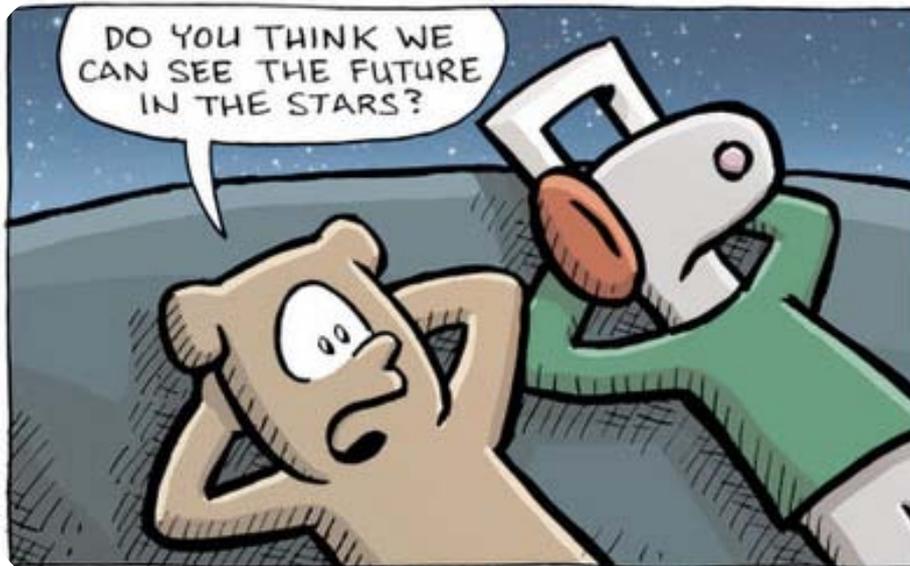


## TECHNO-MORAL VIGNETTES: A useful tool to introduce synthetic biology related socio-scientific issues?



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**RESEARCH REPORT**

**Techno-moral vignettes: A useful tool to introduce synthetic biology related socio-scientific issues?**

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Synthetic biology is a new high-profile area of research in biology that develops rapidly and entails both promises and perils. At the moment, we are therefore on the threshold of social discussions about synthetic biology related socio-scientific issues (SSIs). To be able to form opinions and make informed decisions about SSIs generated by new developments in biological research, i.e. synthetic biology, students need to be prepared. A possible way of introducing those issues is by use of future scenarios. The present study investigated the educational potential of techno-moral vignettes, which are future scenarios, for introducing synthetic biology related SSIs. Ten Dutch upper secondary school students (five males and five females) from the fifth grade of pre-university level with an average age of 16.3 years, were interviewed in individual face-to-face interviews and subsequently in two heterogeneous focus groups. The students were asked to read a vignette and react upon the story described. Five vignettes were used in total. The results demonstrate that techno-moral vignettes have educational potential because they evoked some emotions and a broad range of questions, values and reasoning types in the students. Those aspects are important to develop knowledge on synthetic biology and to work on citizenship education. The vignettes used covered different parts of the broad range of questions, values and reasoning types. Therefore it is advised to use two or more vignettes for the development of a teaching and learning strategy and to test this strategy in a larger setting.

## Introduction

A new high-profile area of research in biology is synthetic biology. This area of research encompasses three broad approaches toward the synthesis of living systems (O'Malley, Powell, Davies, & Calvert, 2007). Those systems are both reproductions of naturally occurring systems and systems that function unnaturally (Benner & Sismour, 2005). By assembling components<sup>1</sup> in a synthetic way, researchers in synthetic biology hope to understand natural biological systems (Benner & Sismour, 2005). Furthermore, some strands of research in synthetic biology are highly instrumental and aim to develop biological technologies (O'Malley et al., 2007), such as technologies for synthesizing complete genomes. Thus synthetic biology encompasses both new biological knowledge and technological developments.

Developments in synthetic biology cause many prospects, such as the creation of microorganisms (or other organisms) that can produce pharmaceuticals, detect toxic chemicals, break down pollutants, generate energy, repair defective genes or destroy cancer cells (Tucker & Zilinskas, 2006). However, synthetic biology brings also certain risks and ethical concerns, such as the risk of a leak out of synthetic organisms from the laboratory, harmful side effects of synthetic organisms after releasing them in the environment, misuse of knowledge or technologies, "playing for God" and creating organisms that fall somewhere between living things and machines (Douglas & Savulescu, 2010; Tucker & Zilinskas, 2006). Moreover, there may be risks which we cannot anticipate on right now because the behaviour of bioengineered systems remains unpredictable (Tucker & Zilinskas, 2006).

Because of the rapid developments in the field of synthetic biology, that entail both promises and perils, at the moment we are on the threshold of social discussions about issues generated by developments in synthetic biology. Such issues with a basic component in science and a potentially large impact on society, are called socio-scientific issues (SSIs). They involve both opinion-forming and choice-making at the personal and societal level (Ratcliffe & Grace, 2003).

To be able to participate in such discussions, people need to be prepared. From 2005 on, schools are required to spend time on citizenship education (Bron, 2006), which prepares students to become a critical democratic citizen. Citizenship education is a task for every teacher (Veugelers, 2007), so also for the science teachers. This fits well with one of the components in the justification of the Dutch science curriculum, that is the role the subject has for creating citizens that have enough knowledge to participate in discussions and to take decisions about SSIs (Boerwinkel, Veugelers, & Waarlo, 2009).

In order to support citizenship education it is important to develop a teaching and learning strategy in the science curriculum that prepares students to form opinions and make informed decisions about SSIs generated by new developments in biological research, i.e. synthetic biology.

Much research is already done on decision making and opinion forming skills in general and on specific SSIs, such as genomics (e.g. Dawson & Venville, 2010; Knippels, Severiens, & Klop, 2009; Levinson, 2006; Sadler & Zeidler, 2005a). However, little is known on how those

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<sup>1</sup> Components may be natural genes made be more efficient, genes applied for new purposes or artificial genes (Tucker & Zilinskas, 2006).

skills can be supported for synthetic biology related SSIs. Moreover, synthetic biology is not integrated in the science curriculum yet, even though this new research area is rapidly developing.

Since synthetic biology deals with high biological complexity and developing technologies, discussions about those issues are complex and involve implications of science that is still in the making. A possible way of introducing those issues is by use of future scenarios referring to applications of synthetic biology. According to Boerwinkel et al. (2009) “social imagination”, the ability to imagine the future, seems a suitable approach to stimulate students to think of applications that are not existing but possible to create. In addition, it has been shown that the use of fiction (movie clips) to introduce a dilemma in the classroom stimulates students to develop their opinion forming skills (Knippels et al., 2009).

The Rathenau institute developed 17 future scenarios related to synthetic biology, called techno-moral vignettes (Swierstra & Boenink, n.d. (a)). Those techno-moral vignettes are short stories in which a possible future moral dilemma is introduced. The vignettes are about an A4 in size, often humoristic and based upon recent scientific publications. They do not predict the future but invite readers to come up with their own imagination about how science and technology may improve our lives (Swierstra & Boenink, n.d. (b)).

Although the vignettes seem appropriate for designing education about synthetic biology related SSIs, they are not in the first place written for educational aims, but to invite politicians to debate. Therefore the aim of this research is to investigate the educational potential of techno-moral vignettes for introducing synthetic biology related SSIs. If it becomes clear that the vignettes have educational potential, further steps can be taken to develop an appropriate teaching and learning strategy for teaching synthetic biology related SSIs and SSIs related to new developments in biological research in general.

## **Theoretical framework**

### *Citizenship education*

In 2005 the Dutch government decided to pass a new Education Act in which schools are required to spend time on “active citizenship and social integration” (Bron, 2006). Citizenship relates to both the political domain and to everyday life. It is concerned with how people give meaning to life on a personal, interpersonal and socio-political level (Veugelers, 2007). In the explanatory memorandum of the new Act, the Dutch Minister of Education emphasizes that engagement and social bonding are central in citizenship education. According to her, active citizenship encompasses willingness and capacity to participate in and contribute to a community (Bron, 2006).

The above description of active citizenship fits best with the characteristics of a critical-democratic citizen defined by Leenders and Veugelers (2004). According to these authors, a critical-democratic citizen combines individual and social development and participates actively in society.

Citizenship education’s task is to prepare students to become such a citizen. Citizenship education is an active process for students. They have to clarify values, evaluate information and viewpoints, participate in discussions and decision making and come to action (Ratcliffe & Grace, 2003). Working on citizenship education in science classrooms is called science

education for citizenship. Another term for it is STS (science-technology-society) (Ratcliffe & Grace, 2003).

### *Socio-scientific issues*

In science education for citizenship, opinion forming and value development about social issues with a scientific background have an important role (Boerwinkel et al., 2009). As mentioned earlier, issues with a basic component in science and a potentially large impact on society, are called socio-scientific issues. They are frequently at the frontiers of scientific knowledge, involve opinion-forming and choice-making both at the personal and societal level and are frequently media-reported. Some require understanding of probability and risk. Moreover, SSIs involve values and deal with incomplete information because of incomplete or conflicting scientific evidence and inevitably incomplete reporting (Ratcliffe & Grace, 2003).

This last aspect, incomplete information because of incomplete or conflicting scientific evidence, is one of the characteristics that makes SSIs controversial according to Stenhouse (1970), Stradling (1984) and Wellington (1986) as cited in Levinson (2006). Other characteristics included in any definition of controversial issues are according to Levinson (2006): involvement of a substantial number of people or different groups and people starting from different premises, hold different key-beliefs, understandings, values or offer conflicting solutions or explanations that are derived from the premises.

Ratcliffe and Grace (2003) distinguish two types of SSIs. The first type (type A) is about the social application of well-established science. It therefore focuses on the implication of scientific evidence and not on the nature of the evidence itself. Examples are vaccination and the management of toxic chemicals. The second type (type B) discusses the implications of “science-in-the-making” and the nature of scientific evidence itself. Examples of this type are global warming and ozone layer destruction. Because discussions about synthetic biology related SSIs involve both implications of science-in-the-making and the nature of scientific evidence itself, those issues could be classified as type B SSIs.

### *Use of future scenarios*

Because synthetic biology related SSIs involve knowledge and technologies that are still under development, it seems quite logical to use future scenarios to introduce and discuss them. Although some people prefer to stay to the facts instead of brainstorming about possible future scenarios, this is inconsistent with the way technology develops. Developers start with possible aims and goals for new technologies. Avoiding speculating about the future therefore is no option, because goals by definition lie in the future (Boerwinkel, Swierstra, & Waarlo, 2012).

Techno-moral vignettes consider the future by means of storytelling. Using or building stories to make something clear is called the narrative approach. This approach is used in medical and educational setting (Vos, Dekkers, & Reehorst, 2003; Widdershoven, 2000). According to Boerwinkel et al. (2012) use of narratives and future scenarios in classrooms seems fruitful in engaging students to debate about technological developments. Narratives are an adequate tool to introduce soft impacts, unpredicted side effects, of technological innovations next to hard impacts, such as risks. Distinguishing between soft and hard impacts enhances socio-

scientific learning and helps to keep discussions flowing (Boerwinkel et al., 2012). Taken together, using techno-moral vignettes to introduce synthetic biology related SSIs seems promising.

### *Role of emotions and moral reasoning in decision making*

As mentioned earlier, citizenship education is an active process, which involves for instance taking part in discussions and decision making processes (Ratcliffe & Grace, 2003). Although, social problems and debate are frequently mentioned as important themes (Levinson, 2003 and Waarlo, 1998 as cited in Boerwinkel et al., 2009), science education for citizenship often emphasizes on developing insights and skills (Boerwinkel et al., 2009). This is in line with a rationalistic point of view, which holds that moral knowledge and moral judgment are primarily caused by reasoning and reflection (Kohlberg, 1969; Piaget, 1932/1965 and Turiel, 1983 as cited in Haidt, 2001). However, nowadays there are more and more indications that we base our moral decisions on our emotions and intuitions. Several years ago, Haidt (2001) developed a social intuitionist model (SIM), in which moral judgment is caused by quick moral intuitions, followed by slow moral reasoning. He defined moral judgments, moral intuitions and moral reasoning as:

- Moral judgment: “evaluations (good vs. bad) of the actions or character of a person that are made with respect to a set of virtues held to be obligatory by a culture or subculture” (Haidt, 2001, p. 817).
- Moral intuitions: “the sudden appearance in consciousness of a moral judgment, including an affective valence (good-bad, like-dislike), without any conscious awareness of having gone through steps of searching, weighing evidence, or inferring a conclusion”(Haidt, 2001, p. 818).
- Moral reasoning: “conscious mental activity that consists of transforming given information about people in order to reach a moral judgment” (Haidt, 2001, p. 818).

Furthermore, Roeser (2006) stresses that emotions are necessary to gain moral knowledge. Scherer (1984) defined emotions as complex states that have cognitive, affective, motivational and expressive aspects (Scherer, 1984 as cited in Roeser, 2006). Without knowing or being able to imagine how a certain situation feels, it is not possible to understand moral life. Emotions are needed to take moral decisions, they help to understand what really matters morally (Roeser, 2011). Roeser (2011) advises to take emotions as a starting point in discussions about risky technologies. In that way it is possible to discover moral values that people find important.

In this research, the definition of moral judgment given by Haidt (2001) will be followed, but in moral reasoning a distinction will be made between three different forms of reasoning used to negotiate and resolve SSIs, described by Sadler & Zeidler (2005a), namely rationalistic reasoning (reason based considerations), emotive reasoning (care-based considerations) and intuitive reasoning (considerations based on immediate reactions to the context of a scenario). Because intuition is part of intuitive reasoning, moral intuition will not be considered separately.

### *Research question*

Considering the importance of opinion forming, value development and decision making in citizenship education (Boerwinkel et al., 2009; Ratcliffe & Grace, 2003), and the above mentioned role of emotions and reasoning, those aspects will be taken into account while investigating the educational potential of techno-moral vignettes. Furthermore, in order to have educational potential, the vignettes have to evoke questions in students. Therefore, to answer the main question of this research project: What is the educational potential of techno-moral vignettes for introducing synthetic biology related socio-scientific issues? the following sub questions were formulated:

1. What kind of emotions and questions do techno-moral vignettes evoke in Dutch upper secondary school students?
2. What kind of underlying values and moral reasoning could be evoked by techno-moral vignettes in Dutch upper secondary school students?

### **Method**

To be able to answer the above stated questions, this study consisted of two parts. In the first part vignettes were analysed based on a set of criteria in order to select the most promising vignettes for use in education. The selected vignettes were used in the second part of this study, which investigated what the techno-moral vignettes evoke in secondary school students.

#### *Part 1: Vignette selection*

In order to decide which vignettes are most suitable for use in secondary education and should therefore be used in the second part of this research, the 17 techno-moral vignettes were analysed and one of the designers of the vignettes, Prof. Dr. T. Swierstra, was interviewed. The vignettes were analysed by the first author based on the following criteria:

- Recognition of the four characteristics of techno-moral vignettes described by Boerwinkel et al. (2012):
  - The scenario is not too far from the future;
  - The application of the technology leads to impacts that cause societal debate;
  - The impacts include changes in routines, and what is considered normal and healthy;
  - Stakeholders react in a way comparable to reactions to similar situations in the past.
- Diversity of topics. In order to say something about the educational potential of techno-moral vignettes, not just one vignette, but vignettes of different topics should be used.
- Possible student reactions. Possible student reactions to the vignettes were predicted in order to make a well-considered decision for vignettes that evoke different reactions, which is in line with the second characteristic of techno-moral vignettes as described above (Boerwinkel et al., 2012).
- Close or distant. Estimating whether the vignettes are close or distant to students' daily life. If the story is inconceivable or uninteresting to the students, they are probably less inclined or motivated to think about the dilemma in the vignette.

Predictions for the third and fourth criteria were inferred from empathizing with the target group. This empathizing was based on daily contact with the target group during teaching internships of the first author.

The interview with the designer of the vignettes could be characterized as semi-structured and intended to get more information about the characteristics of the vignettes, the designing process, his opinion about strong and weak vignettes, and what he expected the vignettes would evoke. Because the interview was semi-structured, it was possible to get more in-depth information, without moving too far away from the subject. The interview was audio-taped and transcribed verbatim.

Based on vignette analysis and insights from the interview, five vignettes (Appendix 1-5) were selected which seemed most suitable for use in secondary education. Those vignettes were used in the second part of this research. The vignettes were translated from English to Dutch to avoid language problems. Translation was done by the first author and evaluated by and discussed with the second author. The core dilemma addressed in the five vignettes are shortly described in Table 1.

## *Part 2: Student interviews*

### **Participants**

To investigate what techno-moral vignettes evoke in secondary school students, 10 Dutch upper secondary school students (five males and five females) from the fifth grade of pre-university level (average age 16.3 years) from a secondary school in Amersfoort, Farel college (Denominational), were interviewed. Fifth grade students were chosen because they already have some knowledge about the cell, DNA and heredity. Students were selected based upon convenient sampling and participated in this research on a voluntary basis.

### **Research design and instrument**

Two types of interviews, individual face-to-face and focus groups, were used for data gathering to answer both sub questions. The method of semi-structured interviews and focus group interviews was chosen, because interviews are particularly suitable to get in-depth information, and to gain insight into aspects such as people's emotions and opinions (Descombe, 2010). The interviews were conducted by the first author and took place in a room at the Farel college, because this is a safe environment for the students. The interviews had a duration of about 15 minutes for the individual face-to-face interviews and 20 minutes for the focus group interviews.

Prior to the main data collection, a pilot interview was conducted with one male student (L0) in order to optimise the interview scheme (Appendix 6). The pilot took place in the same setting as the other interviews. Based on this pilot, only minor adjustments were made to the interview scheme.

- Individual face-to-face interviews: Nine students (L1-L9) participated in the individual face-to-face interviews. First of all, the students were asked what they thought synthetic biology is. This was done to investigate prior knowledge and to make sure that every student knew what we were talking about. Thereafter, the students were asked to read a vignette and to react upon the story described. It is good to bear in mind that during interviews one can never be completely sure whether participants are truly telling what is in their mind and/or if they try to

answer in a socially desirable way. Therefore, in order to increase validity, at the start of the interview the interviewer underlined that there are no right or wrong answers.

Three different vignettes were used during the face-to-face interviews. In this way, every vignette was discussed by three students (Table 1). Two students (L5 and L9) read a second vignette because the interviewer got the impression that those students had a somewhat one-sided view about synthetic biology. After the students first reaction the interviewer continued asking question, such as “why do you say that?” or “could you explain that?” in order to discover underlying values and reasoning types.

It is important to note that between the fifth and sixth interview the interview scheme changed slightly based on insights from a conversation with an educational expert. At first, it was not explicitly asked if the vignette evoked questions, but thereafter it was.

- Focus group interviews: The students that participated in the individual face-to-face interviews were placed together in two heterogeneous focus groups (G1-G2), consisting of five (three males, two females) and four (two males, two females) students. This was done because in a real classroom setting the vignettes would not be discussed one by one either. One female student (L5) was absent at the time of the focus group interviews and therefore the male student from the pilot interview participated in the focus group instead. The students in the focus groups were invited to talk about the vignettes. The interviewer only asked questions to help continuation of the discussion. The questions asked by the interviewer were quite similar to the questions asked during the individual face-to-face interviews. To avoid unequal preparation time, the two vignettes used during the focus group interviews differed from those used in the face-to-face interviews (Table 1). New vignettes could evoke spontaneous reactions again in all students. Both focus groups discussed the same vignettes. Only one student (L9) in the focus group had already discussed one of the vignettes during the face-to-face interview (Table 1). It was taken into account whether or not this student had a more than average contribution to the discussion, but this was not the case.

**Table 1. Core dilemma of the selected vignettes and distribution of the vignettes over the interviews. L0 indicates the pilot interview, L1-L9 indicate individual face-to-face interviews and G1-G2 indicate focus group interviews. G1 consisted of L1, L3, L4, L6, L9 and G2 consisted of L0, L2, L7, L8.**

Vignette	Core dilemma	Discussed by
Reinventing the dodo	Are we allowed to reinvent (extinct) animals?	L1, L2, L3 and pilot (L0)
Mother’s day	Are we allowed to artificially extend life by use of a cure that increases telomerase production in cells in order to counter the aging process?	L4, L5, L6
Frustrated Housewife	Are we allowed to design microbes which can break down cellulosic biomass in order reduce our dependency on fossil resources?	L7, L8, L9
Bioluminescent street lamps	Are we allowed to adapt trees in order to provide a solution to the energy crisis facing our planet?	L5, L9, G1, G2
The Make-Your-Stool-Smell-Nice (MYSSN) pill	Are we allowed to change the smells and/or colors of bacteria in order to use them in sensing and warning systems and for more frivolous purposes?	G1, G2

## Data analysis

The individual face-to-face interviews were audio-taped, while the focus group interviews were both audio-taped and video-taped in order to distinguish who was saying what. All the interviews were transcribed verbatim. The transcripts were analysed in three different ways.

- Question analysis: Student questions were filtered out of the transcripts. Quotes were filtered as questions when they were spoken in a questionable way and if the students indicated “I do not know ...”; “I wonder ...” or “I want to know ...”. With the list of questions that originated in this way categories were formed inductively<sup>2</sup>. Questions were classified to these categories by both the first author and an independent researcher. Because there was only 54% agreement, the categories were slightly revised and data were classified once again. There was however still only 61% intercoder agreement. Differences were discussed and remaining questions were placed in a certain category through intersubjective agreement. During this process one category was somewhat more specified and one sub-category was added.

The low agreement between both coders could partly be explained by the fact that the independent researcher has a mathematics background instead of a biology background. Furthermore, the intention of a question is not always clear. A question about disadvantages could just ask for information, but may also indicate a concern about desirability.

- Emotions and values analysis: Quotes that indicated emotions or values were extracted from the interview transcripts by the first author and evaluated by and discussed with the second author. A list of emotions and values – based on Evans (2001) as cited in Van der Zande, Brekelmans, Vermunt, and Waarlo (2009) and personal communication with Dr. P. Van der Zande (January 23, 2013) – was used to recognize and categorise emotions and values.

- Reasoning types analysis: Parts of the interview transcripts were determined as one coding unit when one type of reasoning was used and when it covered one subject. A total of 101 quotes originated from this and were all classified independently by the first and second author according to the three different reasoning types (emotive, intuitive and rationalistic) based on the descriptions and examples of Sadler and Zeidler (2005a) and Van der Zande et al. (2009) (Appendix 7). There was 85,1% agreement between both coders. The remaining quotes were placed in a certain category through intersubjective agreement. Analysis of reasoning types was only carried out for the individual face-to-face interviews because recognizing and following individual reasoning in a focus group interview is very difficult because students interrupt and complete each other.

## Results

Given the qualitative nature of this study, presentation of the data is descriptive in nature. All quotations used to support the interpretations of the data are preceded by a code in order to refer to the interview and vignette. The first part of the code indicates the specific interview. L1-L9 indicate individual face-to-face interviews and G1-G2 indicate focus group interviews. The letters in parenthesis represent one of the five vignettes (Appendix 1-5). “RD” represents *reinventing the dodo*; “MD” represents *mother’s day*; “FH” represents *frustrated housewife*; “BS” represents *bioluminescent street lamps* and “PI” represents *The MYSSN-pill*. “Int” refers to comments or questions of the interviewer.

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<sup>2</sup> See for more information about the categories the results section.

### *Student questions*

Four out of five vignettes evoked questions in the students. Only *reinventing the dodo* did not evoke any questions at all. The other vignettes evoked several questions, which were subdivided into four categories, some of which consist of subcategories (Table 2). The four main categories are: vignette content, general (biology) knowledge, synthetic biology knowledge and desirability. Questions belonging to categories one to three could be characterized as factual and questions belonging to category four as normative.

All vignettes evoked both factual and normative questions but overall more factual than normative questions were raised (Figure 1; Table 2). In particular, *frustrated housewife*, evoked very few normative questions (Figure 1; Table 2). Most factual question resulted from a knowledge gap in synthetic biology (category 3, Figure 1) and most normative questions were about whether we want the specific application of synthetic biology or synthetic biology in general (category 4a, Table 2).

Although, there were only few normative questions compared to factual questions, from the interview transcripts it becomes clear that students think about the desirability of the vignette specific application of synthetic biology or synthetic biology in general. The following quotes provide an example of this:

L1(RD): Yes, useless.

Int: Useless.

L1(RD): They might as well not have [reinvented the dodo], it is completely pointless [laughing]. Yeah sure, you got yourself a bird, a pile of feathers, cannot even fly and then uh. It is kind of weird.

L3(RD): Well, if you imagine that it is really possible [reinventing the dodo]. Yes, than you have to consider whether you want it.

Int: Whether you want it or not, what do you mean by that?

L3(RD): Yes, if there are those biotechnologies, if they really exist, as in the story, than it goes totally wrong, so if they are actually going to do that, it could go wrong either.

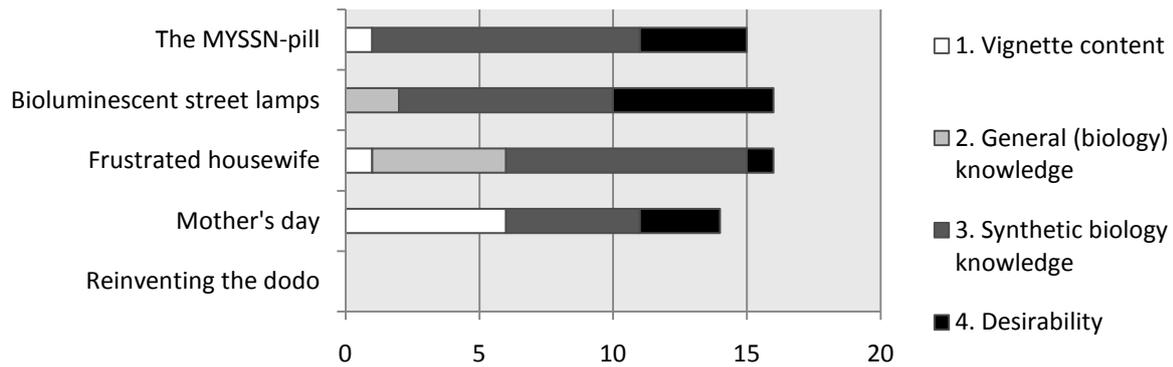
While all vignettes evoked factual and normative questions, the categories were not covered by all vignettes and the questions were not evenly distributed over the vignettes (Figure 1; Table 2). On average, *Mother's day* evoked for example more questions about the application and regulations concerning the vignette specific application of synthetic biology, while *the MYSSN-pill* evoked lots of questions about the functioning, such as:

G1(PI): And how that works exactly, that is what I was wondering, how you eat that pill, what happens in your body so that something purple [faeces] comes out.

Furthermore, only *bioluminescent streetlamps* evoked questions concerning category 4b and questions considering general (biology) knowledge were mainly evoked by *frustrated housewife* (Table 2; Figure 1).

**Table 2. Categories of student questions. Examples are given for clarification. 0 = absent; √ = one or two questions; √√ = three or four questions; √√√ = five to eight questions.**

	Category		Example	Reinventing the dodo	Mother's day	Frustrated housewife	Bioluminescent street lamps	The MYSSN-pill
Factual questions	1. Vignette content	a. Something unclear	L8 (FH): . . . but I do not understand what they mean with that. Oh because their oil export decreases every year.	0	√	√	0	0
		b. Application and regulation	L4 (MD): Yes, questions like (. . .) which persons may buy it [synthetically made cure] . . .	0	√√√	0	0	√
	2. General (biology) knowledge		L5 (BS): The last part? . . . But yes, I do not have enough knowledge to really say something about that [effect from light on animals].	0	0	√√√	√	0
	3. Synthetic biology knowledge	a. Functioning	G2 (BS): Yes, I would like to know that now, how it works etc.	0	0	√√	√√	√√√
		b. State	G2 (BS): I am very curious how, how fast these kind of things actually, uh, how fast these things develop now.	0	√	0	√√	√
		c. Disadvantages (rationalistic)	L9 (FH): Uh, I cannot say that right now, because I do not know the disadvantages of this . . .	0	√√	√√	√	√
		d. Other	L7 (FH): Yes, maybe longer ago [the emergence of synthetic biology], I do not know that exactly.	0	0	√	0	0
Normative questions	4. Desirability	a. Do we want this?	L6 (MD): . . . yes I do not know whether it gives more value to your life, a longer life.	0	√√	√	√√	√√
		b. How far can this go?	L9 (BS): . . . how far would this go, now it is already with the trees, but how far can this . . .	0	0	0	√√	0



**Figure 1. Questions per vignette. Per vignette question belonging to the main categories (1-4) are indicated. Categories 1-3 contain factual questions and category four contains normative questions.**

### *Emotion*

Although every vignette evoked some emotions, overall few emotions were evoked. Also the first student reactions were not very emotional. They were more like “it is a kind of weird” or “it is interesting”.

Some vignettes raised more emotional expression than others (Table 3). The most common emotion expressed is fear. In four out of five vignettes fear can be recognized in one or more students. The following quotes illustrate this:

L1(RD): Uh, yes that is possible, because you have to come there first and you should then, you got everything by trial and error, so if you make a mistake once, but I mean a really big mistake, if you try to change the DNA code than it could just go uh, the wrong way and then a kind of epidemic or something like that could arise that you cannot stop. [silence]

Int: You say, whereby it cannot be stopped?

L1(RD): Well, because you do not know anything about it.

Int: Do you think technology will surpass mankind? That that can happen?

L1(RD): Yes, that mankind surpasses itself, that mankind in worst case destroys itself by its own desire for more knowledge and skills.

Int: Right. And do you think we would be able to stop that then?

L1(RD): No, well at a certain point not. I do not hope so.

L7(FH): Uhm, yes indeed, it is, it is also a bit frightening that it could happen, since those developments do already exist and will always continue, because twenty years ago this [synthetic biology] did not exist. . . . So maybe that is a bit frightening, that, not that I will be there, but the idea that it is possible [to create whole human beings by synthetic biology] is a bit oppressive, it it feels not real actually. As if you are counteracting nature and that, that is something, something that is not right.

**Table 3. Relative occurrence of emotions evoked per vignette. Relative occurrence is based on the number of interviews in which emotions appear, the number of different emotions that appear and the total number of emotions that appear.**

	<b>Reinventing the dodo</b>	<b>Mother's day</b>	<b>Frustrated housewife</b>	<b>Bioluminescent street lamps</b>	<b>The MYSSN-pill</b>
Emotions	√√√	√	√	√√	√√√

Other emotions that appear are: anger, joy, surprise and responsibility. The following quotes provide an example of those emotional expressions:

Anger:

L2(RD): Uhm, the farmers I think it was. That eh, if you chose for something, you have to stay with it, but not put them [the Dodo] down, that totally makes no sense.

Joy:

G2(PI): Yes, I think it is really hilarious . . .

Surprise:

G2(PI): Does it really exists, or?

Responsibility:

L6(MD): And I think, I think it is a good solution indeed as in the story that the state does not compensate for your care. Because you make that decision [to use the cure] yourself, I think, if you stay alive and the state and other people with it, had to compensate for that, I find it a bit, yes that is not the intention . . .

### *Values*

With an exception of *frustrated housewife* in L9, all vignettes evoked underlying values in all interviews. However, the degree in which the values occurred differed per vignette (Table 4) and also the type of values evoked differ a bit. *Mother's day* evoked most (different) values, followed by *reinventing the dodo*. *Frustrated housewife*, *bioluminescent street lamps* and *the MYSSN-pill* evoked relative few values.

Nearly all vignettes evoked values as beneficence and non-maleficence. For example:

Beneficence:

L4(MD): Uhm, yes indeed, synthetic biology could be used for a lot of things as you already said. Uhm, and that is very good in my opinion, because it can be applied to many positive things, so in general I think synthetic biology is good . . .

Non-maleficence:

L2(RD): Yes, [silence]. It does no harm, because you do not harm animals, as it were.

**Table 4. Relative occurrence of values evoked per vignette. Relative occurrence is based on the number of interviews in which values appear, the number of different values that appear and the total number of values that appear.**

	<b>Reinventing the dodo</b>	<b>Mother's day</b>	<b>Frustrated housewife</b>	<b>Bioluminescent street lamps</b>	<b>The MYSSN-pill</b>
Values	√√	√√√	√	√	√

Other values that appeared were more vignette specific. Those values are: responsibility, protect dignity of life, care of nature, justice, autonomy, solidarity and family care.

Autonomy and justice are obvious, because they only appeared in *mother's day* (and here in all three interviews). The following quotes provide an example:

Autonomy:

L5(MD): And that [cure to lengthen life] would be very nice, as long as people have their own choice and they did not get a treatment automatically, but if you can choose for it and you prefer it, I think it is very good.

Justice:

L4(MD): . . . but at the other hand uhm, I think that they if they for example if someone who is about thirty years old decides that he wants to get treated in order to live longer, but it is not allowed, than I will, than I think it is eh, okay that that person says "why may I not use it and I have children" so that is not fair in my opinion, if someone with the age of thirty who has children for example is not allowed to use it and someone who yes, a senior who has no children.

### *Reasoning types*

All vignettes evoked rationalistic and intuitive reasoning, but emotive reasoning was not evoked by *bioluminescent street lamps* (Table 5). Rationalistic reasoning was the most common used type of reasoning during the interviews, followed by intuitive reasoning in most cases (Table 5). Overall, only *mother's day* evoked more emotive reasoning than intuitive reasoning (Table 5). Moreover, emotive reasoning was used more by students discussing *mother's day* than by students discussing the other vignettes. An interesting finding is that only female students used emotive reasoning, independent of the vignette used. Finally, table 5 also shows that intuitive reasoning was used a bit more in *reinventing the dodo* and *frustrated housewife* than in *mother's day* and *bioluminescent street lamps*.

**Table 5. Relative occurrence of reasoning types. Relative occurrence is based on the number of interviews in which the type of reasoning appeared and how often the type of reasoning was used while discussing a vignette. N.d.a. = no data available. \* = The results of *bioluminescent street lamps* were only based on the individual face-to-face interviews.**

	<b>Example</b>	<b>Reinventing the dodo</b>	<b>Mother's day</b>	<b>Frustrated housewife</b>	<b>Bioluminescent street lamps*</b>	<b>The MYSSN-pill</b>
Rationalistic reasoning	L1 (RD): Yes, once again that is the difference, because they did not succeed to let the animal think for itself and to re-create the behaviour, so there is nothing unethical to put that animal down.	√√√	√√√	√√√	√√	n.d.a.
Intuitive reasoning	L7 (FH): I do not know exactly, just yeah, it is not right in one way or another, because it is not natural. I have, I have the feeling that, that, that we as human beings do not have the right to have so much influence on life. . . . Yes, something, yes that way around, I think. Yeah, I think that that goes too far. I Think myself. . . . I just have the feeling that something morally does not fit.	√√	√	√√	√	n.d.a.
Emotive reasoning	L4 (MD): . . . but I think, I do not know eh yeah, if you as senior wants to live longer, if you, if you, if you want that treatment.	√	√√	√	0	n.d.a.

## Conclusion and discussion

In order to investigate the educational potential of techno-moral vignettes for introducing synthetic biology related SSIs, two sub-questions were formulated.

1. What kind of emotions and questions do techno-moral vignettes evoke in Dutch upper secondary school students?
2. What kind of underlying values and moral reasoning could be evoked by techno-moral vignettes in Dutch upper secondary school students?

According to Roeser (2011) emotions are needed to take moral decisions. They are needed to be able to imagine how certain situations feel and without that it is, according to her, impossible to understand moral life (Roeser, 2006). However, few emotions were evoked by the vignettes. Only fear appeared in interviews in four out of five vignettes. The other emotions – joy, surprise, anger and responsibility – were restricted to one or two vignettes. Although, there were only few emotions clearly recognizable, students were able to feel empathy for and sympathy with the characters in the vignettes, considering the appearance of emotive reasoning by nearly all vignettes.

That the vignettes evoked only few emotions had possibly to do with the fact that the stories described in the vignettes are occurring in the future. Maybe therefore, the students did not get strong emotional expressions about them.

Although few emotions were evoked, the vignettes raised a broad range of questions, both factual and normative. It is positive that both factual and normative questions were evoked. The appearance of normative questions indicate that the vignettes clearly put forward the controversial nature of SSIs, while factual questions, and in particular questions that arose due to a knowledge gap in synthetic biology, indicate that students were aware of the need to get more information about the topic, i.e. synthetic biology. According to Sadler and Zeidler (2005b), understanding of content knowledge is related to the quality of reasoning regarding SSIs based on that knowledge. So in that perspective it is good to strengthen one's need of obtaining more content knowledge. Important to note here is that not all questions that arose due to a knowledge gap underline the strength of the vignettes. Questions about general (biology) knowledge could indicate shortage of connection to the student's prior knowledge. This is the case for *frustrated housewife* and to a lesser extend for *bioluminescent street lamps*.

Beside the strength of the vignettes in evoking questions, also several different values can be recognized. By making those values explicit, the teacher creates the opportunity to built on those values when using vignettes in a classroom setting. This fits well to science education for citizenship, in which value development about social issues with a scientific background has an important role (Boerwinkel et al., 2009). Note that not all vignettes evoke the same amount of values. For example *mother's day* evoked most values.

Beside the different amount of values evoked, vignettes also differed in the type of reasoning used by the students. Overall, all types of reasoning were used, but in contrast to the results of Sadler and Zeidler (2005a) and Van der Zande et al. (2009), students did not use all three types of reasoning at the same time while discussing a vignette. Although it is not possible to draw a firm conclusion because of the limited number of participants, it seems that it depends on the topic of the vignette which type of reasoning was used most. Furthermore, the gender

of the students may influence the type of reasoning used. Emotive reasoning, for example, was most often used while discussing *mother's day* and only by female students. Possibly the topic of *mother's day*, in comparison to the topics of the other vignettes, is closer to female students personal and social life. This could explain both the amount of values evoked and the type of reasoning used by student discussing *mother's day*.

All together the vignettes evoke some emotions and a broad range of questions, values and reasoning types. Therefore we can conclude that techno-moral vignettes have educational potential for introducing synthetic biology related SSIs.

### *Methodological reflection*

The interview transcripts were used to investigate whether the criteria used for vignettes selection were recognizable or if something appears that indicated deviation from the criteria. Not all criteria were clearly visible in all transcripts, but some interesting findings will be reflected on here:

- The scenario is not too far from the future: According to one student (L1), *reinventing the dodo* is “really a future scenario, because we are far from creating complete animals”. Furthermore, one aspect of *bioluminescent streetlamps* the “do it yourself synthetic biologists” was mentioned as thinking ahead. Those examples indicate that (aspects of) those two vignettes are maybe too far in the future. However it is hard to determine what is too far.
- The application of the technology leads to impacts that cause societal debate: All vignettes evoked different student reactions and also most of the hypothesized student reactions were recognizable. Only the hypothesized reactions from *reinventing the dodo* and *frustrated housewife* did not completely agree with the real reactions. However, the fact that different reactions were evoked combined with the normative questions evoked indicate that the vignettes are able to cause social debate.
- The impacts include changes in routines and what is considered normal and healthy: Changes in routine were not clearly recognizable in the transcripts. Only in *the MYSSN-pill* this was mentioned.
- Stakeholders react in a way comparable to reactions to similar situations in the past: This criteria is difficult to reflect on. Therefore the credibility was taken into account. At first, most students responded out of curiosity or unfamiliarity with the subject. Furthermore, the example used in *the MYSSN-pill* was mentioned as a bit extreme and *reinventing the dodo* as unrealistic. However, in all cases students discussed seriously about the topic and reflected on several aspects of the topic. In that case it seems no big problem that the examples used might be a bit strange.
- The topic: Two out of three students that read and discussed *frustrated housewife* did not grasp the core dilemma. This is important to note, because in order to have educational potential the core dilemma needs to be clear. Otherwise students do not know where they talk about. In the other vignettes the core dilemma was clear for the students.
- Close or distant to students' perception of their environment: Only the example used in *the MYSSN-pill* was mentioned as a bit childish. This seems not to be a big problem however,

because students also discussed the availability of the technique for sensing and warning systems.

According to the above findings the most important problem is with *frustrated housewife* because some students did not grasp the core dilemma. Furthermore, *reinventing the dodo* is maybe a bit unrealistic and too far in the future. For the other vignettes, deviations from the criteria were absent or only for parts of the vignettes.

Beside the vignette selection some other methodological issues need to be taken into account:

- As mentioned in the methods section, the interview scheme was adapted after the first five interviews. This has possibly influenced the appearance of student questions in the interview transcripts. *Reinventing the dodo* evoked no questions at all, but during the interviews it was not explicitly asked whether the vignette evoked questions. However, this was also the case for interview four and five where questions did appear. It is therefore impossible to conclude that the absence of students' questions in *reinventing the dodo* was due to the interview scheme used.
- Possibly some implicit questions could be missed because of the strict rules used to filter questions. Maybe more implicit questions could be discovered when the rules were less strict. However, it would have become too vague, whether a quote could be considered as a question. Therefore we decided to filter questions based on the strict rules.
- Two students read two instead of one vignette during the individual face-to-face interviews. The second vignette, *bioluminescent street lamps*, was also used in the focus group interviews, in which one of the students participated. This student had already time to think about the problem described and therefore could have a major influence on the group discussion. However, this was not the case.
- Coding units and quotes were only extracted by the first author. Therefore, the possibility exists that certain quotes were missed. However, this is not of big importance because the conclusions are not based on specific numbers, but on the broad view.

#### *Implications for further research and educational use*

Different vignettes covered different parts of the broad range of questions, values and reasoning types. From that perspective, it will be a good idea to use two or more vignettes for the development of a teaching and learning strategy for teaching synthetic biology related SSIs and to test this strategy in a larger setting. One student already mentioned the usefulness of using different vignettes: "I would use more stories, because the more you read the more questions it evokes yeah."

Overall *Mother's day*, *bioluminescent street lamps* and *the MYSSN-pill* seem most appropriate for use in a first design of a teaching and learning strategy. Those vignettes together provide the students with a broad range of possible applications of synthetic biology and cover a broad range of emotions, questions, values and reasoning types. Furthermore, no indications of problematic deviations from the selection criteria were obvious in those vignettes.

From a broader perspective, the results of this study indicate that use of future scenarios seems a promising way for introducing SSIs related to new technological developments in general. In this way, science education can contribute to citizenship education, which schools are required to spend time on (Bron, 2006). In citizenship education value development, opinion forming and decision making take an important role (Boerwinkel et al., 2009;

Ratcliffe & Grace, 2003). Considering the results of this study, by use of future scenarios e.g. vignettes, a first step can be made to prepare students to become critical democratic citizens, who are able to participate in controversial social discussions. Those promising results are in line with earlier studies that indicated the usefulness of fiction and social imagination for stimulating opinion forming skills and thinking about possible future applications (Boerwinkel et al., 2009; Knippels et al., 2009).

It will be interesting to investigate how future scenarios could best be applied in order to support citizenship education. Possibilities that could be taken into account are for example use of the expert method or worksheets.

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## Appendix 1 – Reinventing the dodo

The resurrection of extinct species, especially the large creatures of the past, has appeared as a popular theme in works of fiction. With fast and cheap technologies to ‘read’ (sequence) and ‘write’ (synthesise) DNA currently available, it also becomes the objective of some researchers in synthetic biology. Thus we have seen the resurrection in the laboratory of the extinct virus which caused the deadly 1918 flu pandemic. Most researchers may not be primarily interested in the resurrection of a living animal, but hope to find new ways to understand disease or evolution. But a few, perhaps, would like to bring back one of our lost species in a zoo, or in the wild.

<http://www.telegraph.co.uk/science/science-news/4161743/Extinct-animals-could-be-brought-back-to-life-thanksto-advances-in-DNA-technology.html>

<http://www.nature.com/embor/journal/v9/n1s/full/embor200862.html>

## REINVENTING THE DODO

It was a sorry sight, the immense stable filled to the brim with thousands of ungainly, lethargic, clumsy forms, bumping into one another like blind people, producing that incredibly loud annoying honking noise. She loathed them as much as she felt pity for them

Sara sighed. It was hard to bring back that incredible excitement when the first egg had hatched, only a few years before. Scientists all over the world had trumpeted the event as a moral redemption. Science had finally found a way to make up for our past crimes against nature, to restore creation to its original splendour and richness. A synthesised Eden. After centuries of science and technology spelling bad news for biodiversity, they finally seemed to be taking nature’s side. Synthetic biologists had managed to recreate the dodo!

Some environmentalists remained unconvinced, stubbornly denying that this creature was the real thing, as it wasn’t 100% genetically pure. However, enthusiasts waved their arguments away by pointing out that genetic purity is a fiction anyway. All existing organisms are patchworks and hybrids – that is just the way nature works. Everything and everyone is work-in-progress. And anyway, if restoring biodiversity is the goal, who cares about hybrids? The reinvention of the dodo is just a matter of ‘bios’ getting even a little more diverse!

Every zoo had wanted one, or two, and so had many rich individuals. But the fad had faded quickly, as it soon became apparent that an animal may be restored in body, but not in spirit. Birds depend on imprinting to learn their specific behaviour, but no one knew how dodos behaved. So the re-created dodos were utterly stupid! You even had to force-feed them, as they had no clue themselves about what to do when you laid the food in front of them. In some cases they did learn to be a turkey, but – be honest – what was the fuss all about then? As if we don’t have enough turkeys already. And their natural habitat had also vanished since their extinction. Experiments with turkeys as parents, were inconclusive and dodos that were

let loose in De Veluwe, a Dutch national reserve, soon died in their new habitat. In the end, one had to conclude that the bird was, and remained, completely dependent on humans.

So within two years, the bird that had been designed to be the symbol of the reconciliation of science and technology on the one hand, and nature on the other, had turned into the symbol of artificiality. People started to hate the bird for its stupidity, for its accusatory dependence, for its inability to absolve humankind of its earlier sins.

Naturalists pleaded to have them killed. However, their pleas provoked protests from unexpected corners. Farmers now argued that as we had brought this creature back into the world, we now had a special obligation towards it. Did we really want to commit the same crime twice?

And so the bird stayed. Thousands and thousands cramped together in huge stables like this one. And yes, thought Sara, it was true, these dodos do make excellent, tasty burgers.

## Appendix 2 – Mother’s day

Synthetic biology may contribute to healthier and longer lives by facilitating early diagnosis and prevention of cancer, improving our intestinal flora, but also by countering the ageing process more directly. Telomeres (structures at the end of our chromosomes involved in cell division) have been known for some time to be related to ageing. With each cell division, the telomeres become shorter, ultimately leading to inhibition of the capacity for replicating, and thus to cell death. The enzyme telomerase is known to counteract this shortening of telomeres. Several companies are now constructing synthetic molecules able to increase telomerase production in cells. How effective this will be in countering the ageing process is still being contested.

<http://www.sierrasci.com/proof/index.html>

# MOTHER’S DAY

‘Do you have your drawings, Lisa?’ ‘Yes mom.’

‘Richard, the flowers are in the trunk, right?’ ‘Yes dear.’

‘Seatbelt on, Jonathan?’ She hears a click, followed by ‘Yes mom.’

Richard starts the engine. ‘We are going to your mother first, right?’

Mom Sarah: ‘Yes, we will have coffee and lunch in her nursing home. I brought cake and sandwiches, so it will really be a festive meal for her! After lunch we go to your parents.’

Lisa: ‘Are we going to see granny Smith too? I have drawings for her too.’

‘Yes, we will see her after lunch, dear.’

Lisa: ‘Mom? I don’t understand. Teacher said we should all make five drawings. But I have only two grandmothers, right?’

‘Yes: Granny Smith is the mother of daddy. Grandmother is my mother. And I am your mother of course, but you know that,’ Sarah smiled.

‘Then I have two drawings left,’ Lisa said.

‘Perhaps that’s because many children nowadays have great-grandmothers too. But you can give a drawing to the ladies living in the quarter’s next to grandma’s. They would like that, since they have no children to visit them,’ Sarah answered.

‘You mean the ones who don’t look old at all?’ Lisa asked

‘Yea, the ones that smell funny’, Jonathan mumbled.

Richard did not rebut. After all, he was right. He thought about the ladies living next to his mother-in-law. In contrast to her, they had to share a room. They had been among the first people to buy the juvenating cosmeceuticals that were claimed to stop your telomeres from shortening. The therapy had not been as perfect then as it was today, but it had bought the trendsetters some time. If he remembered it correctly, they were 110 and 112 right now. Back then, the government had been afraid that the therapy would be so effective that widespread use would lead to overpopulation. That’s why the sales of the product were strictly regulated and limited to people who had no children and who had been sterilized. Now that these women were in need of assistance, they had come off second end again. Because of the overflowing of homes for the elderly, only very basic care was reimbursed. Nobody had anticipated that people ‘ageing successfully’ (as they called it) at a certain point would need care nonetheless. If you wanted extra care, you had to pay for it yourself. He was glad his parents had not spent their money on these juvenating therapies. They might grow less old, but at least they could afford sufficient care. Sarah’s mother was less well off, but at least she had a room of her own.

He was startled when the very young voice from the navigator announced ‘You have reached your destination.’ The nursing home looked even worse than on previous visits. Apparently they did not have money to do even basic maintenance. After she greeted her grandmother Lisa went to the two neighbors. She was back very soon, looking disappointed

‘And, what did they say? Did they enjoy your drawings?’ Sarah asked.

‘Actually, I don’t know. One lady started crying and saying, “you are a very sweet girl, why didn’t I realize how much I like children?” It was a bit awkward to get away from her. And the other didn’t say anything! She just put my drawing on this huge pile of drawings in her cupboard.’

## Appendix 3 – Frustrated housewife

Biomass has been seen for some time now as an alternative source of energy and chemicals that might reduce our dependency on fossil resources. The efficiency of the processes in which biomass is converted into useful products is often limited, however. It takes a lot of energy to break down biological feedstock. Synthetic biologists are pursuing a variety of methods to more efficiently extract sugars from cellulosic biomass. For example, they are trying to design microbes which can break down cellulosic biomass, and they are also transforming microbial cells into living chemical factories. With the help of synthetic biology, biorefineries are expected to finally become the basis of a new bio-based economy.

<http://www.stwr.org/multinational-corporations/the-perils-of-the-coming-sugar-economy.html>

# FRUSTRATED HOUSEWIFE

Grace is sitting in front of the television. Her husband Karl is reading the newspaper while she waits for the commercials to end so she can continue to watch her favorite series. Damn, there is that awful advertisement again! A green animated figure, made out of leaves and grass, jumps up and down the television screen. As if that isn't horrible enough, they put jumpy, happy, bubbly music behind it while the green figure sings about biodegradable packaging. How we should separate it from other waste materials to save our environment and help our economy.

'Aarghh I've had it with these stupid advertisements! First the orange plastic hero and now this greenish jumpy clown. Do this, do that, be good and create a better planet. Yeah sure, but they don't have to spend their time walking from the one recycle bin to the other. And in the end they all throw it in one big bio refinery tank. Why should I even care about this separation. It's an illusion we will save the environment by such small scale changes.'

'Well come on honey, it's not that bad, is it? You only have to separate the paper, biodegradable plastics, artificial plastics, food, glass, tin and chemical waste – unless the chemicals are biodegradable, of course, then you put it with the biodegradable plastics.'

'Do you hear what you are actually saying? Chemicals and plastics that are biodegradable. I always learnt that chemicals and plastics are the opposite of biodegradable. Maybe we were not respecting the environment in the past, but at least things were less confusing. When I'm done cooking I have to face my six bins while studying every package to decide where to throw it. Does it contain this label or that symbol, should I separate the cap from the bottle or can I throw it all together? Really, it would save me hours a week if I just threw it in one bin. And if we have trouble doing it, what about less educated people? Carina, you know her, from three blocks down, she says that it's not even processed separately in our town since it is cheaper to throw it all together again and then separate it, instead of looking for the possible mistaken parts in every single recycle line.'

‘But you have to admit that these synthetic bacteria degrading our waste in bio refineries are a great invention! If they had not come up with those, we still would be depending on fossil energy.’

‘Synthetic bacteria! That’s another example of how we have gotten things mixed up lately. Biology is supposed to deal with living beings, with what is there, not with what humans make or synthesize! And no, I’m not too impressed by human invention. It often destroys as much as it is supposed to offer. I hate all these extra trucks on the road, transporting the biomass towards local bio refineries. And these local refineries really spoil the landscape view. Ok, maybe we help the economy of developing countries like Nigeria by importing their cassava, and also the few local farmers left may benefit, but at the same time we demolish the economy in the Middle East since their oil export lowers every year. It only brings political harassment in these countries. And as regards the environment, I’m pretty sure that our kids and grandchildren will grow up just as happy as we did, with or without a bio based economy.’

‘Yeah, you’re right honey’ Karl says absent-mindedly, having started reading his newspaper again. ‘Your series, “as the green world turns” is starting again.’

## Appendix 4 – Bioluminescent street lamps

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 (some bacteria have a gene, luciferase, that enables them to give light). We placed genes from fireflies and bioluminescent bacteria into E.coli to generate bright light output in a range of different colours.

<http://2010.igem.org/Team:Cambridge>

# BIOLUMINESCENT STREET LAMPS

Her husband thought these shining trees were spooky. Awful Christmas days now seemed to last the whole summer and it was only a matter of time until they would teach the damned trees to sing Jingle Bells too. And where was the offbutton on these things, he would complain. What did a man have to do nowadays to get some descent darkness in this world of light?

But she herself thought them beautiful as she gazed up to the intricately fingered web of soft bluish light that waved silently above her head in the gentle breeze. Oh, if only it could always be summer, so that the trees were shining. She had come to hate the harsh, unforgiving mechanical light of the old-fashioned street lamps, which of course still had to be used during winter when the trees didn't work. Especially ugly was spring-time, when the still hesitant glow of the trees had to compete with the street lights that were still on.

Well, her husband was just being grumpy and old-fashioned. Bioluminescent plants had become all the rage, and now each day some creative do-it-yourself synthetic biologist would proudly present a new home-grown bioluminescent garden-variety. There were contests, where juries would visit the beautifully luminating gardens. Of course, during grey seasons you had to 'feed' light into your plants using enormous electric lamps, but then the result was so much better.

To be honest, if you wanted to see 'lumis', you were no longer restricted to streets or gardens. More and more wild varieties were popping up in woods and meadows. Well, what could you expect? It is simply impossible to have all those enthusiastic amateur breeders stick to industrial safety regulations. Never mind! No one has been poisoned yet, and that some species of nocturnal animals had moved on to darker areas of the world....well, who cares. It is hard to shed a tear for animals that you never see anyway.

## Appendix 5 – The Make-Your-Stool-Smell-Nice pill

Synthetic biology has been used by researchers to change the smells and/or colours of bacteria. For example, students managed to change the awful smell of *Escherichia coli* into a minty one. Others engineered bacteria in such a way that they indicate the presence of a specific substance by emitting a specific colour (visible to the naked eye). This technology can be useful for all kinds of sensing and warning systems (it could for example warn that drinking water contains toxins by turning it red), but it might be used for more frivolous purposes as well.

<http://openwetware.org/wiki/IGEM:MIT/2006/Blurb>

<http://www.echromi.com/>

# THE MAKE-YOUR-STOOL-SMELL-NICE PILL

It will be her birthday tomorrow, her tenth already! She has been waiting for it such a long time. Birthdays always means having a party, cake and, of course, lots of presents. She loves presents so much! Only last night she was dreaming about that little doll she saw in the shop and how happy she would be to get it. But her best and probably most unrealistic dream is to get that little pill, the one that makes your poop smell like flowers, sweets, or whatever you like. Actually everybody in her class uses it and when you enter the bathroom it smells so nice there! She likes to sit in the bathroom, likes the cleanliness and pleasant smell of this big white room. Sometimes she even goes there in the middle of a class, just to have a break from the crowded classroom. Not that she would ever dare to use the bathroom for its real purpose – oh no! She will never, never let her classmates laugh about her like they did about Lilly last year. Some children discovered that Lilly did not use the Make-Your-Stool-Smell-Nice or MYSSN pill. In less than a day, all children knew and in the end Lilly had to change schools. It was a shame, one of those shames that is not likely to be forgotten. And of course she was called Lilly the stinky.

Unfortunately her parents do not earn enough to buy MYSSN pills. Moreover, they do not really understand how important it is for her to have it. All the girls from her class started using the MYSSN pill a couple of years ago, often at the age of 8. There is a rule that MYSSN pills can be sold only to children of a certain age. First it was 16, but the minimum norm has been gradually lowered to 8 in past years. All her class mates smell so nice! Mary today used the most fashionable and expensive variety, the one with the Coca-Cola smell. It couldn't be missed when she had to come to the blackboard to make a report. She probably farted on purpose, just to show how trendy she was.

She turns on the TV. A little blue poop sings how nice is it to smell like the ocean breeze. It's a blue, healthy poop. She knows that. She recently saw a BBC documentary in which scientists explained how they can change bacteria in your body so that they will change

colour if something in your body is going wrong. For example, if your poop is pink you need to eat more fruits and vegetables. But actually, every school girl has known for years that bacteria can change colour. At least since they invented these MYSSN pills that not only change smell, but also give your poop a colour. They cost even more than the basic variety.

Her parents seem to think this is all utter luxury. Her father repeatedly told her that there is nothing to be ashamed of in the smell of poop. But of course that is not true. Your poop is something that should smell like flowers, or at least like ocean breeze, and not have that disgusting, unnatural smell that makes you want to vomit! Her parents just do not understand her basic needs.

Yes, it will be her birthday tomorrow, but will it be a happy one? She knows that she will never, never be really happy without those little yellow MYSSN pills!

## Appendix 6 - Interview scheme individual face-to-face interviews

### *Student background information*

Male / Female            Age: .....            Date: .....  
Class: .....            Duration interview: .....

### *Interview background information*

Thank you for participating in this interview. The interview is part of my research project at Utrecht University. I investigate a possible way for introducing a new area of research in biology, i.e. synthetic biology, in secondary schools. Synthetic biology is not integrated in current biology books, while it is a rapidly developing area of research in biology. Moreover, new developments in science and technology evoke questions in society and place people sometimes for difficult choices.

While it is not clear how this subject could best be introduced, we know that opinion forming is an important aspect in synthetic biology. Therefore, I now look at the potential of future scenarios related to synthetic biology to introduce this topic.

It is important, of course, to see what you think about these scenarios. There are no good or wrong answers. For my research it is important to investigate what you think about it / what is your opinion.

Because it is hard to write everything down during our conversation, I would like to audio-tape the interview. Is that okay for you? The audio-tape will only be used for this research and will be processed anonymously.

### *The interview*

1. I already mentioned synthetic biology a few times. What do you think synthetic biology is?

In response to students' answer: Synthetic biology is an area of research in biology that encompasses approaches to make living systems (i.e. organisms). Those systems are both reproductions of naturally occurring systems and systems that function unnaturally.

Is that clear to you?

2. I am going to give you a future scenario now. Bear in mind that it is a possible scenario and no prediction of the future. Please, read the story as well as the part above it quietly.

Student read vignette.

3. What do you think about it?
4. Continue asking questions in response to student reactions. Possible questions to ask are:

General questions:

- I saw you ... [something non-verbal], why did you do that?
- Why do you think that?
- Could you explain that?
- Could you please describe how you feel?
- What do you mean by that?
- If the student focuses too much on the broad meaning of synthetic biology: If you take this specific example in account, what do you think about it?
- How do you think about synthetic biology in a more general term?
- If the student gives both advantages and disadvantages: What is more important for you ... or ... ?
- If the student summarizes the story described, then once again ask: and what do you think about that?
- Do you have a particular feeling or judgement about it?
- What kind of questions do you have?
- What kind of questions are evoked by the story?

Vignette specific questions:

- Reinventing the dodo:
  - With whom could you identify best? The farmer who thinks we now have a certain obligation to the animals, or the naturalist who wants to kill them again? Why?
  - If it would be possible to reconstruct the spirit of the dodo too, how do you think about it then?
- Mother's day
  - Would you like to use such a treatment? Why?
  - How do you think about artificial life extension?
  - What do you think about the suggestion that some people might buy the treatment, while others might not?
- Frustrated housewife
  - What do you think about this way of dealing with fuel problems?
  - What do you think about the statement that human inventions often destroy as much as they are supposed to offer? Why?
- The MYSSN-pill
  - Would you like to use such a pill if it would be available on the market? Why?
  - Could you think of other settings on which such pills could be used? How do you think about that?
- Bioluminescent street lamps
  - What do you think of this solution to the energy problem?

*Completion*

5. Do you think that the use of future scenarios is a good way to introduce synthetic biology in a classroom setting?

Thank you for your support.

## Appendix 7 – Recognizing reasoning types

. . . = Dots that were present in the original example, (...) = Something from the original example is omitted.

	Description	Examples
<b>Rationalistic reasoning</b>	<ul style="list-style-type: none"> <li>• Reason based considerations<sup>1</sup></li> <li>• Reason and logic<sup>1</sup></li> <li>• No influence of emotions<sup>1</sup></li> <li>• Two types of arguments<sup>2</sup> <ul style="list-style-type: none"> <li>▪ Hypothetical, under assumption, but still logically reasoned</li> <li>▪ Empirical proven facts</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Patient rights<sup>1</sup></li> <li>• Side effects<sup>1</sup></li> <li>• Issues of access<sup>1</sup></li> <li>• Technological concerns<sup>1</sup></li> <li>• Severity of disease conditions<sup>1</sup></li> <li>• Rationalistic calculations<sup>1</sup></li> <li>• Parental responsibilities<sup>1</sup></li> <li>• Availability of treatment options<sup>1</sup></li> <li>• Future applications<sup>1</sup></li> <li>• Financial costs<sup>1</sup></li> <li>• Considerations of the evolutionary implications<sup>1</sup></li> <li>• Potential for further stratification of social classes<sup>1</sup></li> <li>• This seems to be getting closer to maybe you can make it a personal choice . . . I would not want to do it but other people can. I would lean toward making it a personal choice. It is not my right to tell people how they should live<sup>1</sup></li> <li>• [But] I don't know. I think that not everyone is meant to be intelligent. There is a reason why some of us are intelligent and others are not intelligent.<sup>1</sup></li> <li>• If other people want to do it, then I think they should do it . . . People have a right to do it. Personally, I would not, but they should have a right to do it.<sup>1</sup></li> <li>• And when you get it, you can always try to operate then<sup>2</sup></li> </ul>
<b>Intuitive reasoning</b>	<ul style="list-style-type: none"> <li>• Considerations based on immediate reactions to the context of the scenario<sup>1</sup></li> <li>• Affective<sup>1</sup></li> <li>• Immediate feelings or reactions<sup>1</sup></li> </ul>	<ul style="list-style-type: none"> <li>• I not really know why, it is just this feeling<sup>1</sup></li> <li>• That just seems wrong<sup>1</sup></li> <li>• It just does not seem right<sup>1</sup></li> <li>• Just that – it is not right<sup>1</sup></li> <li>• Yeah, I think that would be OK.</li> </ul>

	<ul style="list-style-type: none"> <li>• Immediate positive or negative reaction to a scenario that contributed to their negotiation and eventual resolution of the issue<sup>1</sup></li> <li>• Result of gut-level reaction or feeling that could not necessarily be explained in rational terms<sup>1</sup></li> <li>• Directed toward specific aspects of the scenario (instead of real people or fictitious characters)<sup>1</sup></li> <li>• Always before one of the other two types of reasoning<sup>1</sup></li> <li>• Prima facie duties, intuitively known and self-evident (being evident without need of proof) obligations<sup>2</sup> (Audi, 2004 as cited in Van der Zande 2009) <ul style="list-style-type: none"> <li>▪ For example fidelity, justice, gratitude, beneficence and non-injury<sup>2</sup> (Ross as cited in Audi, 2004 as cited in Van der Zande, 2009)</li> </ul> </li> </ul>	<p>Why? I don't know ...<sup>1</sup></p> <ul style="list-style-type: none"> <li>• This is a little strange (...) it just sounds a little weird (...) I don't know it just seems strange<sup>1</sup></li> <li>• I do not know about that one. I think cloning people in general is very sci-fi, very weird, very in-the-future. I do not know if I agree with that.<sup>1</sup></li> <li>• I do not really have a set reason why this should not be done, but I just do not think that it should be done<sup>1</sup></li> <li>• I just think that is wrong. I think it is morally wrong<sup>1</sup></li> <li>• I would be initially against it. I do not think it is natural ... I cannot really pinpoint [a reason] because I am having trouble with this<sup>1</sup></li> <li>• Personally, I think that is a little freaky—the fact that you want to have the same baby from your dead husband—you want to make a baby from your dead husband? I think it is a little weird! I just don't know<sup>1</sup></li> <li>• What kind of woman would be willing to do that? What kind of woman would be willing to<sup>1</sup></li> <li>• [But] I would say that it is more of a moral issue . . . Cloning—cloning a whole human and cloning whole organisms is still—maybe it is just the fact that our minds are not used to it maybe it is just the fact that this is new—maybe in time people will accept it, but me personally I cannot support it, not right now<sup>1</sup></li> <li>• I will not let it be taken away; it would be my child.<sup>2</sup></li> </ul>
<p><b>Emotive reasoning</b></p>	<ul style="list-style-type: none"> <li>• A care perspective in which empathy and concern for the well-being of others guided decisions or courses of action<sup>1</sup></li> <li>• Care based considerations<sup>1</sup></li> <li>• Both cognitive and affective<sup>1</sup></li> <li>• Involve moral emotions: sympathy and empathy.<sup>1</sup> (Eisenberg, 2000 as cited in Sadler &amp; Zeidler, 2005) <ul style="list-style-type: none"> <li>▪ Sympathy and empathy entail feelings of concern for other individuals' needs<sup>1</sup></li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Relational (my cousin....)<sup>1</sup></li> <li>• I don't like to see people suffer<sup>1</sup></li> <li>• Help someone (...) suffering<sup>1</sup></li> <li>• I would say I agree with this because look at this couple who has been through all this and has tried and tried.<sup>1</sup></li> <li>• I think it would be fine if it is going to help the baby . . . If the disease is going to be detrimental to the human, then why not fix it at an early age if you can . . . If we have the ability to keep someone from suffering in the future, then why not? As far as someone thinking it is against the course of nature, I just think that is not a good excuse to let someone suffer<sup>1</sup></li> <li>• I think kids already have a hard time going to school and if you have an intelligence deficiency, it would be even worse. You just will not lead a</li> </ul>

	<ul style="list-style-type: none"> <li>▪ Sympathy/empathy allow students to identify with the characters in the SSI scenarios<sup>1</sup> (Sadler &amp; Zeidler, 2004 as cited in Sadler &amp; Zeidler, 2005)</li> <li>• Sense of care toward individuals<sup>1</sup></li> <li>• Empathic toward well-being of others<sup>1</sup></li> <li>• Directed toward real people or fictitious characters<sup>1</sup></li> </ul>	<p>normal life. You would always have to be taken care of instead of taking care of yourself. So if we used this, it would give the person a better life<sup>1</sup></p> <ul style="list-style-type: none"> <li>• But I am not in her shoes either. That is a tough call. This woman just lost her husband and her baby and now she wants a clone of her deceased child . . . [I thought about the fact that] she starts the day with a new baby and a husband and now she is left alone with nothing.<sup>1</sup></li> <li>• I can see how you would want to do this because it did not have much time to live and then it could live through this cloned baby . . . I guess a mother who has lost a child would give anything to have her child back.<sup>1</sup></li> <li>• I feel bad for people who need organs and organ transplants and maybe it would help a lot<sup>1</sup></li> <li>• I know it sounds horrible, but I disagree because it is like you're telling this mother, this woman—I do not know what the love of a mother is like but I assume it is pretty strong—you are telling her that she cannot have her baby . . . We are telling her that she cannot have [her baby] and we are telling her that she cannot have anything left of her husband because she could not have another baby with him<sup>1</sup></li> <li>• For women it is important, after breast surgery you don't feel at ease, not feminine any more<sup>2</sup></li> </ul>
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<sup>1</sup> = Sadler, T.D., & Zeidler, D.L. (2005). Patterns of informal reasoning in the context of socio-scientific decision making. *Journal of research in science teaching*, 42, 112-138. doi: 10.1002/tea.20042

<sup>2</sup> = Van der Zander, P., Brekelmans, M., Vermunt, J.D., & Waarlo, A.J. (2009). Moral reasoning in genetics education. *Journal of biological education*, 44, 31-36. doi: 10.1080/00219266.2009.9656189