eu/
- SynBio Watch presents critical perspectives on synbio industry grounded in ethics and social, economic, and ecological justice: http://www.synbiowatch.org/
- Video explaining how DNA is synthetized - by GeneArt®: https://www.youtube.com/watch?v=1S0x3aRCviM

What are technomoral vignettes ?

This lesson starts with a 'technomoral vignette' in the form of an animated future scenario. Technomoral vignettes are short stories, informed by recent scientific publications, in which possible futures and moral dilemmas are being introduced.

Techno-moral vignettes can help in imagining SynBio-related futures and starting up the SSIs (Socio-Scientific Issues) -based learning process in secondary biology education. The vignettes were originally developed to invite politicians to debate and have proven to have educational potential[1].

To learn more about technomoral vignettes, you can check the following link: https://www.rathenau.nl/nl/page/synbio-scenarios

[1] Ruijter, C. de (2013). Techno-moral vignettes: A useful tool to introduce synthetic biology related socio-scientific issues? Faculty of Science Utrecht University Master Thesis http://dspace.library.uu.nl/handle/1874/278453

Structure of the module

Lesson 1

1	Introduction	5 min	Introduce the video and provide worksheet Part 1
2	Video: www.youtube.com/watch?v=xGQ6Cp1dC4c	5 min	Video about a hypothetical future scenario, activate students' feelings
3	Lesson module Part 1: 'Synthetic biology: feelings, moral issues and questions'	25-30 min	Recognition of feelings, questions, and moral issues
4	Lesson module Part 2: 'Already a reality: Bioluminescence plants and DIY biohacker'	15-20 min	New perspectives and reflection, worksheet Part 2

Lesson 2

1	Introduction	5 min	Introduce the video and provide worksheet Part 3
2	Video and assignment 5: www.youtube.com/watch?v=rD5uNAMbDaQ	10 min	Video about synthetic biology and Assignment 5
3	Class reflection	15-20 min	Regarding the scientific content knowledge
4	Lesson module Part 3: 'Synthetic biology: What does it actually mean?'; History, Techniques and Applications	20-25 min	Deepening synthetic biology know-how and applications

Lesson 3

1	Introduction	5 min	Introduce the video and provide worksheet Part 4
2	Video: www.youtube.com/watch?v=xGQ6Cp1dC4c	5 min	Video about a hypothetical synthetic biology crisis
3	Group work: assignment 8	10-15 min	Groups involved and affected by the synbio crisis
4	Open dialogue	20-25 min	Whole class open dialogue
5	Final assignments and lesson closure	10 min	Final individual assignment

Instructions per lesson

Lesson 1

1	Introduction	5 min	Introduce the video and provide worksheet Part 1
2	Video: www.youtube.com/watch?v=xGQ6Cp1dC4c	5 min	Video about a hypothetical future scenario, activate students' feelings
3	Lesson module Part 1: 'Synthetic biology: feelings, moral issues and questions'	25-30 min	Recognition of feelings, questions, and moral issues
4	Lesson module Part 2: 'Already a reality: Bioluminescence plants and DIY biohacker'	15-20 min	New perspectives and reflection, worksheet Part 2

Needed

- Smartboard or projector for video (duration: 2.30 min).
- Worksheets Part 1 and Part 2 (for each student) printed in color.
- White (or black, or smart) board for whole class activity.

1. Introduction (5 min)

- Teacher explains that they (the students) will watch a short video about a hypothetical future scenario where plants can emit light.
- Teacher gives to each student the worksheet Part 1 and instructs students to read assignment 1 before the video starts.

2. Video (5 min)

- Teacher plays the video "Bioluminescent streetlamps" and students watch.
    - See background information on page 5 of the student manual.

3. Lesson module Part 1: 'Synthetic biology: feelings, moral issues and questions' (25-30 min)

- Teacher asks students to do assignment 1 (Think ~10 min)
    - Students should write their feelings, questions and identified moral issues.
    - Teacher walks around the class and checks if students understood the assignment and help when necessary.
    - Teacher may help by providing the student with an example of 'feelings' or 'moral issues' or 'questions', depending on each student needs. See Appendix 1 (pg. 14) for examples.
- Teacher instruct students to form pairs and to do assignment 2 (Pair ~5 min)
    - Students in pair should explain to each other their personal feelings, questions and identified moral issues.
    - Students are advised to make notes (on the worksheet) of their classmate answers and explanations.
- Teacher makes key questions to a whole class reflection task (Share ~10 min)
    - Key questions:
        - What were the feelings raised by the video (and why)?
        - What are the moral issues you (whole class) could identify?

        - Which questions were raised by this hypothetical future scenario and what information is still missing at this point? (raising the need for the scientific content knowledge/information).
- Teacher writes on the board (black, white or smart board) students' answers.
    - Teacher can also makes use of the of 'feelings', 'moral issues' and 'questions' examples at Appendix 1 (pg. 14) in order to complement and reveal to the whole class a larger number of possible answers (elevating the whole class reflection level).
    - Teacher makes private notes of the questions raised by the students that can only later be explained with the scientific content knowledge (lesson 2).

4. Lesson module Part 2: 'Already a reality: Bioluminescence plants and DIY biohacker' (15-20 min)

- Teacher gives to each student the worksheet Part 2 and asks them to read the article "When bioluminescent plants and DIY biohackers is already a reality: real threats to life?" carefully and to answer assignment 3 and 4*.
    - In question 3 students should write their thoughts and questions that may have been raised by the article, and to explain their feelings in relation to the current perspective of bioluminescent plants and DIY biohackers.
    - In question 4 students are asked to identify possible moral issues and to describe their personal opinion about each moral issue.
- Teacher asks students (whole class) if their feelings changed after reading the article, and why they changed (or not).
    - Teacher may choose to write on the board a summary of students answers.
- Teacher asks students what were the questions raised from reading the article, and briefly discuss these questions with the class.
    - Teacher makes private notes of the questions raised by students that only later can be explained (lesson 2) with the scientific content knowledge.
- Teacher asks various students what were the moral issues identified from the article and their personal opinion about each issue.
    - Teacher may choose to write on the board students answers.
    - Teacher may advise students to complete their answers when necessary.

* In case there is not enough class-time teacher may ask students to do (or to complete) the assignment 4 as a homework.

Background information on Bioluminescent streetlamps vignette:

Given the energy crisis facing our planet, synthetic biology could contribute by developing alternative ways of lighting, which currently accounts for 8% of our use of electricity. In order to provide any solution to the problem, a biological solution must tap into a currently unused energy resource. For this reason, we decided to consider the use of bioluminescent trees to replace conventional street lamps. A tree in this position would be able to photosynthesise during the day, building up reserves of energy. We then imagined it emitting light by night, using the bacterial luciferase system. We placed genes from fireflies and bioluminescent bacteria into *E.coli*. Codon optimisation and single amino acid mutagenesis allowed us to generate bright light output in a range of different colours. We built a set of Bricks to allow bioluminescence in a wide range of colours which have applications as natural light sources. http://2010.igem.org/Team:Cambridge

Lesson 2

1	Introduction	5 min	Introduce the video and provide worksheet Part 3
2	Video and assignment 5: www.youtube.com/watch?v=rD5uNAMbDaQ	10 min	Video about synthetic biology and Assignment 5
3	Class reflection	15-20 min	Regarding the scientific content knowledge
4	Lesson module Part 3: 'Synthetic biology: What does it actually mean?'; History, Techniques and Applications	20-25 min	Deepening synthetic biology know-how and applications

Needed

- Smartboard or projector for video (duration: 6.34 min - without pauses).
- Worksheet Part 3 (for each student) printed in color.
- White (or black, or smart) board for whole class activity.

1. Introduction (5 min)

- Teacher explains that they will watch a video about synthetic biology techniques and applications.
- Teacher gives to each student the worksheet Part 3 (complete unit) and instructs students to read assignment 5 before the video starts.

2. Video and Assignment 5 (10 min)

- Teacher plays the video "Synthetic Biology Explained" and pauses at 2.50. Students work on assignment 5. Subsequently, the other half of the video is shown, and students finish the table.
    - Students write down the definition of synbio given in the video and write down three techniques and three applications of synthetic biology mentioned in the video.

3. Class reflection (15-20 min)

- Teacher asks various students to share their answers with the class, and makes additional comments (or corrections) when necessary.
    - See Appendix 2 for assignment 5 possible answers (pg. 15)
- Teacher might bring up some of the questions students have made in lesson 1 (teacher private notes) which were related to a 'need to know' of the scientific content knowledge of synthetic biology, and have a short discussion. For instance, the questions: "How does synthetic biology actually works?", "How safe is synthetic biology?" and "Is it possible to create synthetic organisms that are completely under control?"
    - Teacher advises students to develop their answers based on their current knowledge about synthetic biology and biology in general.
        - It is expected that students talk about the unpredictability of biological systems and mutations. Teacher may help if necessary.
    - Teacher may choose to write on the board students answers.

4. Lesson module Part 3: 'Synthetic biology: What does it actually mean?', History, Techniques and Applications (20-25 min)

- Teacher instructs students to read about the History, Techniques and Application of synthetic biology that can be found on the worksheet Part 3.

- Teacher asks students to do assignments 6 and 7.
    - Students should explain the scientific concept of synthetic biology and how does it differs from traditional recombinant DNA technology.
    - Students should expose and explain their opinion in relation to the creation of four specific synthetic organisms.
- Teacher walks around the class and checks if students understood the texts and assignments, and help when necessary.
    - See Appendix 3 for assignment 6 possible answers (pg. 16).
- Teacher asks students to exchange (with a classmate) their answers from assignment 7 and try to understand each other divergent points of view.
    - In lesson three, during the whole class dialogue, students will have the opportunity to understand different students' ideas and to develop more in-depth perspectives and arguments in relation to synthetic biology creations/application.

Lesson 3

1	Introduction	5 min	Introduce the video and provide worksheet Part 4
2	Video: www.youtube.com/watch?v=xGQ6Cp1dC4c	5 min	Video about a hypothetical synthetic biology crisis
3	Group work: assignment 8	10-15 min	Groups involved and affected by the synbio crisis
4	Open dialogue	20-25 min	Whole class open dialogue
5	Final assignments and lesson closure	10 min	Final individual assignment

Needed

- Smartboard or projector for video (duration: 2.40 min).
- Worksheet Part 4 (for each student).
- White (or black, or smart) board for notes.

1. Introduction (5 min)

- Teacher explains that they will watch a short video about a hypothetical future scenario of a synthetic biology crisis.
- Teacher gives to each student the worksheet Part 4.
    - Students are informed that after watching the video they will have to work on assignment 8 with two classmates.

2. Video (5 min)

- Teacher plays the video "SynBio Scenarios: The FertiBac Crisis" and students watch.

3. Group work: assignment 8 (10-15 min)

- Teacher asks students to complete assignment 8 with two classmates.
    - Students should reflect and write about the 'Synbio industry', 'Scientists', 'WHO' and 'Population' hypothetical relationships with synthetic biology developments before the crisis happen.
    - Students are provided with the example of 'farmers'.
    - This assignment aims to complete students' preparation for an open dialogue.

4. Open dialogue (20-25 min)

- Teacher writes on the board (black, white or smart) the perspective chart student have to complete on their worksheet, assignment 9.
    - The chart may be used as the backbone of the dialogue.
        - Assigning arguments to a perspective.
        - Considering more perspectives that haven't yet been used in the dialogue.
- Teacher starts a whole-class dialogue with students, with the central question:
  "Is synthetic biology advisable?"
- Start with discussing the advisability of specific applications one at a time (see examples below) and then continue with a discussion on the advisability of synbio in general.
    - Cheap anti-malaria drug
    - Glowing plants
    - Sustainable fuel
    - Synthetic human genome
    - DIY SynBio

    - FertiBac

- The purpose of the dialogue is to have students talk together, rather than having them defend a position. This means there is more opportunity to listen to each other and to learn from each other. Therefore, it is important to keep asking questions.
- For guidance on how to guide the dialogue you can use the 'Teacher tool for holding a whole-class dialogue' in Appendix 4 (pg. 17).

5. Final assignments and lesson closure

- Teacher asks students to write down their opinion on the advisability of synbio in assignment 9, and 10.
- Teacher briefly summarize what happened in the module.
    - Learning about moral issues related to synthetic biology.
    - Learning about synbio main scientific content knowledge.
    - Learning about applications of synbio.
    - Discussing synbio advisability.

Appendix 1:

Examples of 'feelings', 'moral issues' and 'questions' that may be raise by the Bioluminescent street lamps techno-moral vignette.

Feelings:

Surprise, Excitement, Happiness, Joy
Curious, Interest
Confidence, Optimistic
Sadness, Sorry, Pity
Scared, Fear, Confused, Doubt
Distress, Conflicted, Cautious
Anger, Annoyed, Disappointed
Powerless, Insecure, Negative
Anxious, Uncomfortable

Moral issues and/ or dilemmas (explicit or implicit):

The core dilemma in this vignette / video is: are we allowed to adapt trees in order to provide a solution to the energy crisis facing our planet?

Do 'scientists' have the right to create trees that glow (bioluminescent trees/plants)?
Do 'governments/companies' have the right to put those trees on the streets?
Who can decide to put the bioluminescent trees on the streets?
Do we really want (or need) bioluminescent trees/plants?
Should people be allowed to create at home new plants varieties?
How should this technology/science be managed with respect to human safety?
How should it be managed with respect to other species safety?
Do we want to devastate/ruin the habitat of other species (because of bioluminescent)?
Do we want the government to make more (strict) regulations?

Questions:

What is synthetic biology?
How does synthetic biology actually work?
How safe is synthetic biology to the environment?
How are the bioluminescent trees/plants created?
What does it mean 'do-it-yourself synthetic biologist'?
How the bioluminescent trees/plants actually work/function?
Are there benefits from creating bioluminescent trees? What are the benefits?
Is it possible to have bioluminescent trees 'under control' (e.g. only in cities)?

Appendix 2:
Possible answers for Assignment 5.

Assignment 5

Write down the techniques and applications of synthetic biology mentioned in the video.

Topics that are discussed in the video and that may be given as answers are:

Techniques	**Applications**
GIVEN ***Cutting and pasting DNA, recombinant DNA technology***	***GIVEN*** **E. chromi*: detects various concentrations of a toxin***
BioBricks: standardized DNA parts / systems with a specific function	E. coliroid*: works like a bacterial polaroid camera*
Ordering DNA online	*Artemisinin: a synthetic malaria drug*
Synthetically produced DNA	*Bacteria with a synthetic genome*
DNA as a programming language	*Biofuel from plant waste through modified yeast*

Appendix 3:

Possible answers for Assignment 6.

Assignment 6

Write down the definition of synthetic biology and explain how does it differs from traditional recombinant DNA technology.

> Synbio works on further developing existing techniques such as recombinant DNA technology and DNA sequencing. Researchers use these improved techniques to design and build new biological systems. They can for instance insert new functions into an existing cell, tissue or organism, or create new cells.
>
> In synthetic biology researchers no longer have to cut the desired bits of DNA from existing DNA: they can design the desired DNA themselves and order it online. The DNA is then produced synthetically by a machine, using sugar as a source material.

Formal definition of synbio:

"Synthetic biology is the engineering of biology: the synthesis of complex, biologically based (or inspired) systems which display functions that do not exist in nature. This engineering perspective may be applied at all levels of the hierarchy of biological structures – from individual molecules to whole cells, tissues and organisms. In essence, synthetic biology will enable the design of 'biological systems' in a rational and systematic way."

Source: High-level Expert Group European Commission

Advised synbio metaphor[2]:

SynBio is a new field of science. In SynBio, scientists cannot only read the code of DNA, they can also write it. Thereby forming a new language, in which is written what cells should do, some sort of new manual for the cell. Also completely new manual can be written. This is how scientists created a bacteria that produces a malaria medicine, for instance.

[2] According to the following study: Sekeris, F. (2016). Metaphor usability for clarifying synthetic biology in upper secondary education. Master Thesis Utrecht University.

Appendix 4:

Teacher tool for holding a whole-class dialogue

By: Miranda Overbeek, Marie-Christine Knippels and Arend Jan Waarlo (Freudenthal Institute, Utrecht University, 2014)

Science and technology are constantly developing; how do you prepare pupils for decision making about *socio-scientific issues* (SSIs), i.e. complex problems as a result of scientific/technological developments that influence society? One way to do this is through a whole-class dialogue. But how do you do that? This tool gives some hints on values, since SSIs consist of a knowledge and a values component. This tool targets the values component and considers:

- Why a dialogue?
- Role of the teacher
- Techniques for asking questions
- Frames (of reference)

Why a dialogue[1]?

The goal of a dialogue is to think about a problem together and to understand each other. So a dialogue is cooperative in character[1]. In a dialogue pupils aren't made to defend a position, so that there is opportunity to learn something from the perspectives of the other pupils[2].

In a discussion or a debate the goal is to solve a difference of opinion, so that there will eventually be a winner, also if for example more points of view are possible. So a discussion or a debate is competitive in character[1]. In a discussion or a debate people tend to dig in on their own position and no longer listen to others with an open mind, so they will not learn from the perspective of the other as quickly[2].

Therefore we opted for the dialogue as a method: a dialogue is more suitable to clarify the values of pupils that are often implicitly present.

In a dialogue the following is important:

- Equality: all pupils have the same right to say or ask something.
- Mutual trust, respect, openness and understanding.
- Basing opinions on arguments and discovering the validity of these argumentations together.
- Listening to each other and trying to understand what the other is trying to say.
- Reflecting on what is said.
- Thinking along with each other on the topic.

The role of the teacher[4]

Depending on your goal– development of values through transmission (transferring certain values), through clarification (letting pupils discover their own values) or through communication (teaching pupils to communicate about values)[3] – there are different roles you can fulfil as a teacher in the dialogue. The chart below gives an overview of these different roles and the degree to which they are suitable for developing values through transmission, clarification or communication. ++ is very suitable, + is suitable and – is unsuitable.

Role teacher	Role description	Development of values through:		
		Transmission	Clarification	Communication
Participant	You are free to express ideas, opinions and emotions, like the pupils. This can be confusing for pupils, since teachers are the professionals.	+	+	+
Dedicated teacher	You disseminate your own opinion about the topic. This can lead to indoctrination.	++	-	-
Observer	You do not interfere in the dialogue.	-	+	++
Instructor	You clarify relevant information, concepts and ideas. You ask questions to assess the level of understanding. And you give positive or negative feedback to input from pupils.	-	+	+
Devil's advocate	You take on contradictory points of view to stimulate the dialogue.	-	+	++
Advocate	You present all possible points of view and conclude with your own opinion, supported by arguments.	+	-	+
Neutral chair/ Neutral facilitator	You stimulate pupils to contribute to the dialogue and keep an eye on the rules of the dialogue, but do not give your own opinion or positive/negative feedback on the input of pupils.	-	++	++
Declared stakeholder	At the start of the dialogue you give your own point of view, so that pupils will be able to assess teacher bias later on.	-	+	+

Which role do you usually take on? And would you do so after reading the descriptions of these different roles?

The premise of this tool is development of values through clarification and communication. The role of the teacher as neutral chair/ neutral facilitator in a whole-class dialogue is suitable for that. Development of values through clarification and communication requires the following from a teacher:

- Ensure an open, inviting and safe atmosphere.
- Be neutral.
- Adapt questioning techniques (described below).
- Establish the results of reasoning processes by pupils.

Questioning techniques[5]

In a whole-class dialogue it is important that:

- It is clear to everybody what a pupil is trying to say (**clarity**).
- The foundation for pupils' opinions emerges, this can be both rational and emotional/intuitive (**arguments**).
    - And examine their validity.
- There remains a focus on the original question (**structure**).

Clarity: What question can you ask when …

… it is unclear what a pupil is trying to say?

- "Can you explain this?"
- "Can you give an example?"
- "What do you mean by …?"

… you are not sure that you or the rest of the class understand correctly what a pupil is trying to say?

- "Do you mean … when you say that …?"
- "Do I understand correctly when you say that …?"

… it is unclear what something a pupil says has to do with the topic of the dialogue?

- "What does this have to do with …?"
- "How does this correspond to …?"
- "Does this help us with … in the dialogue?"

Arguments: What question can you ask when …

… a pupil doesn't support his/her point of view?

- "Why do you think that?"
- "What did you base that on?"
- "Can you prove this?"

… a pupil gives an incorrect argument?

- Ask the whole class: "Does anyone have a different idea about that?". And subsequently let them underpin their opinion (as described above).
- Ask the whole class: "If what X says is true, what could be the result of that?"
- "What did you base that on?"
- "Could the opposite be true?"
- "How does this match with what you just said?"
- Introduce your own opinion as a hypothesis: "Suppose that …, what might we be able to say about that?"

… a pupil uses a discussion breaker[6]?

- When a pupil uses a discussion breaker like "It's everybody's own decision whether or not to use the technology" or "You cannot stop/influence technological progress", explain that society and technology/science are intertwined and influence each other: society influences science and science influences society. Two examples:
    - Society influences science: society is in fact able to influence for example the use of technological innovations. When for example the company Myriad Genetics filed a

patent on all medical treatments that are developed based on mutations in in BRCA-1 that they discover, breast cancer patient associations cooperated internationally to stop this.
    - Science influences society: one thing science can do is change the values of society. For example the invention of the contraceptive pill caused

… a pupil gives an emotional argument?

- Stimulate pupils to look at the values behind their emotions[7]. Ask further questions / reflect on the emotion!
    - *Example of asking further questions:* A pupil says "I'm afraid of it." Ask another question: "What is it you're afraid of?" [8].
    - When reflecting on emotions it is important to include both your own emotions and those of others. *Example of reflecting on emotions:* A pupils says: "I'm afraid of the technology." To find out whether the pupil is really afraid of the technology as such (i.e. consequences for society), you can invite the pupil to take a broader perspective regarding emotions, for example: put yourself in the place of people who benefit from or are damaged by the technology. Is the technology socially acceptable or not in that case[9]?
    - Sometimes emotions are based on wrong factual information. In that case it is important to correct these at a factual level8. Emotions can also make us blind to quantitative considerations: for instance, plane crashes are rare, but people with fear of flying focus on them. Also correct these emotions with factual information. You should do so subtly, by acknowledging/going along with, for example: "Yes, that is terrible, but luckily it doesn't happen often." That the chance that something that someone is afraid of may actually happen is small, does not necessarily mean that the emotion 'fear' is irrational. Consider for example nuclear energy: the chance of a nuclear disaster may be small, but the consequences are disastrous. Besides, there are alternatives for nuclear energy[9].

… a pupil gives a general argument[10]?

- Ask the pupil to be more specific. For example: a pupil says "We must respect autonomy." Ask for example: "What does that mean here in this situation?"

… pupils do not (want to) understand each other's opinion/argumentation

- Invite them to take the other's perspective; let them put themselves in the other's place through emotions3.
- Pupils can use different patterns of arguments /ways of thinking. If this is the cause of them opposing each other, make it clear to them that they are both using a different pattern of arguments /way of thinking. There are three patterns of arguments/ ways of thinking[4]:
    - *Pragmatic argumentation:* Action X may (not) be performed, because X leads to the (un)desirable consequence Y.
    - *Deontological argumentation:* Action X may (not) be performed, because X is (not) in agreement with moral principle Y.
    - *Argumentation based on justice:* Action X may (not) be performed, because action X itself or the consequences of X are (un)just.

Structure: What question can you ask when …

… you want to wind up the dialogue?

- "Do we have a better understanding of the situation?" / "Do you have a clearer view of the situation?"
- "Have some of you changed your mind from before?"

… you want to reflect on the dialogue?

- "Have we looked at all possible options?"
- "Is this dialogue completed?"

… the topic of the dialogue has moved away too far from the original question?

- "What does this have do with what we discussed first?"
- "How did we get from … to …?"

Frames (of reference)[11]

Frames are cognitive shortcuts, or rather frames of reference, that people use (subconsciously) to be able to understand complex information. Frames are based on someone's convictions, values and experiences. Frames help you to interpret and organize information. They provide a simplification of the information, by (subconsciously) filtering it: you will consider some aspects of the information as important and others you leave out of consideration because they appear irrelevant or go against your intuition. Because different people have different frames, they can interpret the same situation differently. As a result, frames can interfere with a dialogue[12]. When there is a difference of opinion in a dialogue it is therefore important to discover how pupils frame the dialogue/ what the underlying frames are. To find out, it is necessary to ask questions about underlying convictions/values and then consider the point from the other's perspective (described under questioning techniques).

In addition to the above-mentioned *personal frames*, there are also *media frames*. Media frames concern the way that information is presented in the media: aspects may be over- or underexposed (subconsciously)[13]. As a teacher, there are two ways you can use media frames in the dialogue:

- Make sure that you are not subconsciously framing the dialogue, for example by only looking at the topic from an economic perspective in the introduction.
- Considering the topic of the dialogue from various angles/ contributing new perspectives to the dialogue. You can do so through the exemplary questions from the frame schematic below, or by asking for example "But if you look at it from an economic perspective, what do you think of it then?".

Below you will find an overview of possible media frames in relation to technological innovations, with some possible questions that can be used in the dialogue for each frame. Also, some possible questions from whole-class dialogues on genetic manipulation are given (with the exception of the frame 'law and regulations' which was not considered in these whole-class dialogues). Often you will have to point out the frames 'globalization' and 'law and regulations' yourself as a teacher, while other frames are more self-evident to pupils. The various frames are not mutually exclusive. Some frames are in fact closely related, this has been indicated with arrows in the overview.

Media frame	Description and possible questions	Example
Progress	What could be the consequence of a technological innovation, in terms of progress? Are there disadvantages to this progress? Progress here can take many forms, for instance: prosperity (related to economic frame), well-being (being happier is also a form of progress), doing good (related to ethical frame) or limiting/avoiding damage (related to risk frame).	"You can lessen people's suffering (for instance, if cancer no longer existed)."
Economic	What could the technological innovation yield, in terms of economic progress? And who would profit from that? Are there other ways to gain the same economic progress? Or will the economy suffer? And who would be disadvantaged by that? Or does it have no effect on the economy?	"It doesn't have a positive effect on the economic system, because there will be overpopulation when there are no diseases. The economic crisis will only be worse."
Ethical	Is de technological innovation ethically responsible: can you do this? What might be allowed or not allowed to be done with the innovation, based on ethical principles? Where do we draw the line? Which risks of the innovation are acceptable (from an ethical point of view)? Are there consequences if we are unable to introduce the innovation, because potential advantages can't be realized (*risk of inaction*)? The ethical frame also includes *soft impacts*[14]: the technological innovation influences values (*techno-moral change*). Example: the invention of the contraceptive pill caused homosexuality to be more acceptable, because heterosexuals could now also have sex without procreation as its goa.	"There have to be limits. For example, changing the way you look is less important than curing or preventing diseases."
Risk	The risk frame can be divided into soft impacts and hard impacts[14]. *Hard impacts* are quantifiable consequences of the technological innovation. Questions that might be asked, are: What kind of risks might the innovation carry with it? What are the risks for man, animals and nature (*bio safety*)? Can we predict the risks at all (*unknown risk*)? And can we control the risks? Will the innovation not be put to harmful use (*bio security*)? *Soft impacts* are non-quantifiable consequences of the technological innovation on individuals and on society as a whole. Questions that might be asked, are: How does a pupil see the innovation in relation to her/himself/ how does the innovation influence him or her? How would certain groups look at the innovation (stereotypes) / how does the innovation affect them? What is the effect of the innovation on people's norms and values?	"The long-term consequences are unclear, there are things that could go wrong."
Nature-nurture	Does the technological innovation influence nature/nurture? For example, are environmental influences lessened by the innovation? Will genes / genetic variation change as a result of the innovation? Two *control orientations* can be distinguished within nature-nurture: external (it is fate, this is uncontrollable = nature oriented) and internal (autonomy, you can influence it yourself = nurture oriented). In other words: is something a given or can it be controlled? Developments such as genetic testing change the external control orientation (fate becomes less uncontrollable). Synthetic biology for example results in more control, which means the internal control orientation is enlarged.	"It's natural that there are healthy and sick people, and that is what natural selection works with."
Law and regulation	Who controls the technological innovation: slow down if necessary, regulate? Should/could the populace be involved? Is society responsible? Are there different interests at personal and societal levels?	"The authorities were concerned that the therapy might be so effective that its widespread use might lead to overpopulation. That's why they limited its usage to those without children."
Globalization	What are the consequences of the technological innovation if you look at the global level? Does it improve our country's economic position? Do third-world countries gain anything from it?	"Third-world countries cannot afford it, so that the crops are only going to Europe, and third-world countries don't gain from it, and differences only become worse."

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